Searching For That Killer App!

A New Type of 3D Printing: A 25-year-old technology has caught the fancy of a new generation of designers and engineers. From iPhone cases to customized sake sets, will anything ever be the same again?

by **Alan S. Brown**

Call it the Pocket Factory Tour. This past January, Bilal Ghalib and Alex Hornstein, two 26-year-old computer science graduates of University of Michigan and MIT, respectively, set out from San Francisco with four inexpensive 3D printers in the back of their Prius.

They had met years ago over the Internet. Ghalib was building a $50 laser cutter, Hornstein a computer-controlled Etch-a-Sketch. Ghalib went on to work on autonomous vehicles and set up Egypt's first hacker space, where people with common technology interests shared resources and ideas.

"Rancho", one of the MakerBot Thing-O-Matics that Ghalib and Hornstein have taken on their road trip.

Hornstein spent time at Idealab, a technology incubator that launched dozens of companies, then moved to Hong Kong to start the city's first private hacker space. After it went belly up, he and Ghalib decided to take their 3D printers on the road. They called the project Pocket Factory. They wanted to discover whether they could make a living by designing, producing, and selling products made on their hand-assembled 3D printers.

"We set up in art galleries, parks, and flea markets and we make custom belt buckles, iPhone cases, and 3D portraits. People could talk to us about the uses they see for the technology, and we see what they are willing to pay for," Hornstein said from Salt Lake City.

The tour was a hit in San Francisco, where technophiles embraced customized plastic iPhone cases. But a flea market in Victoria, B.C., was a total bust. "They weren't interested in our story or our products," Hornstein related. "We had some really nice, polite Canadians come up and tell us, 'What you're doing is really stupid.'"

Welcome to the world of makers and ubiquitous 3D printers. A growing cadre of enthusiasts believes that one day, practically everyone with a computer will create artwork, kitchen utensils, spare parts, chocolate desserts, and, yes, iPhone cases and belt buckles, from a small machine on their desk. Some dream of printing robots, others changing the design process as we know it.

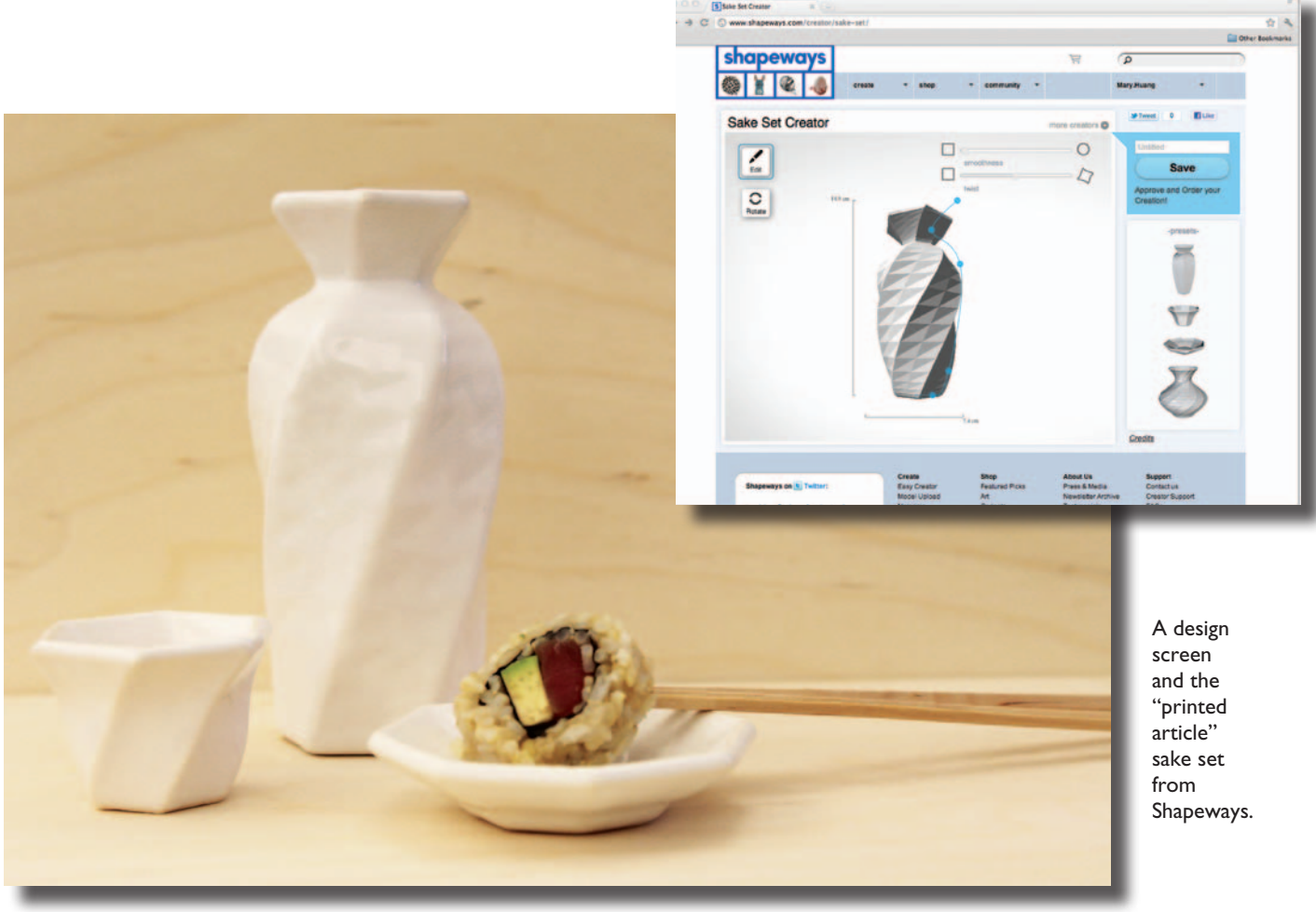
Industrial Strength

If this vision sounds far-fetched, then consider how mainframe computer jocks felt when they read the first ads for the Altair 8800 PC kit in *Popular Electronics* in 1975. The movement attracted hobbyists and visionaries, like Steve Jobs and Bill Gates. Yet PCs did not really take off until the first spreadsheet program, VisiCalc, was introduced in 1979. It made PCs essential in businesses and, later, homes.

Industrial strength 3D printers have grown increasingly capable over the past 25 years, but they are expensive. Think of them as mainframe computers.

Ghalib and Hornstein built the MakerBot Thing-O-Matics in the back of their Prius from kits that cost about $1,000. They are equivalent of those 1974 Altairs. As they travel cross country, Ghalib and Hornstein are searching for that killer app, the design or business model that will turn their road trip into a thriving business.

They are not alone. Over the past two years, more than a dozen new companies have jumped into the market. Fab shops have opened to make 3D prod-



A design screen and the "printed article" sake set from Shapeways.

ucts. Developers have created software that lets anyone customize products. And as the gap between industrial and hobbyist 3D printers shrinks, visionaries are rethinking what might be possible.

3D printing is a child of the digital age. It starts with a 3D CAD drawing, and slices it into thin layers that it prints one at a time. Industrial printers do this by fusing powders or crosslinking resins. The process resembles how a child might build a tall castle one row of Lego bricks at a time.

Over the past decade, they have grown larger, faster, more accurate, and less expensive. They work with a broader range of plastics, ceramics, and metals, including aluminum, titanium, and Inconel.

Once limited to prototypes only, today's printers churn out complex, limited volume, and customized parts. Some, like molds with conformal cooling channels, are nearly impossible to build any other way.

Ghalib and Hornstein do not live in that world. Their three Thing-O-Matics (they cannibalize one to keep the others running) and an Up! are not as sophisticated. They replicated CAD designs by extruding layers of molten plastic three to five times thicker than their industrial counterparts.

On the other hand, these printers are cheap. MakerBot Industries prices Thing-O-Matic kits at $1,099. Delta Micro Factor sells the Up! for $2,600, but it comes assembled. They are an order of magnitude less than the least expensive industrial printer.

Equally important, hobbyist printers are closing the performance gap quickly. "When we started, our printers were 60 percent as good as the commercial models at 1 percent of the price," said MakerBot CEO Bre Pettis. He claims his new model, the Replicator, is as fast as commercial 3D printers and has similar resolution. "When we were starting out, our layers were 0.5 millimeters thick. Now they're 0.2 millimeters."

The Replicator is a distinct break from the past. To start with, it ships assembled. Pettis could build the Thing-O-Matic in six hours, but it took newbies 20 to 40 hours to assemble it. "Now, when they get the machine, it is a better consumer experience. We've opened the market from people who read *Make* to people who read *Wired*, people who are interested in technology rather than do-it-yourselfers," Pettis said.

Replicator also has a bigger build space. "Instead of something you can hold in the palm of your hand, we can make things that take two hands to hold," he continued. "You can print a life-sized skull from CAT scan data, and make other models that you can use in the real world."

Opened The Door

Finally, the new machine has two nozzles and can print parts in two colors at the same time. This sounds almost trivial, but once the developers figured out how to do this (by interleaving instructions to each printer head), they opened the door to printing parts in any number of colors and perhaps in several different materials.

Pettis recognizes the need for a killer app. He even has a candidate: *Thingiverse.com*, a website where the MakerBot community shares designs. "We weren't sure what people would use our printers for, so we built Thingiverse to see if a killer app would emerge," he said.

In many ways, the killer app is everything. People download files for things as practical as coat hooks and smartphone holders. Other times, something seems to catch Thingiverse's collective fancy.

"A designer named Zaggo downloaded a design for a whistle, and within half an hour, hundreds of people around the world were making it. That was the first thing on the site

that went crazy. The next day, it was shower curtain rings or something else," Pettis recalled.

Others have built on the community concept. Shapeways is an example. Artists and designers set up online shops and upload their CAD files. When a customer purchases a product, Shapeways builds it to order on its 3D printers. The company, which started in the Netherlands, operates a manufacturing facility in Eindhoven and plans to open one in New York City in 2012.

Shapeways uses higher end 3D printers. It shows. The products on its website are slick. Some appear handmade. Others are mind-bogglingly complex.

Dutch kinetic artist Theo Jansen's Strandbeests are an example of the latter. Since 1990, he has built stunning combinations of gears, PVC pipe, and articulating joints that capture the wind to walk. For Shapeways, he has shrunk his giant designs to bread loaf size. Strandbeests come out of the 3D printer fully formed, with dozens of moving parts, ready to start their journey without any assembly.

More Typical

Kevin Wei is perhaps a more typical Shapeways designer. An adjunct assistant professor at Columbia University's graduate school of architecture, he makes jewelry on the side. His recent work uses a repeating style of ornamentation called cosmatesque. In its heyday, around 1100 AD, it decorated luxury goods ranging from illuminated manuscripts to church interiors.

The arms of his bracelets have faceted sides so light flashes and flickers off them. "You can get that effect by hand, but you need extremely skilled people to do it," Wei explained. That would make the bracelets unaffordable.

Nor would they be as precise. "There is beauty in repetition," Wei said. "When you try to do this with human hands, you can't help but see the imperfections."

Wei does not print his jewelry directly. Instead, he prints a castable resin model, a positive of the bracelet. Shapeways arranges for someone to dip the model in plaster, then melt it away. That leaves behind a mold cavity with precise, detailed interior structures, he said.

Other companies have followed Shapeways' success. Freedom of Creation, another Dutch company, features an enticing array of lighting, chairs, trays, jewelry, coat hangers, and smartphone cases.

Shapeways CEO Peter Weijmarshausen calls these fab shops "the democratization of production." He has the numbers to prove it: Shapeways' member community of 100,000 sold more than 750,000 products in 2011 alone, he claimed.

Weijmarshausen argues that people want custom products. They rebuild their cars, add onto their homes, and paste decals on the laptops. 3D printing gives them just that, with at least some of the economies of scale of mass production.

Shapeways is pulling out all stops to make its products more customizable for people who have never heard of CAD. An example is the Shapeways sake set creator.

It begins with an image of a deep cup with a pronounced lip. Two sliders on the side determine surface smoothness and the twist of the cup's planes. On the side of the cup are a series of connected dots that describe its curve. By moving the dots, users can make the cup and lip longer or shorter, thinner or thicker, and more or less curved.

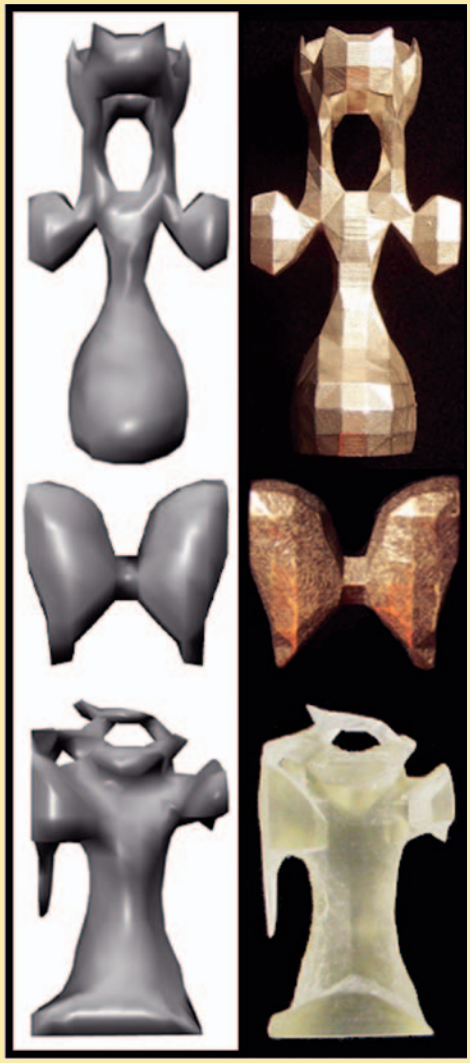
The possible combinations are infinite. One looks like a sake tumbler, another a cup, a third a shallow bowl, and the fourth a flower vase. "We'll print it in ceramics and send it to you in 10 days," Weijmarshausen said.

In London, Digital Forming is on the same track. Its technology lets customers modify a product's shape, surface design, color, and material.

"Most of what we call customization today on the web is really variant production, variations of the same product. What if we allow people to really customize, and take this customization one level further and engage people in the design process to shape and manipulate?" Lisa Harouni, Digital Forming's CEO, asked the audience at the Wired UK conference last November.

Printed Articles

A detailed bracelet from Kevin Wei, top left, contrasts with Cornell's screen-to-silver, bronze and plastic creations in this graphic.



She wants her audience to find out. While her company operates its own design website, she really wants to sell its technology to major lifestyle brands and professional product designers. Her goal is to help them produce custom products in mass at affordable cost.

Digital Forming's sleek design showcase is a world away from Ghalib and Hornstein's often quirky creations. In addition to customized iPhone cases and belt buckles, they have developed gourd-shaped lampshades, a plastic gramophone that clips onto an iPhone's speaker, and a servo-powered Silly String shooter. Yet beneath their playfulness is a very serious idea: 3D printing lets designers and inventors prototype and test ideas almost instantly.

The Silly String shooter is an example. "Driving into Salt Lake City, we saw a Dollar Store and pulled over to get some stuff we could turn into products that would be cool," Hornstein related. He picked up two cans of Silly String.

"We thought it would be cool to make an automatic Silly String shooter with a distance sensor for when somebody gets close," he said. Using some off-the-shelf electronics, he had a working product within 24 hours.

"In product design, that's insane. I've been working in product design for three or four years, and if we got things out in three months, that was crazy," Hornstein said.

Weijmarshausen sees the same compressed time frame. The first iPad cover, he noted, appeared on Shapeways only four days after Apple launched the product.

"Products will evolve much quicker than past," he explained. "If you are mass producing them, you need to make 1,000 and sell them before you go to version two. The iPhone case went through 12 iterations in just one year."

Slashes Risk

He also claims that 3D printing slashes risk. Individuals and companies may have squandered their time, but they are not left with thousands of unsold products and useless molds. "If no one buys it, it's a pity, but you didn't lose any money on it," he said.

Yet these attempts at customization just tap the surface of 3D printing's capabilities. The technology enables designers to create objects that would be impossible to manufacture using traditional methods.

A startling example is a stainless steel, load-bearing engine block segment created by Within Technologies. The London-based engineering firm was founded by Siavash Mahdavi, who is also a partner in Digital Forming.

The block contains two pipes that merge and exit from the side, as well as members to support the load, all sandwiched between two flat plates. If it had been machined, it might have two holes drilled from the top that meet a larger hole drilled in the side, surrounded by straight up-and-down supports.

Instead, the block looks like an alien life form. The pipes merge gracefully into one another, reducing the resistance to flow caused by right angles. The supports appear to grow out of the plates, and look more like a magnified form of life than anything designed by traditional engineering methods.

That is the point. Mahdavi did not design the part on a CAD system. Instead, he set weight, load, and flow goals.

MakerBot Takes off

MakerBot has come a long way since it was founded in January 2009 by Bre Pettis (above with printers awaiting shipment), Zach Smith, and Adam Mayer. That was shortly after Pettis, a former middle and elementary school teacher, discovered the RepRap project while creating videos for *Make,* a do-it-yourself technology magazine.

RepRap, short for "replicating rapid prototyper," was the first open source DIY 3D printer. It looked like a large, wired up Tinkertoy cube with a thermal extruder mounted on a Cartesian platform. It was the brainchild of Adrian Bowyer, a senior lecturer in mechanical engineering at the University of Bath in the United Kingdom. His vision was a printer that could build its own parts and evolve as users modified the design.

"We started this business because we wanted one for ourselves," Pettis said. "When we were done, it was so clear that we should be making these machines."

None of the partners were engineers, although Smith was a founding member of the RepRap Research Foundation (and Bowyer was one of the company's first investors.) In true Maker fashion, they plunged right in. "We used to joke that if we were engineers, we would have taken five or six years to design it. Instead, it took lots of caffeine and two-and-a-half months," Pettis chuckled.

They called it the Cupcake because its build space was the size of the pastry. It cost $750 and differed from the RepRap models in two key ways. First, RepRap had evolved into an ecosystem worth of designs. "If we downloaded a design today and you downloaded one tomorrow, we may not have been able to share parts or software," Pettis said. He wanted a machine with more commonality, so users could share improvements across the entire user community.

Secondly, they wanted to simplify building a machine. At the time, people who wanted to build a RepRap printer needed to order parts from many different vendors (as well as certain parts that could be built only by other RepRap machines). "It could take six months to get the parts. We wanted a kit, a box with everything already in it," Pettis said.

Makerbot uploaded all the source files on its Website, Thingiverse, so anyone could download them and make a Cupcake. Yet the kit was an instant hit. Eighteen months later, it introduced the Thing-O-Matic, a larger, faster machine that incorporated many of the modifications users had created for the Cupcake.

By January 2012, when MakerBot released its latest model, Replicator, it had already shipped 7,500 3D printers.

Lemon squeezers, above, with a bird bones iPhone case, right, created by Digital Forming.

Then he used software to evolve the structure. The software started with a set of rough guesstimates, then picked the one that most closely met Mahdavi's goals. It randomly varied that structure, assessed each of its progeny, and reiterated the process with the best candidate. After several generations, the design emerged.

Evolution works because 3D printing has decoupled production from its traditional constraints, such as the ability of a shop to actually machine a design.

Powerful NewTechnology

Mahdavi is not the only one looking at this powerful new technology. Hod Lipson's lab at Cornell University has developed software to design soft-bodied robots. The robots contain three types of cells, graduate student Jason Yosinski explained. One type contracts, one type expands, and a third provides support. "By moving them through random mutations over thousands of generations, we can generate our best guess of how to make a robot that walks," he said.

Lipson's lab has not yet printed a walking soft robot. On the other hand, it has launched its own open source 3D printer project, Fab@Home, printed out scallop and celery hors d'oeuvres in the shape of the Space Shuttle, and printed a robot fish that wiggles its tail.

Lipson's lab has also launched a website, *endlessforms.com*, that lets users evolve forms by voting. By September 2011, the site had attracted 25,000 visitors, who had evolved two million organisms, a total of 130,000 generations.

Those are big numbers, and they have attracted the attention of investors and large corporations alike. Foundry Partners, a venture capital firm, has invested $10 million in MakerBot. Shapeways spun out of Royal Philips Electronics' lifestyle incubator and recently received $5 million from Union Square Ventures.

Autodesk, a major CAD software supplier, is releasing 123D, simplified online CAD software that enables users to design 3D printing and laser cutting projects. 3D Systems has teamed with Freedom of Creation to create a low-cost 3D printer.

Perhaps more tellingly, Pirate Bay, a website best known for helping people download copyrighted movies, songs, and games for free, announced that it would host 3D printing files. It has even coined its own word, "physibles," to describe them.

Where will it lead? The answer is emerging more quickly than anyone expected. Perhaps Ghalib and Hornstein will have found their killer app by the time they reach New York. Maybe we will all be printing out spare parts and jewelry from our desktop 3D printers in 10 years.

Given the speed of the industry's evolution, almost anything is possible.

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