The Promise of Self-Sufficient Production

As global supply chains have revealed their vulnerabilities during the pandemic, digital fabrication technologies demonstrate a promising way forward.

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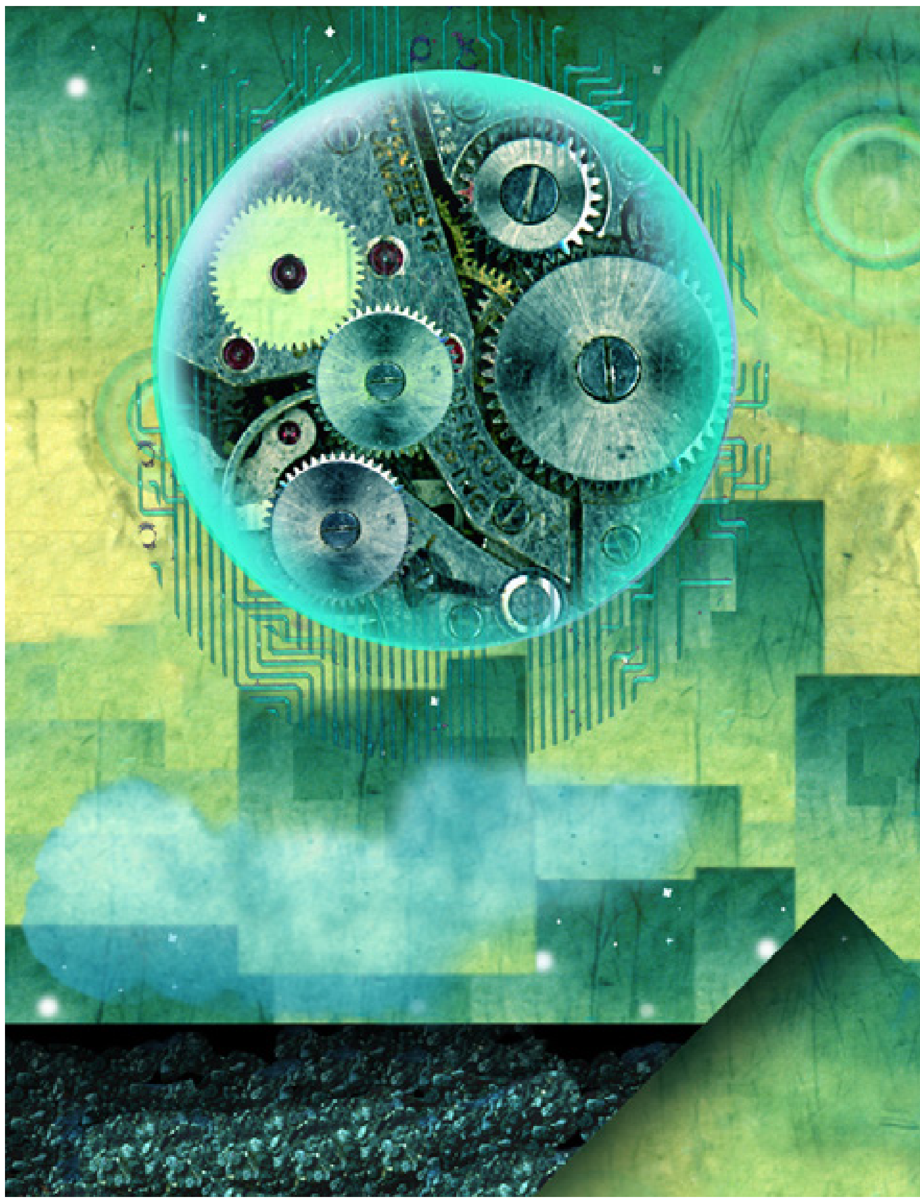
It was a matter of life and death. During the early onslaught of the COVID-19 pandemic, a hospital in Brescia, Italy, was running out of ventilator valves. The normal suppliers couldn't meet the rapidly increasing demand for the parts, which were essential for keeping patients alive.[1] So, in a moment of desperation, the hospital reached out to the local community for help. Isinnova, a company in Brescia with rapid prototyping capabilities, responded to the call. It reverse-engineered, prototyped, and then produced hundreds of 3D-printed valves that proved a good fit for the emergency. The same company then developed an innovative idea to transform a snorkeling mask into an emergency ventilator. Since these emergency ventilators were needed extensively all over Italy, Isinnova connected with the digital fabrication community to make the materials available to the local hospitals, reported Martina Ferracane, founder of FabLab Western Sicily. Thousands of adapters were produced and donated to hospitals across the region. A distributed ecosystem of digital fabrication facilities — some community-based fabrication labs, some commercial — had become an important part of the local supply chain to provide health care facilities with personal protective equipment (PPE), spare parts, and medical devices.

At a time when global supply chains and large-scale manufacturing are being revealed as fragile and vulnerable, the role played by digital fabrication technologies and local ecosystems gives us a glimpse into a future in which new forms of



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THE RESEARCH

This article builds on the research we conducted for our book, *Designing Reality* (Basic Books, 2017), for which we conducted a stakeholder survey and dozens of interviews with experts.

We conducted semi-structured interviews with sources at the frontiers of innovation during the pandemic.

We are also participant observers, directly involved on a personal basis in various pandemic responses. This adds a potential bias to our perspective while also providing for deeper contextual understanding.

self-sufficient production can empower communities all across the world.

We define *self-sufficient production* as producing locally while connecting globally, and throughout the pandemic we've seen how advances in digital fabrication have enabled globally connected local production ecosystems to design and deliver lifesaving products. Global connectivity enabled the open sharing of product designs, the identification of medical-grade raw materials, and innovative approaches for aligning designs with safety standards. Meanwhile, local digital fabrication capabilities enabled the production and delivery of medical devices and parts without dependencies on global supply chains. To support this movement toward increased local self-sufficient production, MIT's Center for Bits and Atoms (CBA) launched a virtual forum that brought together hundreds of experts from academia, industry, government, health care, and nongovernmental organizations to facilitate rapid-prototyping responses to the pandemic. The participants collaboratively worked through dozens of technical and organizational challenges as digital fabrication facilities in schools, labs, libraries, community centers, entrepreneurial startups, and industry all transformed themselves into interconnected, distributed COVID-19 local and regional production ecosystems.

Before the COVID-19 pandemic, the elements of self-sufficient production were already evident if you knew where to look.[2] But during the pandemic, the capabilities have become more widely visible — revealing the advantages of a distributed network when compared with a traditional hierarchical organizational structure. Based on what has worked during the pandemic, it is now clear that self-sufficient production embedded in interconnected networks can have broader impacts beyond the recovery. It's becoming increasingly possible for individuals, small companies, and communities to literally own the means of production — combining practices from a pre-industrial era (practices that have been largely replaced by commercial enterprises) in ways that are both globally connected and locally self-sufficient.

Where Digital Fabrication Stands Today

When they hear the phrase "digital fabrication," most people think of 3D printers. Indeed, 3D printers are the most visible manifestation of this new phenomenon, but they are just one part of the current toolbox. All over the world, people are using a range of computer-controlled tools to make various items such as food, furniture, crafts, computers, houses, and cars. There are machines that cut precisely with lasers; larger rotating cutting tools to carve things like furniture; automated knives to plot out graphics; molds for casting parts; electronics tools to produce, assemble, and program circuits; and scanning tools to digitize objects so they can be replicated. Together, these tools add up to a complete fabrication facility — a fab lab.

These fab labs share designs, methods, and even resources for identifying and sourcing local raw materials. The number of fab labs in the world has been doubling approximately every 18 months for more than a decade. There are now more than 2,000 worldwide, from the northern tip of Norway to the southern tip of Africa, and from rural Alaska to urban Japan. Because fab labs have a common software and equipment footprint, ideas developed in one lab can be applied across the network.

This emerging movement around digital fabrication represents a third digital revolution that is likely to be at least as significant as the first two digital revolutions in communication and computation. Those digital revolutions also started small and grew exponentially to transform society. Digital fabrication today is at approximately the same stage that digital computation was in the early 1980s, when personal computers gave millions of people access to a capability that had previously been limited to large organizations. PCs were to be followed two decades later by billions of mobile devices and trillions of connected things.

Today we have thousands of fab labs, with the potential for making millions of personal fabricators — small-scale fabrication systems for individual use — and a research road map leading to a future with billions of universal assemblers, and then trillions of self-assembling systems in future decades. As with the exponential improvements of the earlier digital technologies, each of these stages of development promises to be faster, better, and cheaper.

Self-sufficient production offers benefits to individuals and communities beyond just the ability to respond to a crisis. Making goods that meet personal, family, and local community needs is deeply satisfying. Not only can individuals and communities reduce their dependence on global supply chains by combining digital fabrication processes with traditional production practices, but they can also raise their levels of well-being, agency, and dignity.[3] The combination of technology and human creativity can help create healthier and more productive communities.

Digital Fabrication During the COVID-19 Pandemic

A key question about digital fabrication is whether the progress toward increased self-sufficient production made during the COVID-19 crisis can be sustained over the long term. During difficult times, people become more self-sufficient out of necessity. Witness the millions of victory gardens during both world wars. Historically, however, such practices have faded away once crises pass. But there are several ways that self-sufficient production can continue to grow even after the pandemic wanes if we recognize the challenges and build on what has been learned to date.

The first challenge in responding to COVID-19 was transitioning from do-it-yourself community facilities to larger-scale production. In California, Danny Beesley, the founder of Idea Builder Labs, reported on his experience rapidly scaling production at the height of the pandemic in April 2020: "Yesterday our production capacity was 450 masks a day; today it is 3,000, and tomorrow we'll double to at least 6,000." This was achieved by validating designs, coordinating the efforts of multiple fab labs, and reaching out to suppliers of raw materials (including Coca-Cola, which donated plastic rolls). Assembling the needed talent was easier than expected, thanks to the quality of people who stepped up during the pandemic, Beesley said. Similarly, Vaibhav Chhabra and Richa Shrivastava from the Maker's Asylum in Mumbai, India, were able to coordinate local distributed production capabilities to make 1 million urgently needed face shields.

The second challenge was collaborating without there being any single organization in charge. The University of Alaska's Pips Veazey, who is leading National Science Foundation-funded research on changes in Alaska's ecosystems, described collaborations that emerged during the pandemic and could continue afterward. "At first, the usual suspects came together — the hospital and the university. But then they were joined by a tent manufacturing company, an IT business, a local distillery, a window and door manufacturing company, and others to produce PPE and devices," said Veazey. The challenge was that these diverse organizations had limited experience working together and few formal agreements, let alone any experience collaborating under such pressure. The resolution was something increasingly seen in the rapid-prototyping community's COVID-19 responses: They formed a consortium, with each organization signaling its strengths and capabilities, in order to create a temporary production system that could accomplish shared objectives.

Probably the most significant challenge has been ensuring that the community-based initiatives align with safety standards and do no harm. In our earlier example from Italy, national regulators issued a cease-and-desist order to the distributed fabrication facilities because they were not operating consistently with regulatory standards (though the hospitals asked them to keep producing because supply chains were still broken at the time). Regulatory standards for the production of medical supplies were developed with individual companies in mind and an assumption of traditional supply chains rather than interconnected networks filling in when supply chains collapsed.

In response to the need for rigorous science to inform the distributed production efforts, the working group hosted by MIT's CBA provided guidance. Early insights included using computational fluid dynamics modeling to highlight how many of the face shields being produced failed to provide adequate coverage by not sealing all sides of the face, and the recognition that widespread efforts to produce ventilators missed the need for assistance with other, more urgent respiratory interventions.

As the crisis continued, the working group expanded to include collaborations with unfamiliar partners. For example, a Boston-based makerspace, Artisan's Asylum, was able to repurpose an unused ultrasonic welder at CBA to make surgical gowns. An expert in advanced computer modeling from Simulia, a Dassault Systèmes company, was able to refine PPE designs being produced by hobbyists.

Emergency room doctors from Boston Medical Center provided near-real-time feedback on PPE prototypes to users of advanced manufacturing tools in CBA's shops. Collectively, these and other developments have made a significant contribution to the safety of front-line health care workers.

The CBA working group roughly corresponds to the R&D function of a company, and the regional consortia of fab labs and makerspaces correspond to production operations. Although fab labs were also experimenting with designs, there were basic science questions and medical standards that were beyond the expertise of individual labs. Embedded in these collective efforts are elements of an organizational form — a multi-stakeholder consortium — that, though not new, has played a critical role in helping local communities solve their problems in a crisis. Along with the accelerated use of digital fabrication technologies is the parallel generation of increasingly robust global consortia that will have expanding importance in the years to come.

Coordination and communication in this virtual R&D process and among fab labs converting to production operations included regular online meetings along with offline collaborations. These forms of distributed R&D and production highlight how innovation and safety can be addressed during a rapidly evolving crisis, even without the structure of a formal organization. The patterns of self-sufficiency that have emerged during the pandemic reveal how distributed R&D and local production could persist and expand as vital organizational and institutional arrangements in the pandemic recovery.

Self-Sufficient Production Following the Pandemic

Innovations and collaborative relationships that emerged during the crisis are now being expanded to meet ongoing community needs. For example, Beesley anticipates broadening the focus of Idea Builder Labs to include housing for the homeless. As he put it, "We can say that the fab lab that helped to create the mask on your face can also create the roof over your head." To meet this challenge, the organization is encouraging stakeholders to form a financially sustainable worker-owned collective.

The COVID-19 crisis also inspired the fab lab network to create innovations beyond medical equipment. A fab lab in Barcelona developed an approximately $100 mini fabrication machine that could be brought home by students of the Fab Academy educational program when they couldn't come to their local fab lab. A fab lab in Finland provided links that let students operate machines in the lab from their homes. And a fab lab in the United Arab Emirates developed a virtual-reality version of its lab, again providing opportunities for remote engagement and skills development. All of these developments — changes that occurred much sooner than expected — challenged what had been an unquestioned assumption that students needed to gather in person in order to participate in fab labs.

Given the expanding role of self-sufficient production that has emerged during the pandemic, is this the moment that the combination of global connectedness and local capabilities can begin to fuel a more self-sufficient world? We know that fab lab projects already include innovations in the local production of food, shelter, energy, furnishings, apparel, medical care, recreation, education, and other goods and services that are in the basket of goods used in calculating the consumer price index. There are countless examples of fab lab projects that fit into each of these categories, among them custom furniture, hydroponic food production setups, prosthetic limbs, cellphone chargers, musical instruments, and tiny homes.

Although there are proof points for all of these projects that can be found in more affluent societies, the global pandemic has also highlighted the importance of local fabrication in the developing world. "In developing societies and disaster situations, the focus of digital fabrication has always been on practical production — people making what they need," notes Andrew Lamb, who leads global innovation for the disaster relief organization Field Ready. It's not too big a leap to imagine that as innovations improve and the lessons of the pandemic sink in, digital fabrication could materially improve the availability of all the categories of essential household goods in communities around the world.

What a Self-Sufficient Production Ecosystem Means for Business

Digital fabrication is becoming increasingly important to large and small enterprises. The entry of

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big business into the distributed ecosystem comes with both great opportunity and risk to the movement toward distributed innovation and local empowerment.

Some companies see the opportunity both to serve their own interests and engage their communities. In Brazil, Fiat Chrysler launched a community fab lab with the dual aim of having its workers, engineers, and managers conduct community outreach and increasing digital and design literacy within the community. Other major industrial companies, such as General Electric, Chevron, and Dassault Systèmes SolidWorks, are also funding the establishment of fab labs in communities where they do business, in coordination with the Fab Foundation. Ikea, which sells furniture for self-assembly and other home furnishings, plans to become a provider of fasteners and other hard-to-produce items for fab labs and makerspaces — adding to its business model an assumption of growing demand for self-sufficient production. There are dozens of producers of digital fabrication equipment and software whose business models embrace digital fabrication for educational use, rapid prototyping, and industrial production. In Shenzhen, China, a global hub of electronics production, planners are already anticipating a role for the region in supplying programmable modules to be incorporated into products designed and produced in fab labs and makerspaces.

Some technology companies and government agencies are investing in the frontiers of digital fabrication to advance the frontiers of local production. For example, Airbus is working with CBA on processes to directly assemble entire airplanes from discrete "digital" materials, without the usual long supply chains. NASA is also engaged with CBA on how programmable digital materials can enable self-sufficient space settlements.

Local digital fabrication can also be a threat to businesses. Self-sufficient production is a counterpoint to the convenience of going on the computer and, with one click, ordering a product that shows up the next day. Digital fabrication can enable products designed, customized, and produced by the individuals and communities for themselves instead of mass-produced and mass-distributed products. Further, the ethos of self-sufficient production centers on open sharing in ways that are contrary to some business norms. For example, material properties are among the most closely guarded intellectual property of commercial businesses in some industries, but the digital platform Materiom, set up by Alysia Garmulewicz, a professor of the circular economy at the University of Santiago, Chile, is designed to share information on local materials used in digital fabrication. Thus, self-sufficient production embodies an open and collaborative logic that is consistent with some aspects of business but contrary to norms that are more competitive and proprietary.

At the same time, there are commercial dynamics that could undercut locally driven, distributed self-sufficient production. The first two digital revolutions were accelerated by the energy, innovation, and idealism embodied in the homebrew computer clubs and the early networked communities that laid the foundations for the internet. There were great visions of digital technologies democratizing all aspects of society, making the world more equitable, peaceful, and healthy. As we look back a few decades later, there is no question that the first digital revolutions transformed the world and improved the lives of many — but they have also fallen far short of optimistic early visions. The internet ecosystem is now dominated by a handful of companies with tight control over their powerful platforms, and their cacophony of toxicity and misinformation, coupled with privacy concerns, has created a global technology backlash.

The ethos of the early fab lab ecosystem clearly echoes that of the early adopters in the first two digital revolutions, but those ideals could be overtaken by the demands of investors seeking blockbuster returns and the competitive dynamics driving proprietary software and hardware. A key question is whether the collaborative ecosystems around digital fabrication will suffer the same commercial fate as the digital communication and digital computation platforms, or whether an open hardware movement will flourish as a physical counterpart to the success of open-source software development.

Where Do We Go From Here?

Realizing the full potential of self-sufficient production will require public-private partnerships, building upon initiatives that had been launched before the pandemic. In the United States, the National Fab Lab Network Act for universal access to digital fabrication was introduced to Congress in 2019. This act now takes on new meaning following the pandemic, providing a framework for digital fabrication and legitimizing it as a middle-tier capability between DIY (which can respond quickly but not scale) and mass production (which can scale but not respond quickly). Internationally, the growing Fab City movement, which began in Barcelona in 2014, involves mayors, city planners, and others who have signed on to a 40-year plan to use digital fabrication technologies to break their dependence on global supply chains.

Progress toward widespread self-sufficient production will not be easy. In addition to the challenges inherent in nonhierarchical distributed production, there are three threshold barriers to ubiquitous digital fabrication, each of which mirrors the ongoing challenges of the first two digital revolutions: access, literacy, and risk. The first of these, access, begins with the current digital divide. Approximately one-quarter of the U.S. population and nearly one-half of the global population has limited or no access to the internet.[4] Of those with internet access, only a tiny percentage have access to digital fabrication equipment. Even doubling the number of fab labs every 18 months will still leave the vast majority of people without access to these powerful technologies for a long time.

While there are over 2,000 fab labs now, real advances in access will depend on progress in the technology that moves toward a blend of both personal fabrication and larger fabrication facilities — so that the multiplier is not one fab lab at a time, but both larger and smaller units of productive capability. It is likely that access will be via community-level ecosystems where some larger-scale productive capability is shared at the community level (like printing service bureaus), while smaller-scale machines — perhaps made via self-sufficient fab labs themselves — are also available to individuals. Access will have both technological and social dimensions, since the means of production will be in the hands of individuals, families, neighborhoods, and other communities, not just business organizations. This will require new norms and operating practices.

Those with access will still need to develop multiple skills specific to digital fabrication. These include developing facility with computer-aided design software and learning to transmit a computer-based design to the relevant production equipment, with the right raw materials. Increasing numbers of mentors who can share these skills in fab labs and makerspaces will help address this challenge, as will the growth in hands-on programs like the Fab Academy. And the technology is steadily becoming more user-friendly as new generations of software and hardware emerge.

As with any new breakthrough technologies and institutional arrangements that aim to create value in society, self-sufficient production also needs to mitigate risk.[5] Most of the protections in society around workplace safety, environmental hazards, discrimination, and, perhaps most challenging, ethical issues focus on the regulation of commercial establishments. Most biotechnology has taken place in commercial, university, and governmental labs, where there are well-developed protocols for ethical oversight, but biofab (the fabrication of biological products) is now becoming accessible on a community scale. Those same risks need to be addressed in the disparate world of digital fabrication. Rather than relying on centralized points of control, there need to be incentives and new mechanisms to bring self-sufficient producers into national and local regulatory frameworks.

Beyond social and environmental issues, there are risks around the misuse of these powerful technologies. These include the intentional production of weapons and the unintentional production of hazards — particularly with the growing use of biofab. There is a deep societal challenge centered on the governance of risk when productive capacity is widely distributed and locally or individually controlled. It is incumbent on us to pioneer agile institutional arrangements that mitigate risk with distributed technologies and that co-evolve as the technologies advance at exponential rates.

Conclusion

The potential for technology-enabled self-sufficiency was present before the COVID-19 pandemic, and we predict that it will accelerate now, given new awareness of the need to reduce dependence on global supply chains, and the demonstrated contribution of digital fabrication to alleviating supply chain problems. But it may develop in ways that either benefit or hurt many stakeholder groups in society.

Self-sufficient production can reach and empower those on the margins of civil society. Already, we see people in urban food deserts exploring hydroponic food production and residents of remote rural locations making their own spare parts. In some cases, people are even beginning to make digital fabrication equipment themselves and adapting the technologies to meet unique local needs. Embedded in the concept of self-sufficient production is the hope for increased human agency and community empowerment. This hope contrasts with the common fear of centralized technology eroding human autonomy and creativity.

What if the long-term response to COVID-19 were a series of small-scale distributed initiatives, with different communities each fashioning a range of different models for self-sufficient production? There would still need to be mechanisms for coordination and periodic standardization through multi-stakeholder consortia at local, regional, national, and international levels. It might not be a centralized moon shot for society, but it could instead involve parallel distributed innovation with shared learning and constancy of purpose, advancing dignity and meaningful work, along with increased self-sufficiency to meet both common and unique local needs. We've seen what's possible, and it offers a glimpse into a better future for all of us, if we choose to collectively lean in and proactively cultivate fab access and literacy.

Previous digital revolutions created digital divides, where half the planet does not have access to the internet and many of those who do have very limited access. We highlight this now to urge collective action to prevent a growing fab divide, where some have access to these powerful tools and the skills to effectively harness them to meet local needs and gain self-sufficiency, while others do not.

The logic of the industrial revolution was one of increasing concentration of productive capacity, winner-take-all wealth, and centralized control. The logic of the first two digital revolutions was initially proclaimed to be that of greater decentralization, with more egalitarian forms of governance. In fact, they have mostly proved to be a continuation of the centralized organizational and institutional logics of earlier eras. Now is the time to learn from the first two digital revolutions — both what to do and what not to do — as the COVID-19 response highlights and accelerates both the promise and the risks of the third digital revolution.

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