With lower costs and fewer barriers to entry, 3D printing can create opportunities for small businesses to enter markets.

3D Printing for Low-Resource Settings

Matthew P. Rogge, Melissa A. Menke, and William Hoyle

Matt Rogge

Melissa Menke

William Hoyle

3D printing has the potential to produce many needed items in low-resource settings, where lack of infrastructure and weak manufacturing capacity make local production impractical, and high tariffs, unreliable supply chains, and economic instability make importation costly. With lower costs and fewer barriers to entry, 3D printing can create opportunities for small businesses to enter markets producing and selling 3D products.

The ability of 3D printing to align local production with global information sharing can be transformational. 3D printers are engines for innovation and can help local designers work together to create solutions to problems faced by their communities. Further, the use of open source designs can create scale in a way that is fast and free.

Matt Rogge is 3D4D technical director at TechforTrade. Melissa Menke is a Nairobi-based entrepreneur working on development of the Digital Blacksmiths Network. William Hoyle is founding chief executive of TechforTrade.

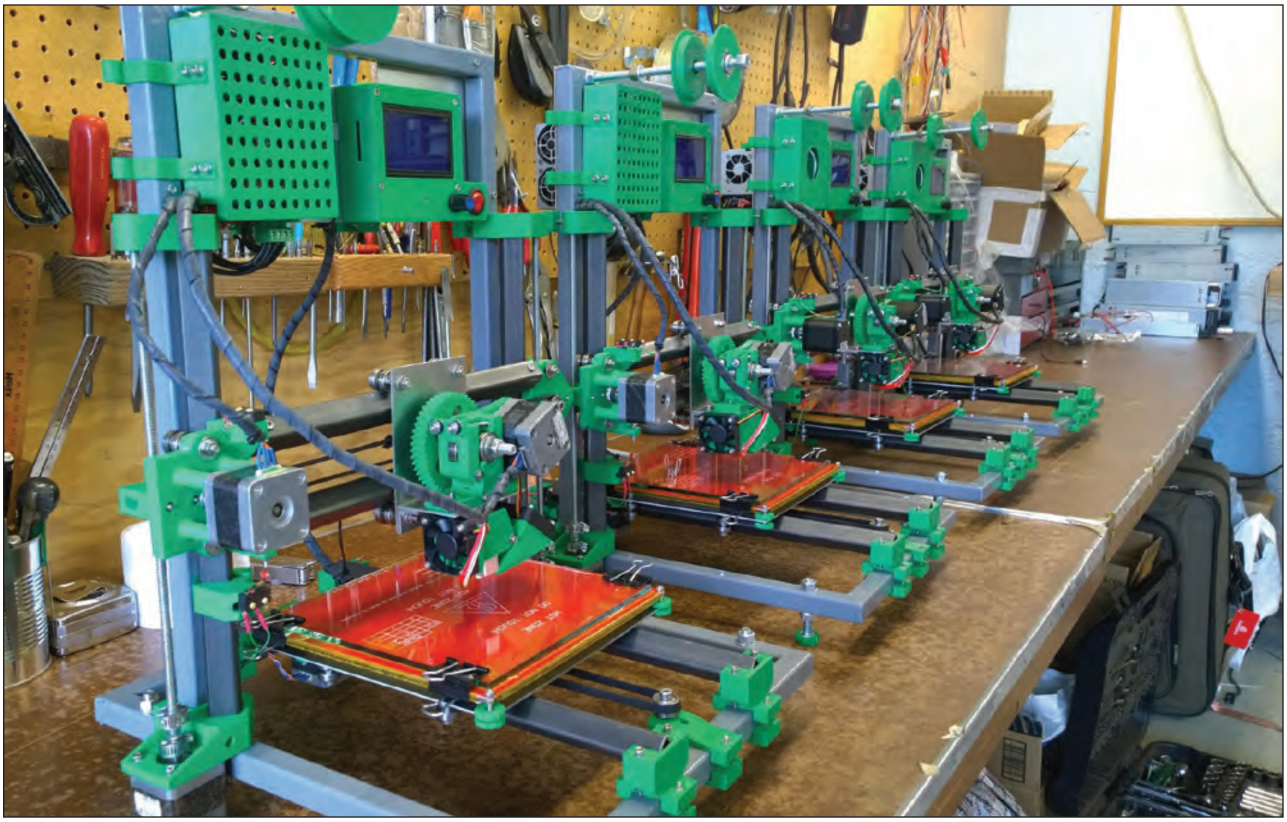

FIGURE 1 Test batch of TechforTrade Retr3D printers.

We review the work of TechforTrade—a UK charity focused on bridging the divide between emerging technology, international trade, and economic development—in its use of 3D printing for development. We also summarize key areas that must be addressed to advance this potential (Birtchnell and Hoyle 2014).

Affordable 3D Printing: The Retr3D Printer

TechforTrade developed the Retr3D printer with the goal of designing an open source 3D printer that is low cost and can be locally manufactured with a minimal number of imported parts (figure 1). To achieve this goal, parts typically found in 3D printer designs—such as linear bearings, smooth steel rods, and specialty aluminum extrusions—have been removed from the Retr3D design. Instead, locally available deep groove ball bearings and square steel tubing are used.

In many developing countries, machines introduced as part of a project are later abandoned after breakdowns occur. The causal factors for their abandonment can be complex, but local ownership and support can help prevent the same fate for 3D printers. Local manufacture is an important step in ensuring that machines stay in operation. Building locally ensures that there is a location in country where replacement parts can be obtained as well as someone with the necessary skills to make repairs. And open source design means that anyone with a Retr3D printer has access to the information needed to keep it running.

Global Configurability

The Retr3D printer design is parametric and can be configured using global variables and equations to accommodate the variation in raw materials between different locations. For example, the square tubing used for the printer's frame and linear motion system vary in dimension by as much as 3 mm from country to country, so making tight-fitting sockets to fit the tubing requires slightly different 3D-printed parts for each location.

It was particularly important to be able to use components reclaimed from discarded electronics, such as motors, power supplies, and fans, when available. Modern computer-aided design (CAD) software with parametric capabilities can easily handle such jobs: adjusting parameters from one country to the next, or even from one printer to another, is just a matter of inputting the dimensions.

Field-Tested Durability

The current version of the Retr3D printer is robust. Testing of initial Retr3D designs and other RepRap printers showed that many were sensitive to transport on rough roads. Loss of calibration and damage were common.

By adopting a design with a stiff welded steel frame, the Retr3D printer has proven to be much more durable. Furthermore, the construction of the printer frames can be easily outsourced to local welding shops.

Open Source Electronics

Use of open source electronics has helped to reduce the printer's cost and improve its maintainability. RAMPS 1.4 electronics are commonly used with RepRap-style printers, and their popularity has helped to make them both low cost and widely available.

The electronics on a Retr3D printer can be entirely replaced for $31 and, thanks to the modular design of RAMPS, if there is damage to only one component it can be easily changed for between $2.50 and $12.00. With proprietary 3D printers, replacement parts generally cost far more—if they are even available.

Local Filament Production

Nearly all low-cost open source 3D printers that are robust and easy to use are fused-filament fabrication (FFF) machines, which use 3 mm or 1.75 mm diameter plastic filament as their raw material. Filament is typically produced on an industrial scale and needs to be imported in developing countries where the market is quite small. This importation can be costly and time consuming and can lead to unpredictability in the production of 3D-printed goods.

TechforTrade has been developing a low-cost, small-scale means for producing 3D printer filament from postconsumer polyethylene terephthalate (PET) bottle flake. PET plastic works well with FFF printers and waste PET is readily available in nearly any location on the planet. Not only does this help to reduce the challenges of import duties and unpredictable supply chains, but it also allows for value to be added locally to the waste plastic.

Postconsumer PET has proven significantly more difficult to process into filament than other plastics readily available in the waste stream—because of its high melt temperature, low melt viscosity, hygroscopicity, susceptibility to hydrolysis, and crystallization behavior—and designing a low-cost solution has been challenging. TechforTrade explored the use of high-density polyethylene (HDPE) and acrylonitrile butadiene styrene (ABS). HDPE is easy to obtain and producing filament with it is relatively easy, but it tends to shrink as it cools, making it difficult to use for printing. ABS is also fairly easy to recycle into filament and prints quite well, but it was eliminated because many products made from ABS, such as electronics enclosures, contain brominated flame retardants, which can be toxic and pose significant health risks (Sepúlveda et al. 2010).

Many of the technical challenges of PET plastic have been overcome, and its availability and superior printability make it a worthwhile polymer to pursue.

> *With proprietary 3D printers, replacement parts generally cost far more— if they are even available.*

Small-Scale Recycling in Developing Countries

Many rural communities in the developing and developed world alike lack access to recycling facilities. Without local means for size reduction or compaction, it is frequently too costly to transport high-volume, low-mass plastic bottles to a centralized processing center. But with relatively low capital requirements, a small-scale recycling system utilizing 3D printing may be a viable means for small communities to handle plastic waste while also gaining access to needed items.

Challenges

In many developing countries, the recycling system is largely informal. Vast numbers of waste collectors work in difficult and sometimes dangerous conditions to make small amounts of money. In Tanzania, for example, waste collectors make around $2 a day selling their plastic at $0.15/kg to groups that shred it and then export it to other countries where the actual recycling and bulk of the value addition are done.

Furthermore, capital investments are generally high, requiring expensive equipment and lots of space in centralized locations. As with many commodities, the route to profitability is through the processing of large volumes.

In addition, local recycling systems are vulnerable to international economic forces. In late 2015 a recycling group that worked with TechforTrade in Tanzania was forced to close its doors because of the effects of plummeting oil prices earlier that year. And the only recycling facility in east Africa with hot wash capabilities closed for similar reasons. While this was certainly difficult for investors and those in higher-level operations, it was surely much harder on the waste collectors.

Opportunities for Value Capture

Developing small-scale equipment for the production of recycled 3D printer filament keeps the value addition steps within the country and enables recycling on a minimum viable scale. Reducing the necessary capital investment makes it possible for those at the bottom of the pyramid to participate in and benefit from the value addition process.

Following the value chain from waste PET to 3D-printed products reveals the opportunities gained through access to the equipment required at each step.

- Collected plastic bottles are valued at about $0.15/kg.
- Converted to clean flake, the value rises to $0.70/kg.
- Recycled PET 3D printer filament typically sells for around $30/kg.[1]
- The value of a printed part made from the filament may reach $600/kg.

Of course the final price depends greatly on the printed product. The value presented here was determined from average low product prices and masses of 3D-printed products (reviewed in Wittbrodt et al. 2013).

Adding value locally increases a country's GDP and reduces reliance on foreign imports. And such small-scale recycling endeavors are likely less vulnerable to swings in the global recycling market.

Because of the high volumes traditionally used in the plastics industry, small quantities of virgin plastic resin pellets can be much more difficult and expensive to obtain than plastic flake. So even if the price of virgin resin crashes, most likely it will still be easier and cheaper to locally produce filament from flake.

Finally, the price of 3D-printed products from recycled PET is much less tied to the price of oil. Even large swings in the value of plastic scrap would represent only minute changes in the value of the final printed product.

Machines for Capturing Value

There have been many technical challenges to overcome in producing PET filament of sufficient quality directly from flake on small-scale low-cost equipment. TechforTrade is developing a bottle washing and delabeling station, a chopper for producing flake, and a filament extruder (figure 2), all of which are open source, with a total materials cost for the whole system of less than $2,000.

The Thunderhead filament extruder can produce 5–10 kg of filament a day and is sufficient to supply 20–40 3D printers for full-time production. In terms of value, based on the sale price of $30/kg for 100 percent recycled PET filament, the extruder is capable of producing $150–300 worth of filament per day. Development is ongoing, but initial prints are promising (figure 3).

In time, as greater numbers of small-scale filament producers are established, they may be able to aggregate their excess product and sell it on the international market under the Ethical Filament mark.[2]

3D-Printed Products with Social Benefit

Expensive items are often imported to developing countries and incur high duties, making them even more costly. Furthermore, foreign sales support can be expensive and time consuming.

Fortunately, a vast number of open source 3D-printable designs are available for download from sites such as Appropedia, GrabCAD, and Thingiverse. TechforTrade focuses on items that are high value added, otherwise difficult to obtain, and have the potential for social benefit.

The Open Flexure Microscope

The open flexure microscope, designed by Richard Bowman and first used to examine water quality in India under the NGO Waterscope, replaces a high-value product that would normally be imported (Sharkey et al. 2016). It uses a USB webcam or a Raspberry Pi camera and a monolithic 3D-printed body to display the magnified sample onto a laptop or Raspberry Pi screen with a resolution of around 2 μm. TechforTrade has made the microscope in Tanzania and Kenya and sees it

---

[1] Information from www.bpetfilament.com.

[2] See "Setting the standard for ethically produced 3D printer filament from recycled waste materials" (http://ef.techfortrade.org).

FIGURE 2 Thunderhead filament extruder prototype at STICLab in Dar es Salaam, Tanzania.

FIGURE 3 Keychain printed with recycled polyethylene terephthalate (PET) filament made with the Thunderhead filament extruder and printed using a Retr3D printer.

as an excellent product for demonstrating the potential impact of open source design combined with distributed manufacturing via 3D printing (figure 4).

Use in the Field, Lab, and Classroom

TechforTrade has been examining herd health, human health, and educational uses of the open flexure microscope in East Africa. The ability to quickly download and print our first microscope allowed us to get out into the field and talk with potential customers, with a minimal investment of time and money.

The microscope was tested in a veterinary science lab in Nairobi, where technicians anecdotally preferred the product but needed a carrying case and higher resolution. Changes were made in coordination with Bowman, after which our team in Kenya returned to the veterinary technicians to begin work on a sales and distribution agreement.

The microscope was also tested at a local health clinic, where technicians used it to correctly identify pathogens. The clinic director cited the capability of capturing digital images as a valuable feature, as it allowed for quality assurance by routinely reviewing a random sampling of slides; without digital imagery, such reviews are not possible because the sample is destroyed after the test is performed.

FIGURE 4 Open flexure microscope (left) made in Nairobi using Retr3D printers. Microscope view is projected on the laptop screen.

TechforTrade also spoke with five schools in Tanzania and six in Kenya about the feasibility of introducing the microscopes in the classroom. STICLab and AB3D have sold a few microscopes to parents and are starting to test them in schools. Early feedback indicated a need to bundle the microscope with educational materials to make learning easier. Digital Blacksmiths Nairobi has started to bundle the educational microscope with slides and activities.

Bowman's group has continued development of the microscope, adding a low-cost motorized stage and focus (Sharkey et al. 2016). These developments open up a range of possibilities such as automated sample scanning, remote control, and even the potential use of artificial intelligence to assist with diagnoses.

Other Products for Research, Education, and Health

Low-cost 3D printers can print a wide variety of items that have great potential for impact. For the laboratory, open source syringe pumps (Wijnen et al. 2014), centrifuges (Pearce 2012), and micromanipulators (Baden et al. 2015) are available.

Printable items for education include molecular model building kits (betawolf 2014), manipulatives for understanding mathematical relationships (Mshscott 2014), and fossils (AfricanFossils.org). In health and medicine, applicable products include eyeglass frames (Vivenda 2015), prosthetics (EnablingtheFuture.org), and orthotics (dsnettleton 2013).

Millions of open source designs are available but lack instructions for use, promotional materials, packaging, or other features needed to quickly move into sales. Such challenges are being addressed by a supportive new network whose goal is to help make promising designs into products ready for sale and then share the products through the network.

Developing Globally, Implementing Locally: The Digital Blacksmiths Network

TechforTrade is building the global Digital Blacksmiths Network (currently piloted in Africa) with the goal of helping to coordinate open source product development and ensure that network member businesses have access to the technology, training, and support they need to bring 3D-printed products to the local marketplace.

Standardization and Support

The network will run like a franchise that gives each member a high degree of freedom in designing business and product lines while standardizing quality, business systems, supply chains, and support. The network is in pilot phase, with three early-stage businesses and a central organizing body working on further product development and support.

Businesses that sell 3D-printed items require much more than a working design in order to take a new product to market. Items must have the polish of a professional product: packaging, marketing materials, instructions, assembly guides, aftersales service, quality standards, vendors of nonprinted parts, regulatory approvals, and the like. Frequently, however, open source designs lack these "extras."

Creating a consumer-ready product is no small task.

Innovation and Knowledge Transfer

Another goal with the Digital Blacksmiths Network is to reduce the distance between where needs are and where solutions are developed. Local implementation does not necessarily mean producing exact copies of the standard design used in the network. Many items require some modification for the local context in which they will be used.

With the rapid prototyping capabilities of 3D printing and the use of participatory design techniques, which are becoming more prevalent in many aspects of consumer product development, novel designs can be quickly and cheaply market tested. For example, STICLab, a Digital Blacksmith business working with TechforTrade in Tanzania, modified the design of the Retr3D printer so that it includes an enclosure. This was in response to customer requests for printers that have dust protection and barriers between the user and the printer's moving parts. Now their designs are being included as an option for other groups.

When items that are under development require expert knowledge that an individual site may not have, other members of the Digital Blacksmiths Network can provide technical assistance, knowing that their efforts will be rewarded as their access to fully developed products grows. As a side benefit, experts from around the world who would like to contribute their knowledge but don't have an easy outlet (they can't just fly off to Tanzania for a month) can make significant contributions by consulting from afar on aspects such as design, legal concerns, and marketing strategy. This also enables the transfer of knowledge and skills through participation in the network.

With a catalogue of fully developed products, network members will not need to invest large amounts of time and money into developing their products from scratch. Rather, they can use their time to produce a wider range of products and thus access markets that might be too small to sustain a business on their own. Conversely, groups working in international development might use the network to quickly deploy new technologies.

Gaining Access to Risky Markets with Leapfrog Technology

The cell phone has become the classic example of a leapfrog technology that has had tremendous impact on the developing world. 3D printing technology is similar in its potential to be a leapfrog technology in the manufacturing sector in developing areas.

> *A 3D-printed microscope was tested at a local health clinic, where technicians used it to correctly identify pathogens.*

Cell phones are used in many ways that address the needs of the poor around the world. Entrepreneurs and rural farmers have access to banking services and payment methods that are cost effective for them even at small scale (Kikulwe et al. 2014; Suri and Jack 2016). Small-scale growers and agricultural traders use mobile devices to track produce prices and transactions, helping to even the playing field and encourage collaboration rather than competition between producers and middlemen.[3] Many of the characteristics that have made cell phones so successful in developing countries—versatility, low cost, ease of use, portability, and connectivity—also apply to 3D printing.

---

[3] See "Trade Transparency: Open Book Trading" (http://tt.techfortrade.org/en/).

Just as cell phones ended the isolation of rural communities in terms of information, 3D printers may play a part in reducing material poverty in rural areas, where access to physical products is both limited by remoteness and costly in terms of last-mile delivery.

Versatility of 3D Printers

Like cell phones, 3D printers are extremely versatile. Without any change in setup, they can produce a vast array of items.

They are low cost, especially when compared to traditional mass manufacturing equipment. They are also lightweight and portable, making them easy to transport and set up in rural locations.

> *The goal is not to replace mass manufacture, but to fill in where mass manufacture is unable to deliver.*

While 3D printers are not capable of high production rates, this isn't much of an issue for small-scale production of high-value items. The goal is not to replace mass manufacture, but to fill in where it is unable to deliver. And there is the potential for scaling up: when a shop's printing capacity is not sufficient to meet demand, additional printers can be added. Finally, because 3D printers are automated, one person can operate a number of machines.

Minimal Power and Skill Requirements

Low-cost 3D printers such as the Retr3D have low power requirements, around 130 W at 12 V DC, and so naturally work well with solar installations.

Minimal prerequisite skills and literacy have contributed to the success of the cell phone. Similarly, 3D printers require surprisingly little skill to set up, operate, and maintain when compared with traditional manufacturing equipment. The same process and setup are used regardless of the part being printed. This feature enables different groups to easily replicate a part developed elsewhere. All that is needed is access to the digital files.

Low-Risk Product Testing

The versatility of 3D printers makes them suitable tools for accessing small niche markets that would be very risky endeavors using other methods. Once a 3D printing shop is set up, new products can be tested almost on a whim. A catalogue of developed products will enable network entrepreneurs to quickly test their local markets and identify which combination of goods will yield a sustainable income.

There is no need to rely solely on one product or to carry large inventories, both of which can be quite financially risky. This is an important benefit in areas where resources are limited.

Legal Challenges

A number of challenges must be overcome for 3D printing to become a successful means for distributed manufacturing in developing countries. In addition to technical and financial challenges (from part availability to electronics repair, reliance on imports, and access to expert knowledge), there are issues concerning product liability, regulation, safety certification, and fair use. Obtaining needed legal advice and ensuring that a product is in compliance can be daunting, time consuming, and expensive.

In areas where regulation exists but is difficult to enforce, consumers may be exposed to dangerous products and designers' intellectual property rights may be infringed.

With increased abilities come more responsibilities and legal assistance will surely be needed.

Conclusion

Distributed manufacturing of open source hardware via low-cost 3D printing may open the door for many small-scale entrepreneurs, which in turn could play an important role in providing their communities with access to needed items while converting waste to value through recycling.

The use of automation and artificial intelligence in manufacturing is accelerating and there are concerns that low-wage earners in developing countries may be most vulnerable to job loss (UNCTAD 2016). With open source 3D printing technology, developing countries can foster the skills needed to be competitive in an increasingly technical world and at the same time steer design and manufacture toward products that are locally relevant.

References

Baden T, Chagas AM, Gage G, Marzullo T, Prieto-Godino LL, Euler T. 2015. Open labware: 3-D printing your own lab equipment. PLoS Biology 13(3).

betawolf. 2014. Molecular model set. Available at https://www.thingiverse.com/thing:334917.

Birtchnell T, Hoyle W. 2014. 3D Printing for Development in the Global South: The 3D4D Challenge. Basingstoke: Palgrave Macmillan.

dsnettleton. 2013. Orthotic insoles (customizable). Available at https://www.thingiverse.com/thing:46922.

Kikulwe EM, Fischer E, Qaim M. 2014. Mobile money, smallholder farmers, and household welfare in Kenya. PLoS One 9(10).

Mshscott. 2014. Pythagorean theorem. Available at https://www.thingiverse.com/thing:245202.

Pearce JM. 2012. Building research equipment with free, open-source hardware. Science 337(6100):1303–1304.

Sepúlveda A, Schluep M, Renaud FG, Streicher M, Kuehr R, Hagelüken C, Gerecke AC. 2010. A review of the environmental fate and effects of hazardous substances released from electrical and electronic equipments during recycling: Examples from China and India. Environmental Impact Assessment Review 30(1):28–41.

Sharkey JP, Foo DCW, Kabla A, Baumberg JJ, Bowman RW. 2016. A one-piece 3D printed flexure translation stage for open-source microscopy. Review of Scientific Instruments 87(2):025104-1–025104-7.

Suri T, Jack W. 2016. The long-run poverty and gender impacts of mobile money. Science 354(6317):1288–1292.

UNCTAD [United Nations Conference on Trade and Development]. 2016. Robots and industrialization in developing countries. Policy Brief No. 50. Geneva.

Vivenda. 2015. Personalised spectacle frames. Available at https://www.thingiverse.com/thing:794040.

Wijnen B, Hunt EJ, Anzalone GC, Pearce JM. 2014. Open-source syringe pump library. PLoS One 9(9).

Wittbrodt B, Glover A, Laureto J, Anzalone G, Oppliger D, Irwin J, Pearce J. 2013. Life-cycle economic analysis of distributed manufacturing with open-source 3-D printers. Mechatronics 23(6):713–726.