How 3D Printing Can Revolutionize Developing Economies

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Faculty Adviser: Dr. Benjamin Meiches

Essay completed in partial fulfillment of the requirements for graduation with Global Honors, University of Washington, Tacoma

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Abstract

3D printing technology has the potential to completely revolutionize development in emerging markets. While 3D printing can make a wide variety of objects, and create the capacity for local manufacturing, it can also change the nature of the economy and how things are made. When looking at the potential for development, we must realize that much development is attained by the unequal exchange between nations. For this reason, capitalism often fails the developing world while benefiting the developed one. However, thanks to this technology, there might be a path toward breaking this cycle. Examining how 3D printing is opening up new economic realities, such as the Social and Solidarity Economy, and models of production reveals the true potential that this technology has to help address important social issues such as equity and sustainability.

Introduction

All around the world 3D printing is revolutionizing manufacturing. Traditionally, manufacturing methods have been rigid and expensive, which meant that only those with extreme amounts of wealth could establish the means to produce items. Once the assembly lines and equipment are set up to produce a certain good it is hard to repurpose it to create another. Ultimately, the wealthy determine what is made and where it is sold. 3D printing fundamentally changes this relationship by considerably lowering the barriers to directly access manufacturing equipment. In a middle-income country, a 3D printer is something that can be bought and personally owned (Birtchnell & Hoyle, 2014). In a developing country, a 3D printer can be shared amongst a community thanks to its adaptability and lack of rigid tooling. 3D printers can be manufactured at home with commonly available parts or even from e-waste. This allows for an expansion of production capacity unlike ever before which is already playing out globally. 3D printers have been set up in places where other fabrication machines have not, and without supporting infrastructure (Savonen et al., 2018). However, 3D printing does not simply change the means of production, it also has the potential to change global economic relations structured by existing practices of industrialization. To truly understand the revolutionary potential of 3D printing the current landscape of development must also be understood to see how 3D printing can shift us away from the current order of things. This potential comes from the fact that 3D printing makes manufacturing more accessible and empowers people to produce items that are needed in their communities.

This paper starts by covering a short overview of 3D printing technology, then tying the technology to design considerations to establish the core capabilities and constraints of 3D printing. I then move on to the applications of 3D printing to explore successfully printed items that show what specific problems and needs it is able to address. With this technical foundation laid, I introduce the problem of unequal economic exchange and how it prevents countries' development. I then start to explore solutions enabled by 3D printing including alternative economics, communal manufacturing spaces (aka makerspaces), and volunteer manufacturing. Finally, I explore how 3D printing can open the door to other, complex manufacturing methods as well as more sustainable methods of manufacturing through the repurposing and recycling of waste. Through all of this, I will demonstrate that 3D printing is fundamentally changing manufacturing and through such can be used to change the social and economic order that has been created by historical relations between people and manufacturing.

A Short Overview of 3D Printing Technology

The technique of 3D printing began when Charles W. Hull, an American engineer, successfully printed a teacup using a stereolithography-based device that he himself designed and built (Jiménez et al., 2019). Since then, an array of printing methods have been developed that are able to use a wide variety of materials ranging from bioplastics, polymers, and metals. Some common methods of 3D printing include the following technologies: Stereolithography, Selective Laser Sintering/Melting, Material Deposition, and Jet Prototyping. However, Material Deposition and Stereolithography are the most common methods.

Stereolithography (SLA) is a method where a photopolymerization laser is directed into a vat of resin to selectively solidify the resin along a 2D plane in order to create layers, which are then stacked in order to create an object (Jiménez et al., 2019). This method is capable of high-resolution printing with good surface finishes, allowing printed objects to be air and watertight and creating transparent parts. For this type of printing epoxy-acrylic resins are a common feedstock. Stereolithography is the earliest method of 3D printing.

Material Deposition uses a filament (most often made from a bioplastic or other polymer) that is fed into a heated nozzle, which then melts it, before laying it down and cooling it in place to form a layer (Jiménez et al., 2019). It then repeats the process to create other layers on top of each other. Each layer needs to be supported, either by layers below it or by the placement of support material. This method is used in Fused Filament Fabrication (FFF), which is also sometimes referred to as Fused Deposition Modeling (FDM), the cheapest and most accessible form of 3D printing.

Knowing these processes will help to understand the design considerations of 3D printing as well. These techniques use certain materials, in a specific manner, that create physical attributes unique to 3D-printed objects.

Design Considerations for 3D Printing

When designing for 3D printing, designers must be aware of a number of constraints since these differ from those of other manufacturing methods. While not exhaustive, the geometric constraints of 3D printing can mostly be broken down into the categories of maximum print size, print resolution, dimensional accuracy, gravity, surface quality, and anisotropic considerations (Savonen, 2019). First, the object being designed needs to be able to fit inside the print volume of the available printers. If it can't be printed all at once within this volume, it must be broken down into component parts that can be. A second constraint is the resolution of available 3D printers. This represents the minimum size that can be printed as well as the ability of the printer to capture detail. A general rule of thumb is that features smaller than 2 mm across a nominal dimension will be difficult to accomplish on the average 3D printer. Dimensional accuracy refers to the ability of a 3D printer to replicate the dimensions from the source design. There is some amount of error during printing that will cause the printed object to vary somewhat across dimensions. This is relevant if one needs a certain level of tolerance with other parts. These dimensional limits also put some tasks out of reach, such as air filters, which require a level of detail that is too demanding for commonly available 3D printers.

Continuing on the topic of common design constraints, gravity concerns arise from the layered nature of 3D printing (Savonen, 2019). Overhanging features should be avoided when possible for 3D printed designs, as they will require supporting material (called supports) to be generated to print the object on top of. These supports will need to be removed after printing and will affect the surface quality of the object. In the cases of inaccessible inner chambers, supports cannot be removed and, depending on requirements, might not be able to be used as a result. This limits the steepness of overhang angles in such places. Surface quality is a concern in itself, as the layered method of printing causes the surface of an object to be stepped and have small ridges. This means that parts that need a smooth surface will require sanding or other methods of post-processing. Such demands increase the labor and time needed to be put into each printed item and reduce production throughput. Lastly, there are anisotropic considerations, which are differences in physical properties (such as flexibility and strength) across different axes. This is yet another consequence of the layered nature of 3D objects, where the orientation of layers impacts these attributes of an object in a similar manner to the direction of the grain on a piece of wood. For certain designs, this may create a need for a design to be printed in a certain orientation to maximize strength along a given axis. These constraints determine what parts and objects can be 3D printed and how they are printed, which helps to ascertain which designs can be manufactured via 3D printing. However, it is also worth exploring what people are already producing with 3D printing as well.

Applications for 3D Printing

One of the most common questions about 3D printers is: what can be printed with it? One might be aware of it as a manufacturing method but without concrete examples of what it can produce, it can be difficult to see the value of 3D printing. Concrete examples of 3D printable items will help answer this. Some common areas of concern that can be supported by 3D printing are health care, agriculture, and education.

In a medical context, 3D printing can produce many useful items such as Personal Protective Equipment (PPE) for healthcare workers, as discussed elsewhere in this paper, but can also produce many parts, and medical devices. During the COVID-19 pandemic parts for ventilators and splitters that allowed a single ventilator to support multiple patients were 3D printed (Advincula et al., 2020). Umbilical clamps have been produced for a hospital in Haiti (Ibrahim et al., 2015). 3D printing splints, common lab equipment, and prostheses are possible as well. 3D-printed versions of medical equipment drastically reduce cost. For example, a myoelectric hand that might typically cost $25,000 can be 3D printed for around $250 (Hagen et al., 2018). Notably, 95% of medical devices in developing communities are produced by the developed world — meaning that local manufacturing through 3D printing has the potential to drastically increase availability (Savonen, 2019). 3D printing's ability to produce replacement parts can also help address the fact that 40% of the medical devices in the developing world do not function properly.

In an agricultural context, 3D printing also has many uses. Producers can manufacture insect traps for pest management as an alternative to using pesticides (Dickens & Snyder, n.d.). Hose splitters, adapters, and other fittings can be 3D printed for irrigation (Crisostomo & Dizon, 2021). Tools can be manufactured using 3D printers, such as clawed fruit pickers for harvesting. Like in healthcare, spare parts for equipment can be manufactured. Pearce’s analysis of open-source 3D printing for small farming applications found that "five categories of prints: 1) hand tools, 2) food processing, 3) animal management, 4) water management and 5) hydroponics were all found to be technically viable" (2015, p.31). The case of water management is particularly interesting, as "3d printing may be used in water desalination, membrane separation and water purification applications" (Crisostomo & Dizon, 2021, p.7). One of the latest developments in 3D printing for agriculture has been the development of a 3D printable agricultural drone, named the Ardufarmer, that can sow seeds and reduce sowing times by at least 74% (Venegas et al., 2022).

Education is yet another place where 3D printing has made and can further make an impact. One of the main ways 3D printing applies to education is through the production of models and other visual aids. 3D printed models are already being used to help teach chemistry and anatomy (Pinger et al., 2020; AbouHashem et al., 2015). 3D printing can also be used to manufacture chemistry lab equipment, such as a 3D-printed smartphone spectrophotometer. The technology even empowers students to learn by doing, allowing students to rapidly prototype and build design skills. At Stellenbosch University in South Africa, students have used 3D printing to create prototypes of a wide variety of products, ranging from cell phones to underwater cameras (Alabi et al., 2019).

These applications help us imagine the broad potential of 3D printing. While not everything can be 3D printed, there are many things that can be. While physical limitations in regards to materials, such as strength, play a role in what can and can't be 3D printed, a large part of what can be printed is determined by what designs for 3D printing have been created by designers. This makes the question of what 3D printable designs currently exist an important part of the conversation.

Now that it is clear that 3D printing is able to produce useful items and how it does so, it is time to examine how the problem it serves to address: economic development. The technical details and logistics are just one piece of the puzzle, and to fully address the problem at hand the social and economic factors at play need to be explored as well. It is this exploration that reveals that one of the main things holding back developing countries is the limits of capitalism itself.

How Capitalism Fails Developing Economies

Many of the tools of international capitalist interventions in the lowest rung of developing economies show an underlying theme. Investments in developing economies are seen as risky (Banerjee & Duflo, 2012). Since they are perceived as risky they require high returns in order to attract investment. In an effort to maximize profits to create these returns, transnational enterprises will often do things like seek the lowest labor cost, charge high-interest rates on loans, lobby local governments to relax labor and/or finance regulations, or other problematic behavior. The risk of investing in poor countries incentivizes predatory dealings in the capitalist economy. Even newer paradigms such as microfinance require charging a bare minimum interest rate to counter-act the losses from defaulting borrowers in order to keep lenders solvent. These approaches to investment run counter to the needs of a developing nation because they do not generate local wealth or self-sufficiency since the factories built by international investments are owned by transnational corporations. Through the Fordist model they can produce a standardized product for homogenous markets with rigid specialized manufacturing — but with the twist that there's no guarantee that local workers will fit into the markets that they produce goods for. Meanwhile, we see that development in rich countries is largely driven by a system of unequal exchange where the Global North gets both the products and the profit (Hickel et al, 2022).

The net appropriation of wealth from the Global South to the Global North from 1990–2015 exceeded $10 trillion USD a year. The inflow from charity during this time was outnumbered by wealth transfers by 30 to 1 (Hickel et al, 2022). Unlocking growth opportunities for developing countries requires breaking this cycle of unequal exchange — otherwise, developing countries may just adopt their own models of unequal exchange that are in their favor, at the cost of their peers. Ideally, the solution should be to move past this system of exploitation rather than try to virtually move one's country from the Global South to the Global North.

Much of the divergence in wealth between the Global North and the Global South originates from colonialism (Rasler & Thompson, 2009). In this colonial model, colonies were prevented from developing manufacturing capabilities by their colonizers to prevent competition, which made colonies dependent on goods produced in the Global North, and this colonial period of world development allowed the Global North to amass capital and become the primary beneficiary of trade globalization. In order to break from the current pattern of exploitation, dependency, and periods of low growth strategies of development that don't rely on capital interest need to be established — particularly strategies that build self-sufficiency and local capacity. Fortunately, 3D printing and other technologies of the fourth industrial revolution are reducing the cost of access to manufacturing to a point that people can finally forge their own paths instead of being beholden to capital. Dr. Adrian Bowyer, the creator of the RepRap open-source 3D printer, argues that 3D printers can create wealth without money. As Birtchnell & Hoyle expertly state, "Bowyer points to the ability of 3DP to create material wealth, in terms of the ownership of goods, without the need to sell labour in order to participate in the Global North’s consumer markets" (2014, p. 37). By directly accessing manufacturing new economic arrangements, possibly even in a plurality of economies, may emerge that allow alternative economics to exist alongside capitalism rather than outright replace it. Capitalism is often thought of as the economic hegemony that we live under, but we can also think of the world as one that contains many economies of different types that exist alongside one another (Gibson-Graham, 1996). After all, there are organizations that aren't driven by profit. This thinking opens up other forms of economic development that are outside of the capitalist tradition but might still be used to leverage emerging technologies to their full potential.

Alternative Economic Approaches

3D printing has sometimes been described as being part of the fourth industrial revolution. How can the fourth industrial revolution transform economics?

Alternative economies are an important part of the discussion of alleviating worldwide poverty. While capitalism may remain the dominant economic configuration, we can see a plurality of economic configurations in the current world. This is something that's been recognized by the UN which has launched an Inter-Agency Task Force on Social and Solidarity Economy and incorporated the concept of Social and Solidarity Economy (SSE) into the UN's 2030 Agenda (Quiroz-Niño & Murga-Menoyo, 2017). The SSE, which is also referred to as the solidarity economy, is defined by RIPESS (an international SSE network) as "...an alternative to capitalism and other authoritarian, state-dominated economic systems. In SSE ordinary people play an active role in shaping all of the dimensions of human life: economic, social, cultural, political, and environmental. SSE exists in all sectors of the economy production, finance, distribution, exchange, consumption and governance" (RIPESS, n.d.). The core essence of SSE organizations is that they operate on the basis of social impact rather than profit. The SSE generally encompasses cooperatives, mutual benefit societies, social enterprises, foundations, and associations (Borzaga et al, 2019).

The SSE is of interest to our purposes for a few reasons. SSE organizations have been able to grow significantly even in the face of economic downturns (Borzaga et al, 2019). SSE organizations have shown that they can succeed in weak legal frameworks or even without legal recognition entirely. The SSE also demonstrates a popular will to explore alternative economics and opens up new options for those who would like to start an enterprise for the public good.

3D printing opens up many new social entrepreneurial avenues as well, making it a fitting pairing with alternative economics. The fact that 3D printing is cost-efficient at small scales, can produce a wide variety of products, doesn't need complex management, and is affordable make it an ideal technology for social and cooperative enterprises (BEN-NER, 2018). 3D printing technologies enable hobbyists to become entrepreneurs and remove uncertainty in the entrepreneurial processes, as 3D printing allows entrepreneurs to overcome challenges at the development, manufacturing, and distribution stages of the production process (Rayna & Striukova, 2021). This creates new avenues for social entrepreneurs who are looking to start non-capitalist enterprises. It needs to be stated, however, that entrepreneurship often doesn't follow the common understanding of the word in developing communities. Where many might think of it as starting an enterprise (usually a business) that will ultimately employ others, in the developing world entrepreneurship is often simply about creating an employment opportunity for oneself, where there was none, and nothing past that (Banerjee & Duflo, 2012). Evolving the understanding of entrepreneurship past the capitalist understanding of the word, and including self-employment and cooperative enterprise, enable a greater set of possibilities

In Kenya, African Born 3D Printing (AB3D) shows us another way that social enterprises can pair with 3D printing technology. AB3D uses electronic waste from a local e-waste center to produce cheap 3D printers at a fraction of the cost of commercially available machines. AB3D also provides printing services, education, and training to build local 3D printing capabilities (Schonwetter & Van Wiele, 2020). Social enterprises like AB3D create value from waste to help solve environmental issues while developing local manufacturing capacity at the same time.

A common focus of SSE advocates is the cooperative. Worker cooperatives are enterprises that are democratically run by laborers. Importantly, cooperatives are able to address equity issues (Bell et al., 2018). When considering the attributes of 3D printing technology it becomes apparent that it enables democratization in a way that more rigid manufacturing can not. Let us consider a hypothetical worker cooperative. This hypothetical cooperative produces cell phone cases via traditional injection molding. In this scenario, if a worker wants to exercise control over the collective's fabrication machines, they have few options. For example, they can convince their cooperative to change the mold to a new one or convince the cooperative to create a new mold that is put into rotation in order to expand the number of commodities that they can produce with the cooperative's injection molding machine by one. Both options will be expensive, representing a cost barrier to such actions, which is also accompanied by other obstacles such as collective decision-making. However, with 3D printers, the cooperative can create any number of different commodities without substantially changing manufacturing costs while circumventing other barriers as well. In fact, the cooperative could share the 3D printers they own by allowing workers to schedule production on the printers and divide available production time equally among workers — allowing workers to create, as well as take ownership of, their own product lines inside the broader organization. The workers are then able to produce any item they wish to sell as a commodity or even use their time allotments to provide printing services to members of their community. The adaptability of 3D printing over rigidly tooled manufacturing methods leads to new forms of democratizing manufacturing.

Pairing 3D printing with the SSE gives us a way to optimize towards equity while we create economic development. It isn't enough to introduce 3D printing through commercial enterprise, we should seek to use 3D printing to build a better set of economic practices that work for people — rather than the other way around. After all, giving workers control over their means of production empowers them to address the issues that they see in their communities. One method of increasing access to manufacturing is by making it publicly accessible.

The Many Roles of Makerspaces

Makerspaces are also sometimes called fab labs and are sometimes placed inside a larger category of tech hubs (Corsini, 2022). Makerspaces are collaborative workspaces where there is a collection of publicly available manufacturing equipment that people can use to make things. Makerspaces are excellent vehicles for increasing the accessibility of 3D printing and learning manufacturing. They're spaces that connect learners with mentors and act as a place to network with other makers. These spaces allow the average person to not only build things but also to learn manufacturing processes, experiment, and innovate. Like 3D printers themselves, they change the relationship between people and means of production in a way that empowers people to be producers instead of just consumers by allowing them to directly create the items they wish to use. Communal manufacturing like Makerspaces fundamentally shifts production relations by removing capitalists as the middlemen and allowing people to directly access the means of production.

Makerspaces also act as a vehicle for capacity building. The UN has defined capacity building as the “process of developing and strengthening the skills, instincts, abilities, processes, and resources that organizations and communities need to survive, adapt, and thrive in a fast-changing world” (Okuonghae & Nkiko, 2021). Teaching people 3D printing skills is essential to expanding the practice of 3D printing. The operation, maintenance, and repair of 3D printers require skilled laborers despite the automated nature of the technology (Savonen, 2019). Without people in place to support the operation of local 3D printers these machines risk becoming derelict and unused. The availability of 3D printing experts is one of the largest barriers to the adoption of 3D printing technology in developing economies (Ishengoma & Mtaho, 2014). Makerspaces' ability to act as places of collaborative and individual learning help to approach the problem of capacity building in developing economies (Okuonghae & Nkiko, 2021). In turn, makerspaces are a place where people can be exposed to 3D printing technology, practice using it, and through this learn the skills necessary to support the local adoption of said technology. This ties into the observation made by Birtchnell & Hoyle (2014) that community-shared 3D printers are a better fit for developing areas over individual ownership. Makerspaces are excellent places to station such shared 3D printers.

Makerspaces could also easily fit into the ‘hub and spoke’ supply chain model that is proposed by Corsini et al. for building out 3D-printing-based humanitarian supply chains. This is a model "where design and testing take place in a central facility (the hub) and the product is locally manufactured in-field (the spoke)" (Corsini et al., 2022a). Makerspaces, especially the ones hosted by universities, could become places for designing and testing designs to then be printed where they are needed. This would allow hobbyists to better interface with humanitarian efforts, given the interest, while designating a hub for this model to build its spokes. For the decentralized manufacture of goods, these makerspaces could also act as a drop-off point for organizing volunteer manufacturing efforts. 3D-printed items can then be validated for quality by community members with an appropriate level of expertise before then being distributed to where they are needed.

As an advocate for 3D printing for development in the Global South, William Hoyle has also proposed that makerspaces, as well as other tech hubs, should be treated as incubators for local innovation. Hoyle (2014) highlights how a makerspace in Nairobi, Kenya was used to design a product, an internet router, that was successfully funded through the crowdfunding website Kickstarter. Makerspaces act as innovation intermediaries while building larger entrepreneurial ecosystems through networking (Seo-Zindy & Heeks, 2017). Building on this, makerspaces can be imagined as a place we could use to incubate social enterprise as well. Makerspaces in South Africa and Kenya are already hosting several social entrepreneurs (Schonwetter & Van Wiele, 2020). These hubs could be used to distribute information about grants, crowdfunding, and other local finance opportunities to fund the creation of worker cooperatives and humanitarian projects, as well as a place to offer workshops about using technology for social entrepreneurship to stimulate the development of a larger solidarity economy.

There are many examples of the ways that Makerspaces change the nature of manufacturing, but they are also changing how manufacturing can be organized. The introduction of publicly available manufacturing makes it so anyone can be entrepreneur. At the same time, it also allows for other manufacturing models outside of the profit motive. A great example of this is how Makerspaces empower the practice of volunteer fabrication.

Volunteer Fabrication

During the COVID-19 pandemic, 3D printers were put to work printing PPE for frontline healthcare workers and medical equipment to address shortages caused by the pandemic. What makes this situation unique is the type of people who took on the task of printing this equipment. Manufacturing is usually reserved for corporations, yet there were participants who were printing PPE ranging from hobbyists with 3D printers at home, to makerspaces, as well as non-profits (Niranjan, 2022). The democratization of manufacturing through the popularization of 3D printing allowed the creation of a citizen supply chain (Larrañeta et al., 2020). While some printing was profit-driven, a great deal of 3D printing was a novel case of mass mobilization of production capacity in the absence of profit. This represents an important cornerstone to the true potential of 3D printing: the proliferation of personal and small-scale manufacturing, as well as the possibility to mobilize it towards addressing public needs.

At Ethiopia's Bahir Dar Institute of Technology's makerspace, a researcher was able to manufacture and distribute over 3000 face shields and 2000 face shields to frontline workers in the country (Corsini, 2022). The Twenti makerspace in Malewi was able to produce 2000 face shields, within just two weeks of its opening, which were donated to two of the largest local public hospitals (Corsini et al., 2022b). 3D printing also allowed South Africa to avoid relying on PPE provided by Europe, which was a common situation for African countries (Dzogbewu et al., 2021).

The COVID-19 pandemic not only illuminates the capabilities of 3D printing to us but also reveals the ability of manufacturers to act in an altruistic manner given the right circumstances. This behavior could be useful if we consider how we might cultivate it and use it to address other problems.

It is worth noting that large-scale efforts in volunteer production existed before the Covid-19 pandemic, however, and the mobilization of makers with 3D printers is just one example. During World War II the Red Cross coordinated 3.5 million volunteers in efforts to sew and knit clothing and other goods for soldiers and refugees (Parry-Hill, 2019). It isn't unheard of for individuals to take up making things for those in need, particularly in times of crisis. While the Social Solidarity Economy shows us a potential broader organization that we can use to harness this impulse of people to provide for one another, volunteer manufacturing shows the initiative that people will take to support others.

3D printing enables a higher level of technical capabilities and a broader set of applications for volunteer fabrication than ever before. Take for instance e-NABLE , a group that uses open-source design and 3d printing to produce prostheses for individuals in underserved communities

(Parry-Hill, 2019). According to the group, "There are approximately 40,000 e-NABLE volunteers in over 100 countries who have delivered free hands and arms to an estimated 10,000-15,000 recipients " (e-NABLE, n.d.). 3D printing also allows a relatively small number of volunteers to punch above their weight. For example, during the US-based 3D Printed Toys for Tots drive, organized by the 3D printing business IC3D, where 351 volunteers were able to produce 73,657 3D printed toys for underprivileged children in the year 2022 (IC3D, n.d.).

The adaptability and low cost of 3D printing couple particularly well with the nature of volunteer fabrication. One day a 3D printer can print one item for one cause and immediately switch to printing another thing if a more immediate need arises. In other words, 3D printers are able to produce what is needed when it is needed. This makes 3D printing unique in its capacity to address crisis conditions since it can change the goods it produces depending on the circumstances (Saripalle et al, 2016). The automated and digital nature of 3D printing also works with the strengths of the technology to lower the stakes, leading to situations where those with personal printers can contribute to causes without exorbitant effort.

Efforts to capture the potential of volunteer manufacturing for development should be taken. There have been printing drives that printed toys and prostheses, it is time to create a new international movement of 3D printing and assembling RepRap 3D printers (as well as other 3D printable manufacturing tools) in order to send them to interested parties in the developing world. Let us use international solidarity to start approaching the issue of global development. For too long economic advancement has been tied to the profit motive — it’s time to try something different than the pure capitalist approach.

Building New Manufacturing Capabilities

The 3D printer's adaptability leads to a peculiar possibility, the possibility of near-self replication. While a 3D printer cannot fully replicate itself, simply because a 3D printer can’t produce the computer chips needed to drive it, it can print a majority of the parts required to manufacture another 3D printer. This is the concept behind the RepRap project, which marries open-source design and free software with 3D printing to create 3D printable 3D printers in order to lower costs and increase accessibility while being competitive with commercially available alternatives (Ishengoma & Mtaho, 2014).

The RepRap project has also created new avenues for entrepreneurship. An Indian social entrepreneur named Angad Daryani was able to adapt the RepRap design to be easier to build in the country by changing the design to use parts that are readily available in the Indian market and created a business that offers low-cost 3D printers using locally sourced components (Hoyle, 2014). Daryani, a high school dropout, designed his first 3D printer by age 16 and went on to found a Mumbai makerspace named Makers Asylum to empower other makers like himself (Chhabra, 2014). Daryani's story demonstrates the importance of the open nature of 3D printing, where open-source designs can be adapted to local contexts and then used to build out local manufacturing capacity.

3D printing is also able to make more traditional manufacturing devices that can create items that 3D printing cannot. One device for traditional manufacturing is a CNC (Computer Numerical Control) machine. A CNC machine is a device that will take a solid block of material and then use a cutting tool, such as a rotary cutter, to carve away material layer by layer to create an object. There are now mostly 3D-printed CNC machines that one can build themselves, such as the PrintNC (Omer et al., 2022). 3D printing can also be used to create molds for injection molding, another traditional manufacturing method where melted plastic is injected into a mold to make an item (Dizon et al., 2020). The ability of 3D printing to aid in the building of traditional manufacturing devices allows us to create a pathway to building other open designs. This pairs well with initiatives like the Open Source Ecology's Global Village Construction Set (GVCS), a collection of 50 open-source industrial machines meant to help build sustainable communities (Omer et al., 2022). The GCVS, while still in development, aims to include a broad range of important designs for developing communities such as a solar concentrator, wind turbine, tractor, truck, and well drilling rig (Jakubowski, n.d.).

3D printing and free open-source design lay a road to more traditional methods of manufacturing without prohibitive costs. Even if a 3D printer isn't able to directly manufacture a device, there is a chance it can be used to build another manufacturing tool that can make the item of interest. For this reason, it is important to not only consider the direct manufacturing potential of 3D printers but to also see it as something that can act as a jumping-off point to build out local capacity through a wide array of manufacturing methods — and it can do so in a way that is more sustainable and environmentally friendly than traditional industry.

A Path Towards Sustainability and Self-Sufficiency

Fused Filament Fabrication 3D printing has the potential to decrease the environmental cost of manufacturing. The most popular filament among hobbyists, polylactic acid (PLA), is plant-based and biodegradable (Shogren et al., 2019). While PLA has a complex production process it can be mixed with plant waste as filler and still maintain workable physical attributes (Kyu Min

Cheong et al, 2016). The filament for these printers can also be made from existing plastic waste using devices like the Filabot, a filament manufacturing machine developed by Tyler McNaney (Ibrahim et al, 2015). There is also the Polyformer, a similar device that is specifically designed to be 3D printable, that recently won its creators Swaleh Owais and Yang Cheng the 2022 James Dyson Global Sustainability Award (Kittani, 2022). This helps build a circular economy, which can be defined as an economy with minimal waste and maximum reuse of products.

Protoprint, an Indian social enterprise, is a shining example of how 3D printing can help us build circular economies. Protoprint takes plastic litter and transforms it into 3D printing filament locally, while also offering affordable 3D printing and rapid prototyping services to students and professionals. By working with a local trash pickers union to gather local litter they were able to make filament that was then sold internationally, which allowed them to pay the trash pickers enough to increase their income by eight to twelve times while also reducing the cost of filament for local 3D printers (Hoyle, 2014).

Similarly, we should explore the potential of reusing and repurposing e-waste to build 3D printers and the computers required to operate them — like how African Born 3D does. This helps address the equity issues that arise from the fact 50–80% of the e-waste from industrialized countries ends up in China, India, Pakistan, Vietnam, and the Philippines (Wong et al., 2007). Once accomplished, at least some small portion of this e-waste can be transformed from a burden into an opportunity for developing economies.

Another concern of sustainability is that 3D printers require electricity, which can be a challenge in developing countries. Fortunately, solar power has offered us a workaround for this issue. Researchers have shown that portable solar power can be used to drive high-efficiency 3D printers in off-grid communities (Gwamuri et al, 2016). By removing the use of a heated print bed, the power usage of the printer can be considerably reduced. This is a critical point when we consider that International Energy Agency has forecasted that population growth in sub-Saharan Africa will outstrip electrical infrastructure development resulting in 75% of the population not being able to access electricity by 2040 (Gwamuri et al, 2016). While such areas probably won't be impacted the most by 3D printing technology, due to available resources and infrastructure, such approaches allow 3D printers to be deployed in more resource-constrained contexts as part of humanitarian responses or in communal spaces.

Conclusion

3D printing by its very nature is already democratizing manufacturing. Thanks to low-cost printers, open-source design, and widely available files for 3D printable designs the 3D printer can transform an average person from a consumer to instead be a producer. This democratizing nature should fully be taken advantage of and built upon.

3D printing can create many useful objects which can help fill the basic needs of developing communities such as food, water, healthcare, education, and greater self-sufficiency. Using this technology these goods are able to be produced locally, where they are needed, when they are needed. At the same time, this technology can create commodity wealth without money.

This technology is revolutionary, not just in the sense of changing the nature of production, but also by changing the relationship between people and manufacturing. The cycle of unequal exchange that acts as a source of oppression for these communities can be broken through increasing self-sufficiency. Instead of being content with capitalism and the exploitation that comes with it, something better can be built.

Given these truths, it is possible to start creating solutions. By linking 3D printing technology with alternative economies, and alternative models of production such as makerspaces and volunteer manufacturing, the many issues of the developing world can be addressed. However, to 3D print for development, a certain set of best practices need to be followed. There needs to be an emphasis on open-source design and development to reduce costs and allow objects to be adapted to local contexts. Manufacturing needs to be made more communal and more accessible through the expansion and investment in Makerspaces. Volunteer manufacturing should be globalized and set to the task of building the capacity of communities so that volunteers across the world can empower the Global South. Most importantly, all of this should be paired with more equitable work arrangements such as worker cooperatives and social enterprises to break away from the limits of capitalism and maximize positive societal impact. Through such actions, we can implement 3D printing practices in a way that revolutionizes economic development.

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