Personal Fabrication: From automated machines to augmented tools

Fully automated digital fabrication tools are the darling of the personal fabrication movement, but they may not be the best format for harnessing digital fabrication for personal use. Instead we should be developing tools that work cooperatively with users to augment natural abilities rather than eliminate human involvement altogether.

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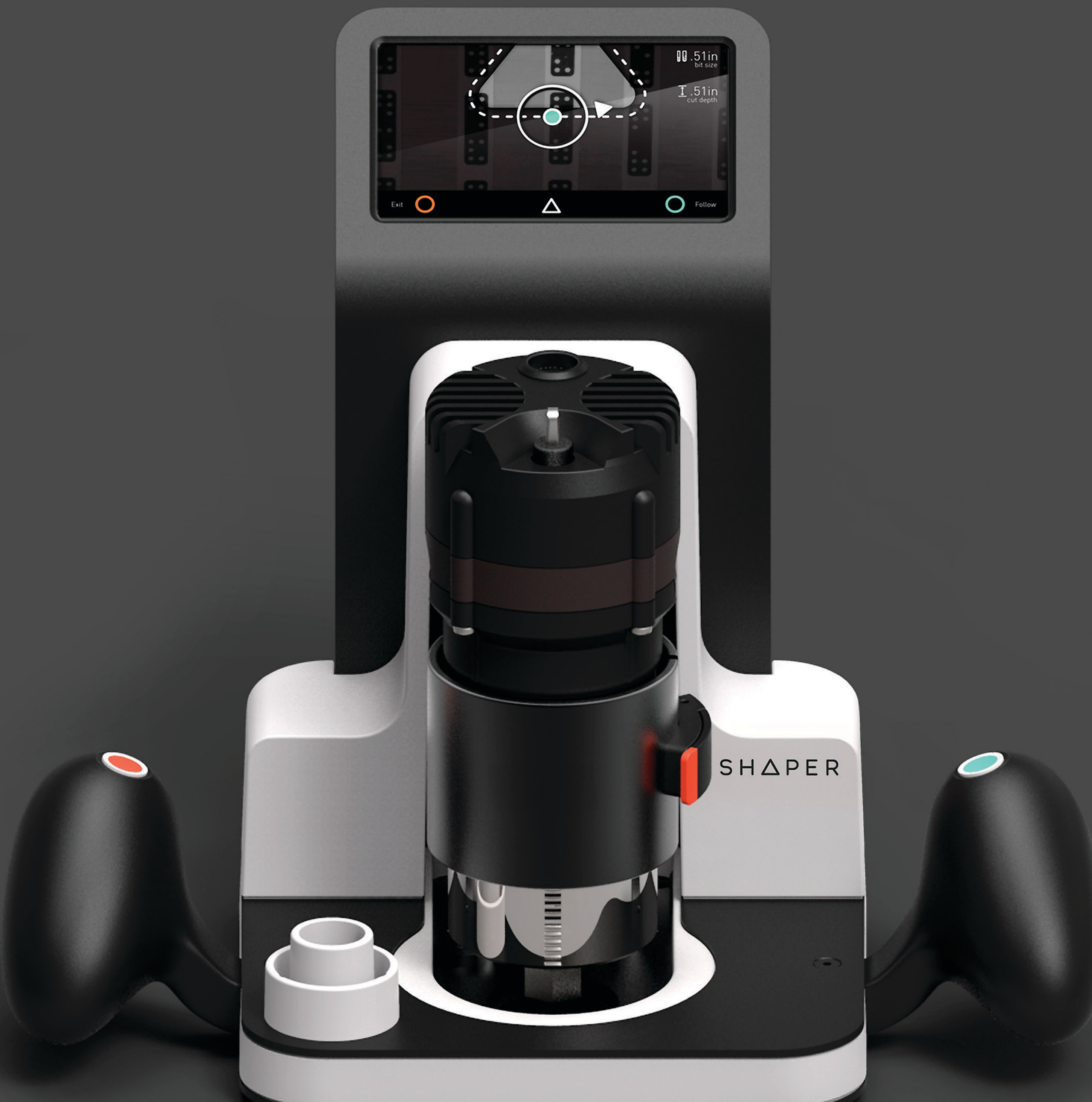
Digital fabrication is an exciting set of technologies that use a computerized workflow to first design and then precisely create physical objects. These tools have existed as the workhorses of industry soon after their invention in the 1950s, but only in the past decade have they been miniaturized, cost-reduced, and simplified to the point that they are now accessible to the general public. Inexpensive (or free) computer-aided design (CAD) tools, such as SketchUp and Autodesk Fusion360, make it easier for anyone to design nearly anything. Small computer numerically controlled (CNC) milling machines and 3-D printers are popping up at an astonishing rate in makerspaces, hackerspaces, schools, museums, and garages across the world. While this trend promises to vastly expand the abilities of the individual to create, there is still a long way to go before digital fabrication truly finds a widespread home on peoples' desks and in their garages. The best solution to the challenge of democratizing digital design and fabrication is likely not through the incremental cost reduction and simplification of industrial tools, but instead demands a fundamental re-examination of how we use computers to help us make things.

The path that digital fabrication must traverse to fully integrate into a new context of "personal fabrication" has a precedent: personal computing. In his book *Fab: The Coming Revolution on Your Desktop—from Personal Computers to Personal Fabrication*, Neil Gershenfeld draws an apt parallel between digital fabrication and the rise of the personal computer in the '70s and '80s. Both technologies were first developed for military purposes around the time of WWII; early computers were used to calculate fire control tables for artillery guns, and numerically controlled milling machines were invented to better produce complex airplane components. Computers were then adopted by industry for tackling laborious computational tasks like payroll, and digital fabrication was used for tasks like high-speed high-tolerance manufacturing. It was not long after that

Figure 1. The Shaper Origin computer-assisted cutting tool.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the lockstep held between these sister technologies was broken. While the computer began to rapidly evolve into a consumer product, digital fabrication remained exclusively a tool of industry.

By the early 1970s, the mainframe was shrunken to desktop proportions. Although the technology had been made human-scale, the human-machine interface remained an 80 character-wide glowing cathode-ray tube. The early adopters of personal computers were enthusiastic and passionate enough to subject themselves to an interface whose designers were more likely interested in maintaining a status quo than improving user experience. It wasn't until the widespread introduction of the Macintosh in 1984, with its graphical user interface and desktop metaphor, that personal computation had finally taken a form accessible and intuitive to the average person. Personal computation was enabled by a fundamental re-invention of how people interact with an existing technology.

Just as computers transitioned from the military-industrial complex to the realm of personal use, the same is happening now with digital fabrication tools almost 50 years later. In the words of Gershenfeld, "personal fabrication is the 'killer app' of digital fabrication." There are many benefits to this new style of digitally enabled personal fabrication. One is the abstraction of skill. You can shape complex metal or plastic parts with your digital hand

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simply by drawing the shape in a CAD program. Related to that is repeatability. Just as a mathematical expression will evaluate the same value on any computer system, ideally a 3-D model fed to a digital fabrication tool should result in identical outputs, whether you are sitting in a garage in the U.S. or a makerspace in Norway. This is essential to the third benefit, which is the ease of digitally sharing plans. Placed within the context of the Internet and accessible CAD tools, these attributes enable someone with little skill to go online, download a plan, perhaps make a few changes, and press "print."

However, along with these benefits come some distinct challenges. In spite of its new personal fabrication audience, the process of using digital fabrication has remained largely identical to the practices of industry. The end-to-end workflow starts by designing an object in a CAD program, followed by the use of computer-aided manufacturing software to create instructions for an automated machine to follow, and concludes with the set-up and operation of a CNC tool. In an industrial mass-production context, segmenting the use of a tool into these distinct steps is logical. Each domain requires specialized training and a large corpus of task-specific knowledge and experience. Indeed efficiency via specialization has been a dominant strategy of industry since at least the days of Henry Ford. The technology historian David Noble even went so far as to argue the segmented specialization of digital fabrication—enforced in part through deliberately complicated machine interfaces—was a tactic of management to maintain hierarchy in their organizations. Yet as digital fabrication now makes the leap from industry to personal fabrication, it is important we question whether there might be a better way of interacting with this powerful set of tools.

Digital fabrication is stuck in a rut equivalent to personal computers of the 1970s. Just like the awkward period preceding the introduction of the Macintosh, today's personal digital fabrication tools have been miniaturized to fit your desk, but little has changed in the way they are expected to be used. You still need to learn how to use CAD software, often times learn how to generate tool paths, and then learn the nuances of setting up and operating a digital fabrication machine.

All of this is required to generate any output. In contrast, the operation of a hand tool occurs on a much more analog scale. As you acquire skill the output improves, but even a first-time user can create a first-order approximation of their goal. The success of the Macintosh was largely in its approach of making the technology of computation intuitive to its user, rather than insisting that the user bend to the technology. The graphical user interface and desktop metaphor were key to this, as were the subtle hints pervasive to the user experience (often found in its iconography) that suggested the machine was a bit "human." Digital fabrication could serve to learn from the early success of the Macintosh. Instead of forcing the user to adopt a technology-centric system designed for industry, digital fabrication should fit itself into the natural way people are already using tools to make things.

There are a few examples of this starting to happen already. One recently announced tool, Glowforge's 3-D laser printer, is probably the first laser cutter to be designed from the perspective of the personal fabrication customer rather than clinging to the precedent set by existing tools. An onboard camera makes it easy to locate digital shapes to be cut on a piece of material, and a user can even draw with a pen directly on the material. Glowforge then uses computer vision to trace and cut along hand-drawn lines. The camera is also used for automatically snapping certain designs to known objects (e.g., the back of a MacBook), detecting material types by reading barcodes printed with invisible ink, and cutting out a large shape in multiple steps by finding where prior cuts ended.

Another example is the work being done by my own company Shaper. We are designing a computer-assisted handheld cutting tool called Origin (see Figure 1). It enables users to cut complex shapes from materials like wood, plastic, and light metals with the accuracy and at the scale of a large CNC tool, but entirely freehand. Origin works using a combination of

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"tool GPS," which can locate the tool on the material within thousandths of an inch, and a small automated stage that is constantly adjusting the position of the cutting blade to account for user error. The experience of using Origin is equal parts hand tool and video game—you move the tool along the work-piece, doing your best to follow the outline of the digital shape you want to cut on the onboard screen. Meanwhile the tool makes minor corrections to your position to ensure your cut ends up exactly as intended.

The driving idea behind the tool is not about its underlying technologies of computer vision and motion control. Rather, Origin is challenging a pervasive assumption that the re-contextualization of digital fabrication for personal fabrication must steadily approach the single-push-button paradigm of the "Star Trek" replicator. Fully automated digital fabrication tools make perfect sense in a mass-production environment, where speed and absolute repeatability are paramount and operator intervention is expensive. There is little pressure for industrial automated tools to be easy to use, because the cost of paying a highly skilled technician to set up the tool is quickly amortized over the volume of a production run. These considerations are quite different than what should matter in a digital fabrication tool intended for personal use. In this new environment, ease of use is the most important consideration. Accuracy is important, but not all-important. Flexibility is essential, because the average person can't afford a new machine to do a specific job. And the trade-offs of time and money weigh less heavily at home, so it's OK if the "cycle time" to produce an object is a bit longer. There's also a long history of pride in hand-craftsmanship that, while still sometimes present in the abstract sense in mass production, is a very real thing in personal fabrication. Origin takes a step toward restoring the craft practice of concurrent thinking and making, which were intentionally divorced by industry, while still offering the many benefits of repeatability and communication afforded by digital fabrication.

We are steadily approaching a crossroads in the nature of our relationship with our tools. One path is leading us to fully automated universal fabrication machines—like the replicator—as household appliances. In this future, the physical act of making will be as simple as pressing a button on a computer screen, similar to pressing "print" to send a photo to an inkjet printer. All of our skills and craft become interactions with a computer screen. This is the terminal stop on the vector currently established by traditional industrial digital fabrication technologies. The alternative path is leading us to an era of personal fabrication when intelligent tools, such as Origin and Glowforge, will enhance the innate physical abilities of their users rather than attempting to eliminate their involvement in the fabrication process altogether. Of course these two potential futures are not necessarily mutually exclusive. In any event, it is difficult to make a qualitative judgment of which might be preferable. Fully relinquishing our ability to make things with our own hands in favor of push-button convenience could be the price of a future of highly customized abundance for all; or it may be just enough rope to hang ourselves. But regardless of which future is more appealing, it is clear digital fabrication needs to take a different—and I would argue more human—form if it is to be widely adopted by individuals as the empowering tool it has the potential to be.

Biography

Ilan Moyer is a co-founder and mechanical engineer at Shaper, where he is helping to build the future of power tools. Moyer has been interested in creating tools for personal fabrication since writing his MIT undergrad thesis on the topic of Rapid Prototyping of Rapid Prototyping Machines in 2008.

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