The Dream Factory

From design to delivery, custom manufacturing is coming soon to a desktop near you. Writer Clive Thompson joins the fab Lab" revolution.

If you could make anything you wanted, what would it be?

For me, that's not a rhetorical question, because right now I'm staring at my own personal fabricator. It's eMachineShop, an application that produces a physical 3-D copy of almost anything I draw. "You know the machine on *Star Trek*? The replicator? That's what I was aiming for," says Jim Lewis, the guy who created this tool.

The concept is simple: Boot up your computer and design whatever object you can imagine, press a button to send the CAD file to Lewis' headquarters in New Jersey, and two or three weeks later he'll FedEx you the physical object. Lewis launched eMachineShop a year and a half ago, and customers are using his service to create engine-block parts for hot rods, gears for home-brew robots, telescope mounts - even special soles for tap dance shoes. "Designing stuff used to be just for experts," Lewis says. "We're bringing it to the masses."

I'm going to test that claim. I have no experience in design and can barely draw a convincing stick figure. If I can manage to engineer a product, then he's right: Any idiot can do it.

I launch eMachineShop's software and stare at the blank screen. What to make? I consider and discard several ideas. I'd love to create a tricked-out mobile phone, but after doing some research, I realize that installing the electronics are beyond my ken. A futuristic MP3 player would be easier - but too obvious. Then it hits me: Ever since I began playing electric guitar as a teen, I've wondered what it would be like to make my own instrument.

I begin tentatively sketching shapes, using eMachineShop's box drawing tool to sketch some chunky outlines. Unfortunately, boxy edges make for a rather dorky-looking guitar; everything I'm producing seems like it was designed with a hatchet. I poke around for another hour, with equally ungainly results.

Finally, I stumble upon a tool in the software that lets me draw swooping, Stradivarius-like curves. This is more like it! In a flurry of creativity, I dash off a dozen concepts, stunned at how easy it suddenly is. I remix various classic guitar designs by drawing the outlines of famous models, like the Fender Stratocaster and the Gibson Les Paul, then stretching and skewing their outlines to make my own mutations. As I finish each concept, I click a button and up pops a lifelike 3-D view of my design. I spin it around to view it from all angles. Seeing a virtual version of each creation floating in space is very cool. I quickly discover that amateur engineering gives me the same rush as playing a round of Halo. I even lose track of time, obsessively tweaking and refining my guitars until I look up and realize it's way past midnight.

After a week of experimentation, I settle upon my favorite - a curvy, amoeba-like adaptation of a Flying V guitar. I had originally hoped to have it cut out of pine, like a normal guitar body, but when I explore the options for materials, I find that eMachineShop doesn't stock wood thick enough. The software offers me several possibilities, and each time I swap in a new material, it reprices the entire job, down to the penny. In the end, I opt to have a 3-D milling machine carve my design out of a single block of clear acrylic, with unbuffed raw aluminum for the faceplate. A guitar made of metal and Lucite: This is going to look like something beamed down from a UFO. It'll cost $880 for the two parts and take about a week to make them. Then all I have to do is snap them together and bolt on the neck, bridge, and a few electric components.

At 2 in the morning on a Tuesday, I finally hit the Place Order button. My design shoots off to Lewis' farm of roboticized fabrication machines.

I've just printed a guitar.

MIT professor Neil Gershenfeld calls it the fab revolution - every bit as important as the invention of the personal computer, he says. Cyberspace and PCs made bits flexible; fabrication technology is doing the same thing to atoms. Eventually, he claims, you won't even need a middleman like eMachineShop, because every house will have its own personal fabricator.

Every house? That's rather sci-fi. But Gershenfeld, director of MIT's Center for Bits and Atoms, makes a reasonably good case and has already taken an important step: He has shrunk the personal fabricator down to a single room's worth of off-the-shelf tools, all of which are available right now. "You can make essentially anything," he tells me.

Gershenfeld has developed a universal theory of fabrication, plus a shopping list of what you'll need. It goes like this:

First, there are subtractive tools, devices that can cut through materials with computer-guided, down-to-the-micron accuracy.Gershenfeld opts for a $1,900 Roland CAMM-1 CX-24 sign cutter; it works like a dot matrix printer, except the head is a knife that can slice through thin sheets of materials like vinyl or copper and is thus suitable for chopping out precision circuit board elements and bendable plastic. For thicker materials, he suggests the $15,000 Epilog Legend 24TT laser cutter. It uses a 35-watt carbon dioxide laser to slice through wood and acrylic as thick as an eighth of an inch.

Though the cutters sound complex, they're both guided by ordinary desktop drawing programs like CorelDraw, so "you can learn them in about an hour," Gershenfeld says. Anything you can sketch onscreen, the cutters can create, with tolerances as fine as one-thousandth of an inch. That's so exacting you can punch out 2-D shapes that simply press-fit together, like six panels to form a box. "And that's key, because it means you can move much, much faster when you're making something," he says. "In a few seconds, you can transform a two-dimensional sheet of acrylic into a three-dimensional object."

To produce even more-complex 3-D shapes, like an engine-block part, you need a different sort of subtractive tool - something that can cut up entire chunks of metal, working the way a sculptor chisels a figure out of a block of marble. Gershenfeld has a $4,500 Roland Modela MDX-20, a milling machine that uses a computer-guided drill bit that can move in three dimensions. The MDX-20 is small enough to sit on your desk and can handle materials - from plastic to light metals like aluminum and brass - with precision of up to two-thousandths of an inch.

Then there are the "additive" tools, machines that fab stuff from the ground up, the way a potter or bricklayer might do. The $18,000 Formech 660 vacuum-former can take any object and mold a quarter-inch-thick sheet of hot plastic around it, quickly producing shapes like bowls or computer mouses. For more exactitude, you have the $16,500 WASP injection-molding Mini-Jector #55, which melts plastic pellets and squeezes them into a metal mold - perfect for making things like cases for electronic devices.

The final group of tools consists of circuits and chips to give your creation "intelligence." Atmel AVR microprocessors cost about a buck apiece, but they're robust enough to control sophisticated robotics and can be programmed using simple languages like Python, Basic, and Logo. Roland's CAMM-1 sign cutter and Modela milling machine can quickly produce circuit boards. Pop in the chips and you're ready to go.

Using this lineup of machines, Gershenfeld has set up seven "fab labs" in towns around the world: Boston's South End; Takoradi, Ghana; Solvik Gård, Norway; Pabal and Bithoor, India; Cartago, Costa Rica; and most recently Pretoria, South Africa. After each lab opened, locals swarmed to fab a spectacular variety of stuff. A Norwegian sheepherder built GPS-enabled tags to track his flock; an Indian businessman created an electrode-driven device that measures the fat content of milk (he wanted to make sure he wasn't being sold watered-down stock); and a Boston teen created a motion-detector security system to protect her diary. This, Gershenfeld says, is the peculiar genius of personal fabrication: It fills the gaps in the mass market, helping people build idiosyncratic one-offs that no company would bother with.

"Fab is about making the things you can't find at Wal-Mart," he says. "It's stuff for a market of one."

Still, can you really call fab a democratizing technology when laser cutters cost $15,000 and require special venting to remove the noxious fumes they generate while hacking through plastic? Predictably perhaps, Gershenfeld invokes Moore's law. He maintains that in two decades - maybe even one - the marketplace will produce a single, $1,000 device that sits on your desk and does everything one of his fab labs can. All you'll need to do is feed it raw materials, like wood, metal, and plastic. "Even microchips," he says, which are now a commodity akin to ink in a printer.

In Gershenfeld's vision of the fab future, when you break the remote control to your fourth-generation TiVo, or the handle on your fridge, you won't go out and buy a new one. You'll just download the specs, put in your order, and have it fabbed at Kinko's or Home Depot. Eventually you'll just make one yourself at home. Toddlers today will grow up in a world where using 3-D engineering software to make a custom object will seem as routine as formatting a term paper in Microsoft Word or posting to a blog.

They're already living that future in a small warehouse in Emeryville, California. It's the headquarters of Squid Labs, run by a gang of five MIT alums who by day create prototypes of new technologies for outside firms - and by night fabricate weird gizmos just for fun.

"Everything I own is basically one of a kind," says a cheery Saul Griffith, one of the cofounders, as he crouches on the floor of his dust-covered workshop, rooting through an enormous bucket of

metal brackets and bolts. A tall, shaggy Australian, he's wearing ragged flip-flops and a pair of cargo pants so stained with oil and grime that I can't determine their original color. Dozens of his group's inventions lie scattered about: a Frisbee embedded with microchip-driven LEDs, a set of robots precision-cut from plastic, a bunch of helmet-mounted laser-and-GPS sensors designed to help firefighters locate one another in a blazing house.

Today, Griffith is building a "hybrid electric bicycle" with a hidden battery compartment inside the bike's 4-foot-long, chopper-style front forks. To hold the forks in place, he spent the morning designing a bracket, then cut out a flat template for it on Squid Labs' laser cutter. Now, with that template as a guide, he hacks the shape out of quarter-inch steel, using a terrifyingly loud metal cutter. "I'm really into this 'tractor' aesthetic, getting everything to look like industrial machinery!" he hollers over the cutter's shrieks, while a 3-foot cone of orange sparks flies up and ricochets off his face.

Every few minutes, Griffith pauses to snap a photo of his progress. When done, he'll write up a comprehensive guide on how to build his project. This, he argues, is the next crucial step in fab culture: getting hobbyists to carefully document their plans and share them online. Squid Labs is hoping to kick-start such sharing this fall when it launches Instructables.com - an open database of interesting projects and fab techniques, "kind of like a Wikipedia for making stuff," Griffith explains. If people want to build his electric hybrid chopper bicycle, they'll be able to download the CorelDraw design of the bracket and send it someplace like eMachineShop to have their own copy printed.

"We got inspired when we looked at all these guys who'd engineered these incredible, modded parts for their Harleys. They'd have amazing photos of them, but they'd never post the CAD image," Griffith says. "We were like, Why not go open source?"

Later that day, I get a taste of how weirdly transformative this idea is. I'm hanging out with Dan Goldwater - another Squid Labs cofounder - and admiring one of his inventions. It's a pair of plastic gears that sit on a bike pedal and power a tiny generator. As you ride, you can run LED lights or a radio. I tell him I'd love to have a version of it myself. So a couple of Squid Labs guys go over to the laser cutter, pull up the design, and a few minutes later hand me exact copies of Goldwater's gears. Design once, print often. "Pretty cool, eh?" Goldwater grins.

Griffith imagines that fab tools could produce new economic models for creators. Suppose a hobbyist made a cool plastic exterior for an MP3 player. Suppose she put the design online, and 700 people downloaded the file and had it printed at eMachineShop. "At what point," he asks, "would a manufacturer say, Hey, there's a market here - and offer to buy the design from her?"

So, sure, soon we'll be able to build anything. But should we? "Let's say everyone suddenly can make their own hood ornaments. What if they actually do that? The real world would look like the Internet in 1996, when people started making their own Web sites." Griffith shudders. "Remember those hideous-looking psychedelic backgrounds and stupid animations? And blinking tags?"

"Rainbow dividers," Goldwater adds.

It's a good point - and it makes me anxious about my guitar. Sure, it looked fine onscreen. But what if it turns out to be a monstrosity in my hands? Recalling my decision to use clear acrylic for the body, I break into a nervous sweat. It's going to look like something from a mid-'80s, big-hair heavy-metal band! What the hell was I thinking?

Griffith interrupts my panic to announce that his chopper is ready. He wheels it onto the street,

all five Squid Labbers in tow. Eric Wilhelm, a lanky designer, offers to be the test pilot. He straps on a helmet and mounts the seat. "Does it have brakes?" he asks.

"Sort of," Griffith says.

"It's amazing how often brakes are an afterthought," Wilhelm sighs. Then he hits the electric starter and peels off.

After a week of suspense, I get an email from Lewis at eMachineShop telling me my guitar body is ready. Too impatient to wait for FedEx, I drive out to his office in New Jersey and sit down with him at his desk, which is crowded with six computers and dozens of metal parts. Amid the mess, I notice a brass saxophone mouthpiece, a bunch of finely wrought metal blocks, and a thin strip of brass with incomprehensible hieroglyphics laser-cut into the surface. ("That? Oh, that's a headband for a robot," Lewis says.)

He offers to show me how the guitar was fabbed. The eMachineShop software, he explains, includes artificial intelligence that operates like a "virtual machinist." In the background - invisible to the user - it runs a precise emulation of the real-world machines that fabricate parts, to determine whether the job is possible and how much it'll cost. He pulls up the image of my guitar and clicks a button to show me the hidden emulator.

As I watch, an onscreen animation of the spinning bit on a 3-D milling machine approaches the guitar body slowly from the left side, pauses at the edge, and begins to roam diligently along the contours, adhering precisely to the curves I drew. "It makes several passes, cutting deeper each time until it gets to the specified depth," he explains. When the outer shape of the body is done, the robot grabs a smaller milling bit and deftly drills a constellation of holes in the body, where I'll be attaching the guitar neck and the electronics. Lewis points to the screen, where a timer shows that the fabrication would take 44 minutes.

Now for the guitar's unveiling. Smiling uncertainly, I wait in a conference room while Lewis fetches it from storage. I'm still wondering whether I've produced a freakishly nasty aberration. Then the door opens and he lays it on the table.

At first, I'm amazed that the damn thing even exists. I've seen it only as a virtual object, so there's something surreal about its abrupt teleportation from my imagination to reality. Then I realize with relief that it looks kind of cool. The clear acrylic gleams like an otherworldly brick, and the brushed aluminum has precisely the sort of industrial flavor I'd hoped for. When I lay the pickguard down on the body, every hole for the pickups and electronics is precisely where I'd specified.

There's only one problem. "It's kind of heavy, isn't it?" Lewis asks delicately. He's right. Worried that the acrylic wouldn't be strong enough to sustain deep milling, I'd made the guitar body far thicker than I should have. When I pick it up, I realize with horror that it's much heavier than a conventional guitar. I'm going to give myself spinal damage trying to play this thing.

By the time I get home, my excitement has worn off, and I begin to notice many other design errors I'd made. I'd forgotten to round the corners on all sides of the guitar, so the back part looks like a tabletop; I also neglected to taper the neck joint, so it'll jut out like a two-by-four into my arm while I play. Worst of all, I accidentally carved too much space out of the interior of the guitar, making it impossible to attach a nice, thick bridge to anchor the strings. I'll be forced to use a lighter, crappier one. Why didn't I measure this stuff more carefully?

I'm reminded of a stern lecture Griffith delivered about the dangers of designing solely on

computers: When you're operating in a virtual realm, it's hard to feel any consequences. It really is too much like a videogame. "You learn a lot from actually holding your materials in your hands," he told me that day at Squid Labs. "That's when you have to grapple with your design." The computer screen is forgiving; the real world isn't.

I push on and spend the weekend assembling the rest of the guitar. I remove the neck from a cheap $99 Fender Squier and bolt it onto my custom body. I solder in the electronics; since this thing is probably doomed to look like a guitar from an '80s metal band, I buy a Seymour Duncan Dimebucker pickup, which according to the manufacturer's description will produce the tone of a "searing, crushing, metal massacre."

As the final pieces come together, I find I'm getting excited again. For all its imperfections, my creation looks surprisingly close to my original vision - less a straight-head guitar than a piece of mildly psychedelic Soviet machinery. When I attach the strap and sling it around my neck, it has the heft of a weapon. Maybe this is the ultimate appeal of the fab revolution: When you create something from scratch, even the flaws are charming. So I plug it in, turn on my amp, and start to rock.

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