Photo Credit: USAID

PRIMER ON 3D PRINTING

IN INTERNATIONAL DEVELOPMENT

October 2022

USAID
FROM THE AMERICAN PEOPLE

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About This Work

This Primer was researched and written by Dakota Crookston, with support from the Strategy & Research Team in the Innovation, Technology, and Research Hub of USAID's Bureau for Development, Democracy, and Innovation (DDI). The research and writing for this work was completed between October 2020 and August 2021, while Dakota was a Virtual Student Federal Service intern at USAID.

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WHAT YOU NEED TO KNOW

Photo Credit: Riaz Jahanpour for USAID / Digital Development Communications

- 3D printing is a tool for making physical objects from digital files.
- It offers value for high-customization and low-volume use cases, such as rapid prototyping and creating spare or custom parts.
- It is limited globally by the range of available printing materials and low local capacity to design and print 3D models.
- It offers opportunities for fostering an ecosystem that supports creative, fit-for-context hardware design fueled by skilled jobs to meet community needs.
- The international development community should engage with local production ecosystems, including 'makerspaces', and better assess their impact on societies.

As manufacturing processes digitize, there are a number of opportunities for governments, donors, and private sector actors to invest in key economic growth-aspects of the digital ecosystem of developing economies. This document specifically focuses on 3D printing (often referred to as digital fabrication), but there are a number of other ways in which digital technologies intersect with traditional manufacturing processes, from design to production to product maintenance and servicing. The purpose of this primer is to guide actors in the international development community through important key considerations when adopting 3D printing technology in their work. The document features three use cases of 3D printing technology that demonstrate how it is currently being used to make housing more accessible for impoverished communities, circumnavigate restrictive supply chains, and provide low-cost upper-limb prostheses to people in low- and middle-income countries. At the end, this document offers a general assessment of the state of 3D printing and provides a list of key considerations for gauging the appropriateness of its use in development contexts worldwide.

BACKGROUND AND HISTORY OF 3D PRINTING

Common Terms and Definitions

3D Printing: the process of making a physical object from a three-dimensional digital model. This process is typically achieved via a machine that deposits thin layers of a material (filament) in succession until the object has been completed.[1]

Filament: the raw material used by some 3D printers to create physical objects. There are different types of filament, each with unique properties. Most filaments are a type of thermoplastic: a category of plastics that become malleable when heated and solid when cooled.

When supply chain interruptions threatened access to essential medical items at the onset of the COVID-19 pandemic in spring 2020, Everton Lins saw a way to help out. He contributed to making an online map for medical personnel all over Brazil to request face shields and other personal protective equipment (PPE). Then, he tapped into a volunteer network of people with 3D printers to begin producing and distributing face shields across the country, for free. In just a few months, Everton facilitated the delivery of over 100,000 masks across Brazil[2]. Projects like his happened all over the globe: in Lithuania, Mažvydas Sverdiolas organized the production and distribution of over 14,000 3D printed face shields across his country[3]. In Sacramento, Operation Shields Up called on volunteers to 3D print PPE for local area hospitals.[4] In Hong Kong, the Hospital Authority reached out to Polytechnic University to 3D print face shields for local hospital staff running low on supplies.[5] In a time when closed borders and inflated costs made essential items inaccessible to the hospitals that needed them the most, 3D printing offered an innovative, though temporary, solution.

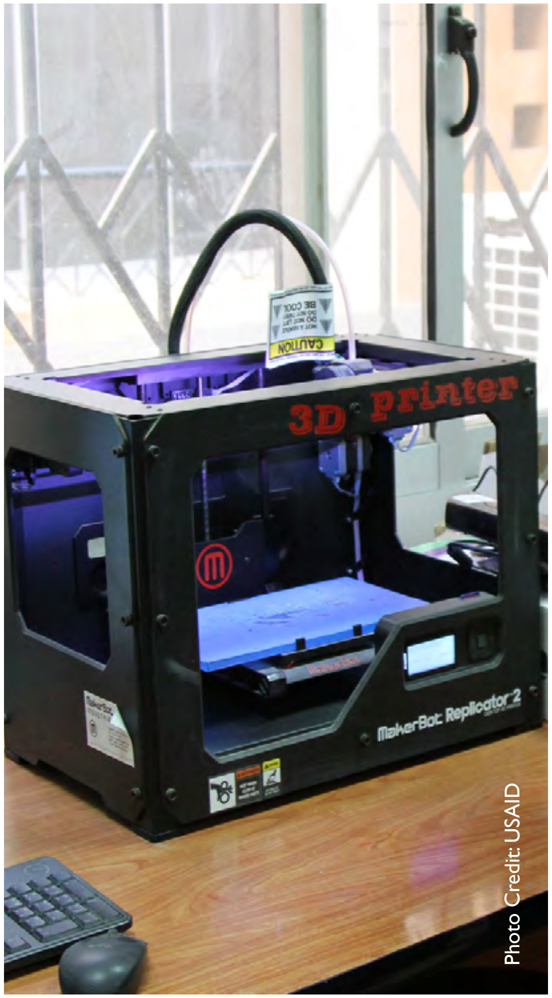

Photo Credit: USAID

1 "What Is 3D Printing?"
2 Rubin, "E-NABLE in the Time of Covid."
3 Rubin
4 "Operation Shields Up (@OpShieldsUp) / Twitter."
5 "Polytechnic University 3D Prints Face Shields to Combat Coronavirus."

3D printing was not originally conceived of as a medical technology. In fact, it was first developed in the 1980s as a tool for rapid prototyping—a technique to quickly and cheaply make models of parts for testing purposes. While not strictly a 'digital' technology, 3D printing can be considered a hybrid approach, combining analog and digital processes for faster and more customizable manufacturing. 3D printing involves a computer-controlled tooling process that relies on digital models, but also requires the right raw materials and parts to build products. Both model design for the final product and control of 3D printing machines relies on computing systems ranging from basic to advanced. As the technology has matured, digitized open sources for models and printers are also becoming widely prevalent. The technology did not receive widespread public attention until 2009, when patents for a type of 3D printing, called Fused Deposition Modeling, entered the public domain.[6] This event, and the inauguration of 3D printers at the 2011 Consumer Electronics Show, marked the beginning of the 3D printing hype cycle. Around this time, popular media forecasted that the technology would completely revolutionize manufacturing by equipping businesses and households to produce goods locally, rather than relying on centralized manufacturing. However, even as the technology improved and prices of printers and materials fell over the next few years, demand for 3D printing in the consumer market never rose as anticipated. Once it became clear that the inflated expectations of 3D printing would not be met, manufacturers reoriented their focus to finding professional niches, targeting biomedical, educational, academic, and engineering applications.[7]

An overemphasis on the consumer market and lack of understanding of 3D printing's true value led to widespread expectations that the technology would completely replace mass manufacturing by equipping individual households with the means of production. In reality, 3D printers never became a household staple, partly because most products are more than layers of plastic, and partly because most products consumers could print are often readily and cheaply available for purchase. 3D printers have had far more significant impacts on industrial processes than as a consumer product. The technology facilitates rapid prototyping, allowing industrial manufacturers to create product molds in-house, without large upfront investment. It is also better suited than traditional processes for fabricating complex shapes. This capability is valuable in instances where, to create an item with an odd geometric shape, traditional processes would need to produce numerous individual pieces that would then require assembly. Instead, a 3D printer may be able to make the same item as one piece, eliminating room for error in assembly and often creating a lighter, stronger piece.

A second cause of inflated hype was a lack of understanding of 3D printing's true value: high customization and low volume use cases rather than mass manufacturing. Prime examples include fabricating prototypes, spare parts, and personalized medical technologies, such as in dentistry and prosthetics. The technology can also be beneficial for filling in supply chain gaps, especially in extremely remote locations. Whereas traditional manufacturing excels at economies of scale, 3D printing is characterized by economies of scope—efficiencies formed by variety, not volume.

6 Sculpteo, "The History of 3D Printing."
7 "CES 2020 Shows Us What the End of the Consumer 3D Printing Hype Cycle Looks Like."

3D PRINTING IN DEVELOPMENT

3D printing is being used in development to…

- print face shields for hospitals facing shortages in Tunisia.
- restore coral reefs in the Caribbean island of Bonaire.
- help automate early flood detection and alerts in Cambodia.

In the field of international development, 3D printing has been employed to solve a range of problems in manufacturing processes and supply chains, often in a faster, cheaper, and more locally relevant way. At the same time, like other digital-related technologies, its use is constrained by access to adequate infrastructure and skills, as well as limitations to scale. Applications of 3D printing in development are varied, spanning use cases in disaster prevention and response, health, supply chains, and business and skill development, among others. For example, DAI Global has applied 3D printing as part of a workforce development project in El Salvador, funded by the USAID Puentes para el Empleo project. Plastics products are among the fastest growing exports in El Salvador; however, the country has limited capacity to design and produce molds for plastic products such as shampoo bottles. Historically, to provide a customer with a prototype, a company would typically have to spend USD $15,000-20,000 to design the mold and have it produced in Costa Rica. If the design was not suitable, the process would have to be repeated. The introduction of 3D printing in this industry has facilitated more efficient prototyping, enabling companies in El Salvador to do it quickly, inexpensively, and locally. DAI Global has funded 'makerspaces' in the country to train people on these methods, thereby facilitating job creation and skill development.

DAI also facilitated an activity in Cambodia called Think Global, Make Local. The project engaged ten young innovators in an eight-week product development course in which they learned design thinking skills and computer-aided design (CAD) and prototyped and iterated their ideas mostly with 3D printers. This enabled them to design, test, and iterate quickly, and show prototypes to potential funders. The activity culminated in a pitch competition at which judges chose the most promising idea to receive modest seed funding. As it happens, the winning idea, a construction toy called Doy Doy, ended up going to market as a 3D printed product, as the founder discovered that standard manufacturing was not available to him for economic and regulatory reasons.

Field Ready, discussed further in the case studies below, is using 3D printing to overcome supply chain hurdles and produce goods better, faster, or cheaper than would otherwise be possible. The Field Ready team has demonstrated that fabricating products at the point of use can strengthen local markets by fostering entrepreneurship and leveraging expertise in the community. For instance, the organization provided 3D printing skills training in Nepal, which a local inventor applied to designing and producing more fuel-efficient cookstoves. As a result of the product improvement, the manufacturer grew his enterprise and won government contracts to make 210,000 stoves[8]. The capacity to produce quality items locally is especially significant in Nepal, where the remoteness of certain locations can cause serious time and logistical bottlenecks.

Costs and benefits of 3D printing in development and humanitarian applications	
3D printing technology can be a valuable tool in low-resource environments, presenting several benefits: • Uniquely cost-efficient for small production runs, complex designs, making custom items, and rapid prototyping • Ability to produce a wide variety of items • Lower overhead costs than traditional manufacturing equipment • Opportunities to circumnavigate certain supply chain challenges	While 3D printing technology holds promise in developing country contexts, it may be limited by: • Infrastructural hurdles (limited electricity and internet access) • Lack of access to 3D printers and printing materials • Limited availability of printing materials • Limited skills to design and print 3D models in target communities • Slow printing speeds • Low production volume

3D printing is not uncommon in developing countries. The "maker movement" has yielded a network of makerspaces across the globe. These community spaces are equipped with tools to create, innovate, and build, often including 3D printers. While makerspaces in developed countries are generally centers for STEAM education, hobbyists, and personal projects, Andrew Lamb, Innovation Lead at Field Ready, describes makerspaces in developing countries as locales for production, entrepreneurship, and business development. Both Field Ready and the DAI Maker Lab regularly engage with, support, and leverage makerspaces in their programming. Makerspaces present an under-appreciated partnership opportunity for humanitarian and aid organizations to work with local communities and extend their work portfolio and impact.

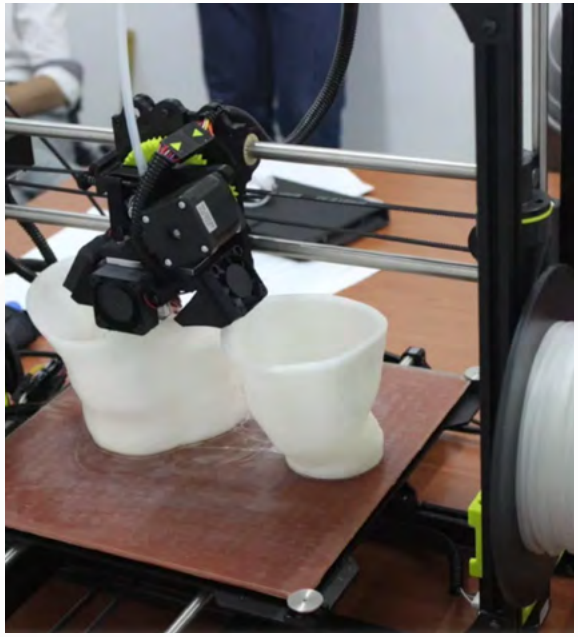

Photo Credit: Comprehensive Community-Based Rehabilitation, Tanzania

8 Field Ready, "Cost-Effective Manufacturing in the Field," 10–11.

Common Terms and Definitions

Fab Labs: A global network of small-scale workshops equipped with various digital and physical tools to make things, founded and organized by MIT's Center for Bits and Atoms. Fab Labs provide free public access, subscribe to the Fab Lab charter, share key capabilities between centers, and participate in the global knowledge-sharing Fab Lab community.[9]

Makerspaces: A community workshop intended to facilitate collaboration and innovation, typically equipped with some combination of high- or low-tech tools to make things. Both makerspaces and Fab Labs are centers for creation and collaboration. However, Fab Labs are more formalized entities, governed by a foundation and trademarked, while makerspaces are not. Because makerspaces are nonproprietary, they may feature any range of high- or low-tech equipment and exist within established community spaces, such as libraries, universities, or schools.[10]

Local innovation ecosystems: The locally-available infrastructure, including human capacity, that enables people to generate solutions to local challenges. In the context of this document, local innovation ecosystems primarily concern the local network of production capabilities, which may include makerspaces, craftsmen, factories, and more.

Makerspace highlight: MoTIV

MoTIV is a makerspace in Kampala, Uganda that supports entrepreneurs to develop and scale their businesses by providing tools (including 3D printers), training, mentorship, a collaborative community, and marketplace opportunities. MoTIV's goal is to support homegrown industries across Africa by fostering creative ideas that meet local and international market demand. MoTIV recently launched an equipment-financing program, Tools to Create, to support the creative sector in Uganda.

USAID, through its Bureau for Humanitarian Assistance (BHA) (formerly the Office of U.S. Foreign Disaster Assistance), has developed a low cost and sustainable automated weather station using 3D printing to improve weather and climate observations.[11] The stations are being tested to be used in advancing early warning and addressing disaster risks to save lives in multiple countries. Based on the results, BHA is expanding station development to advance monitoring of river and coastal areas for flood and storm surge warnings. Throughout the past decade, USAID has invested in several other 3D printing projects as well. These include converting waste into printing filament in Colombia[12], educating youth in Moldova[13], and providing vocational skills training in El Salvador[14]. A working list of USAID investments in 3D printing is linked to in Appendix F (not accessible outside USAID). For a list of non-USAID investments in 3D printing, please go to Appendix E.

Below, this primer features three use cases of 3D printing and a list of key considerations for gauging the appropriateness of 3D printing's use in development contexts.

Photo Credit: USAID

9 "Getting Started with Fab Labs."
10 "What Is a Makerspace?"
11 "How 3D Printing Can Help Save Lives";
12 "Higher Education Solutions Network - Annual Report (FY 2015)." 41;
13 "Program 1: Promoting STEAM Education and STEAM fields Careers" in Moldova Competitiveness Project: Annual Work Plan Year 3, 74.
14 Valero, "Bridges to Employment Project."

A Principles-based Approach to 3D printing

The following tried and tested approaches, rooted in thoughtful design principles and methods, can be integral to ensuring that investments in unique, hybrid technologies like 3D printing yield the desired benefits in development contexts without contributing to existing challenges.

- The IDEO Human-Centered Design Toolkit, along with the Field Guide to Human-Centered Design, provides tools and methods for applying design thinking to problem solving in the social sector.
- The Principles for Digital Development provide high-level best practices for integrating digital technologies into development programming around nine different areas. The guidelines help development practitioners identify and tackle a range of challenges related to implementing digital programming, such as failure to scale projects and the lack of end-user engagement, among others. In each of the case studies below, we attempt to show how aspects of each project are aligned with certain principles, thus contributing to stronger digital ecosystems and adding value to local communities.

Photo Credit: USAID El Salvador

CASE STUDIES

Case 1: Local manufacturing to hasten earthquake recovery in Nepal

Goal: To reduce lead times, lower costs, and improve access to essential items in the aftermath of earthquakes in Nepal.

RELEVANCE: Can 3D printing add value in this situation?

Logistical and physical bottlenecks prevented communities affected by the 2015 earthquakes in Nepal from receiving essential supplies in a time- and cost-appropriate manner in the aftermath of the devastation. The crisis worsened existing supply shortages in the country—medical supplies were already being rationed and requests for new items were often only partially met, with unpredictable lead times. Even three months after the earthquakes, international aid agencies were not allowed to import anything over $200 and were subject to a 101% import tax. Due to a blockade at the border with India, items had to be flown in, rather than trucked in, to emergency sites. Some affected communities were effectively cut off from life-saving supplies in remote and mountainous terrain.[15]

By using 3D printing to manufacture essential supplies locally, the Field Ready team was able to reduce costs and overcome supply route challenges associated with manufacturing and shipping, and ensure that items were available where and when they were needed. Because the versatility of 3D printing allows production of any range of spare and custom parts, it is possible to solve problems as they arise. The Field Ready team produced items including fetoscopes, otoscopes, cookstove knobs, and vacuum pump parts on site to quickly restore critical services to communities such as prenatal care and safe food preparation tools.[16] Producing these items at the point of use was, in general, functionally comparable to and cheaper or faster than procuring the best available alternative (Table 1).

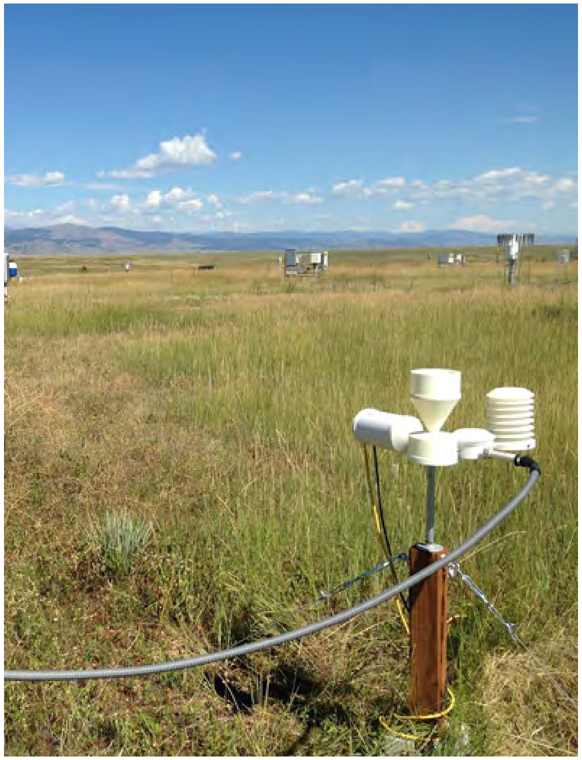

Photo Credit: Kelly Sponberg, NOAA

15 Field Ready, "Cost-Effective Manufacturing in the Field," 5–6.

16 Fetoscopes and otoscopes are both medical devices routinely used by healthcare providers. The former is used in prenatal care to listen for the heartbeat of the fetus; the later is used to look into ears and screen for illnesses.

Table 1: Cost comparisons between locally 3D printed items and best available alternatives

Item	Cost of making item locally	Cost of best available	Cost saving of local item over best	Comments on comparability of costed alternatives 1
Fetoscope	$3.03	$2.57	(-18%)	The item is directly comparable.
Otoscope	$11.48	$46.31	75%	The item is directly comparable.
Cookstove knobs (Cost per knob)	$0.70	$0.71	(-1%)	Although costed, the alternative introduced more risk against a critical deadline.
Vacuum Pump Part	$4.33	$48.54	91%	Alternative spare part requires you to buy more than is needed.
Improved Cookstove Air Supply Disk	$76.98	-	N/A	No suitable alternative was identified.

Source: Field Ready's technical brief, Cost-Effective Manufacturing in the Field

APPROPRIATENESS: Is 3D printing right for these circumstances?

Working on the ground and engaging with the affected communities, Field Ready was positioned to bring end users into the design process and ensure that the 3D-printed products functioned as intended. Given the limited quantity of the items needed, the team found that 3D printing these parts reduced costs and lead times associated with acquiring and distributing them. Field Ready was also able to lower costs of maintaining items such as otoscopes by designing them to be compatible with locally available bulbs, demonstrating that 3D printing can enable communities to tailor goods to their specific resources and needs.

Beyond providing parts, the Field Ready team found that the use of 3D printing in disaster relief efforts can have long-term community impact. For example, introducing this technology has helped the organization better engage communities impacted by disaster to be a part of the recovery solution, provide business opportunities for local merchants to offer services to other businesses and international aid organizations, and enable the founding of Nepal's first 3D printing company, Zener Technologies. Field Ready's application of 3D printing improves the use of local expertise and entrepreneurship, incentivizing highly trained and intelligent people to stay in the country by providing the opportunity for them to get their hands on high tech.

FEASIBILITY: Are the necessary resources for successful implementation available?

The Field Ready team was equipped with the relevant equipment, raw materials, and expertise to implement 3D printing as part of their disaster relief efforts in Nepal. At the time, they had to carry 3D printers with them on the plane, which occasionally presented challenges. Over time, they have worked towards greater sustainability by helping develop local capacity to own and operate 3D printers.

Assessment: 3D printing should be considered as one of many tools to help toward recovery in disaster relief contexts. It is not a catch-all solution for every manufacturing need, and approaching the technology as another "tool in the toolbox" helps the Field Ready team use it appropriately. This problem-first approach, in concert with participatory methods that serve the unique logistical and cultural needs of a local community, are fundamental factors for success in the organization's work. Other success factors include curiosity and tenacity of the community and designers.

The sustainability of Field Ready's applications of 3D printing is also due to their commitment to upskill workers and strengthen the local manufacturing sector in the places where they work. In Nepal, the organization provided 3D printing workshops to local communities and partnered with World Vision Innovation Lab to create a makerspace, which eventually led to Zener Technologies, Nepal's first 3D printing company.

Makerspace highlight: Nepal Communitere

Nepal Communitere is a makerspace, innovation hub, and business incubator located in Lalitpur, Nepal. Founded in the aftermath of the 2015 earthquakes, it offers a space where community members can learn carpentry, welding, soldering, and 3D printing, and collaborate to solve problems and start businesses. Recently, Nepal Communitere designed and piloted a leadership coaching program for female deputy mayors.

Applying Human-Centered Design and the Principles for Digital Development

Field Ready implements a five-step approach in its projects: assess the situation, design with end users, manufacture items that are useful, share the items and knowledge in a timely manner, and replicate where there is need. Using this approach, the Field Ready team is able to efficiently make items that are impactful for the community. They design for scale by passing these skills on through training and capacity building. Finally, Field Ready carefully documents their practices for future learning and iteration, and makes their designs open-source.

From the Principles for Digital Development, a few relevant principles in this case - Design with the User; Understanding the Existing Ecosystem; Design for Scale; Use Open Standards, Open Data, Open Source, and Open Innovation

Case 2: Providing low-cost upper-limb prosthetics

Goal: To provide low-cost upper-limb prosthetics to children and adults in need.

RELEVANCE: Can 3D printing add value in this situation?

There are approximately 2.4 million upper-limb amputees in developing countries.[17] The high price of prosthetics, often in the thousands of dollars, prevents the vast majority of people in need from accessing these medical devices. e-NABLE is an online organization of volunteers who give their time and printing resources to provide below-the-elbow prosthetics to amputees in underserved communities for free or at a low cost. The material cost to print a prosthetic hand is about USD $35.

In certain respects, 3D printing could be well suited for manufacturing prosthetics. Many designs are open-source and customizable. 3D printing can also reduce the time and costs of production, taking between 30-60 hours to print, and using more affordable materials than traditional prosthetics. The reduced cost is especially significant when making prosthetics for children, given that they grow out of the devices quickly and need more frequent replacements.

APPROPRIATENESS: Is 3D printing right for these circumstances?

While it is possible to produce low-cost prosthetic devices with 3D printing, their range of use (and possible users) continues to be limited. The materials used for 3D printed prosthesis (such as PLA, ABS, or Nylon) are not yet as durable as traditionally made prostheses (which may use carbon fiber, silicone, aluminum, and titanium), nor are they as closely customized for the user. Specialized medical and/or rehabilitation expertise, such as a prosthetist, is always recommended in the assembly, fitting, and rehabilitation process, and can be largely unavailable in developing country contexts. The lack of proper expertise can lead to ill-fitting devices, resulting in secondary health conditions. Moreover, there is currently no widely accepted approval and certification for 3D printed prosthetics, adding to challenges with quality, usability, and durability.

Logistically, distributing prostheses in developing countries is challenging in part because users in rural areas may live far from a hospital/prosthetic and orthotic clinic. The e-NABLE network also only produces prostheses for specific upper limb amputations; commonly available materials are not strong enough to reliably support a person's body weight on a lower-limb prosthetic device. Further, designs may only be available for limited types of upper-limb amputations, and 3D printed devices tend to not be as adept at tasks which require specific or specialized movements like careful and exact finger manipulations.

17 Phillips, Ritter, and Mehta, "Printed Prostheses: Not Yet Ready for Developing Countries."

FEASIBILITY: Are the necessary resources for successful implementation available?

The availability of a community of volunteers with printers, organized into chapters, eliminates the need for those in need of prosthetics to buy a printer or printing materials. However, the lack of medical guidance on the development and use of 3D printed prostheses, as well as distributional challenges, pose barriers to safety and access.

Assessment: Although 3D printing provides opportunities for reducing the cost and improving accessibility of upper-limb prosthetics, the challenges detailed above must be addressed before adopting this as a sustainable solution in resource-poor environments. Moreover, the lack of expertise, quality assurance, and regulatory mechanisms in charity-based health service models can negatively impact development of quality, accessible health services to all. While 3D printed prosthetics are not always suitable for use, the technology could hold value for designing and manufacturing custom sockets, which connect prosthetic devices to the body. Though this application significantly reduces service delivery time required, there is insufficient evidence on longevity and durability, as well as challenges to sustainable and responsible adoption into health systems in developing country contexts, to recommend its use at scale.

What it would take to extend the reach of 3D printed prostheses

"Printed Prostheses: Not Yet Ready for Developing Countries," published by the Alliance of Advanced BioMedical Engineering, posits that 3D printing prosthetics could be a more viable solution if…

- Designs for a wider variety of limb differences become available (particularly lower-limb prosthetics, which could have greater impact to the extent that the ability to work requires mobility)
- Designs work with stronger materials than the plastic currently in use
- Metal 3D printing becomes more affordable
- Designs improve to allow for finer control
- 3D printing is used jointly with injection molding processes to better optimize time, cost, and customizability

Applying Human-Centered Design and the Principles for Digital Development

The e-NABLE community achieves scale by facilitating connections between those who have resources and those who have needs. The thriving online community facilitates widespread adoption of its services by sharing resources and knowledge through open-source designs that are constantly being reused and improved upon. Chapters around the globe bring the technology to new communities and regions. In 2020, several chapters within the e-NABLE network have modified their approach to address the needs of the COVID-19 pandemic, sharing designs for and providing PPE, including face shields.

From the Principles for Digital Development, a few relevant principles in this case - Design for Scale; Use Open Standards, Open Data, Open Source, and Open Innovation; Reuse and Improve

Case 3: Safe, affordable housing for families in Nacajuca, Mexico

Goal: To make housing faster, safer, and cheaper for families experiencing poverty

RELEVANCE: Can 3D printing add value in this situation?

Over 1 billion people worldwide lack housing with a) adequate privacy, space, security, lighting and ventilation; b) safe and resilient infrastructure; c) and an appropriate location with respect to work and basic facilities. For low-income families in Nacajuca, Tabasco, Mexico, the lack of adequate, affordable housing is exacerbated by seismic activity and flooding. Traditionally, the process of building a house in Mexico is a slow and expensive process, contributing to the widespread issue of inadequate housing.

New Story is a non-profit organization dedicated to finding stronger, quicker, and cheaper ways to address global homelessness. New Story partnered with ICON, an Austin-based construction technologies company, to build a series of 3D-printed homes in Nacajuca, Mexico, and Echale, New Story's nonprofit partner in Mexico, to create a master-planned community that will eventually have 500 homes, a shopping center, and other community spaces.

New Story is working with a community of families living in extreme poverty and unsafe, makeshift shelters made with slats, wood, and pieces of canvas, covered with nylon and sacks. Due to the community's proximity to a nearby river, these shelters are prone to flooding. In a survey New Story took, 74 percent of families responded that these living conditions feel unsafe and significantly impact their quality of life. Traditional homes in the area are cost-prohibitive for the low-income families New Story is working with. The built-to-last 3D printed homes are safer and more durable, providing families two bedrooms, a living room, kitchen and bath. The families will receive these homes at minimum cost: interest-free and at a zero-profit seven-year mortgage of 400 pesos a month (approximately $20 USD at the time of publication).

Using 3D printing technology to build homes has the capability to reduce the amount of waste and time needed to construct a house; ICON's Vulcan 3D printing process produces nearly zero waste, requires 3-4 people for operation, and each 500 sq.-ft. home can be 3D printed in a cumulative 24 hours over the course of several days. According to ICON, the houses, made out of a proprietary concrete blend named Lavacrete, are more resilient to natural disasters, create less waste than traditional construction, are more energy efficient, and last as long or longer than their traditional counterparts. In June 2020, the 3D-printed homes withstood a 7.4 magnitude earthquake with no visible damage.

APPROPRIATENESS: Is 3D printing right for these circumstances?

New Story and ICON's initiative to 3D print houses in low-resource countries is the first project of its kind. New Story's experience building homes in under-resourced communities and ICON's expertise as a construction technologies company makes the partnership well positioned to design and evaluate the safety and functionality of 3D-printed homes for families in Nacajuca and beyond.

Part of New Story's success has been due to their approach to community engagement. The organization utilizes a "lean participatory approach," engaging families during a four-hour session to understand aspects of the local culture that should be reflected in the homes. For example, through this process the team learned that most families in Nacajuca do not cook indoors, but instead prefer to cook and eat outdoors. This information was critical in the design process, resulting in design options that featured outdoor kitchens, and ultimately building homes that people would want to live in. Designing with the users also ensured that families would use and care for the houses in the long term. New Story took the data gathered in the process to come up with four house designs families could choose from. Indeed, one of the many benefits to 3D printing home construction is the design freedom it affords. The ICON team was quickly able to implement design feedback from the community and architects translating it into code for its Vulcan printer to carry out.

FEASIBILITY: Are the necessary resources for successful implementation available?

As pioneers of this effort, much of the pilot project's success in implementation has been through trial and error. The project faced various obstacles across all stages of the work from border challenges and weather-related issues to the global pandemic. ICON's technology had to first successfully cross the border in a trailer driven from the U.S. There was no precedent for transporting a large 3D printing robot across international land borders. The printer and material delivery system also had to be inspected to ensure that it was appropriate for shipment.

The teams also had to learn to navigate challenges regarding logistics, geographic variability, weather events, and the sensitivity of the building material on the ground in Mexico, in addition to COVID-19-related challenges. Altogether, the team adapted and was able to address most challenges, in part by using local materials which made for increased productivity, increased sustainability, and reduced costs.

In spite of multiple challenges, the teams from New Story, ICON and Echale delivered a full street of 3D-printed homes and Echale additionally delivered ecoblock homes within the growing community. Importantly, their success is in large part due to buy-in from relevant stakeholders and strong partnerships with local government and non-profit organizations. Support from the local government helped the team navigate infrastructure obstacles, such as setting up an electrical grid and accessing building land. Local partnerships have also been essential in finishing the houses with roofs, windows, and doors.

Assessment: Delivering extremely low-cost housing in developing countries using 3D printing technology continues to face barriers, although some have been addressed. Learning from their experience in Mexico, ICON developed its latest construction system to fit in a 20-foot container for easy shipping to alleviate border challenges and further reduce costs. ICON's materials scientists also continue work in utilizing local materials to lower costs of shipping proprietary material to foreign countries. The resilient 3D-printed homes in Nacajuca, Mexico will soon be home to families who have experienced extreme poverty, and New Story believes this technology will see long-term viability in the developing world.

Applying Human-Centered Design and the Principles for Digital Development

New Story implements an inclusive, participatory design system. Part of their process includes hosting a community design workshop to take away actionable insights from community stakeholders. To ensure that traditionally underserved groups can meaningfully engage, New Story chooses a time and location that is preferable for the local community and provides food and childcare at the workshop. The New Story team has also developed a mobile app to identify community needs, trends, and actionable insights to build trust and maximize resources. This app has increased the data-collection efficiency by 400% and allowed New Story to iterate and adapt their work. In addition, New Story partners with experts across various disciplines, local nonprofits and governments to build the homes, plan the communities, and align their work with existing initiatives in the communities where they work.

From the Principles for Digital Development, a few relevant principles in this case - Design with the User; Understanding the Existing Ecosystem; Be Data Driven; Be Collaborative

REVIEW: CHALLENGES OF 3D PRINTING

3D printing is a powerful tool that can foster innovation and empower communities to make certain goods locally. 3D printing alone cannot fix supply chain issues or localize manufacturing entirely. Traditional processes, which can produce tens or hundreds of thousands of items a day, are much faster and cheaper for mass manufacturing, and can use a broader range of raw materials. While 3D printing is not time- and cost-effective for mass manufacturing, it is very well-suited for small production runs, complex designs, and making custom items.

The use of 3D printing has potential benefits in development sectors not discussed here, including agriculture and education (e.g. custom 3D-printed tools for farming; 3D printed anatomical or historical models for teaching). While there is a relatively low barrier to entry for adopting this technology, and many designs and modeling software programs are readily available for free online, knowledge of 3D modeling is necessary in order to benefit from the full range of opportunities the technology offers. This may be a significant challenge in areas where overall digital literacy and access is low. Moreover, the digital divide might impact who has the ability to engage with designing and producing 3D printed items. 3D printing also requires resources, including power and materials for printing. In the future, opportunities will expand as advances in 3D printing technology allow use of locally produced filament and the costs of using alternative materials to plastic diminish.

Users and designers of 3D printing solutions must have certain skill sets, including the creativity to identify the types of problems that can be solved with 3D printing. Developing a problem-first approach and employing human-centered design thinking are also critical to successfully and sustainably using this technology. Further, users must be able to objectively evaluate whether a 3D printed object has been fabricated adequately, as well as whether a 3D printed part is an appropriate alternative to its traditional counterparts. For certain items such as medical devices, additional expertise beyond making 3D models may be needed. In the case of 3D printed prosthetics, for example, specialized expertise is necessary to make evaluations about fit and quality.

While 3D printing can be a useful tool, it does not solve systemic problems in any of the case studies described. The technology provides opportunities and workarounds to reduce reliance on complex and restrictive supply chains in certain cases, but the technology cannot fix broken supply chains or eliminate the need for transporting materials altogether. Similarly, while 3D printed prosthetics may be a valuable solution for amputees who cannot access existing healthcare solutions, they do not obviate the need for access to adequate healthcare in general (or for more complicated prosthetics).

CONCLUSION: WHERE DO WE GO FROM HERE?

The opportunities 3D printing technology provides for rapid prototyping, increasing customization, reducing overhead costs, and circumnavigating faulty supply chains may be relevant and suitable for applications across many development sectors. These case studies demonstrate that 3D printing technology can be a valuable tool in disaster relief; the case studies also highlight the potential for 3D printing technology to improve access to housing and prosthetics as the technology continues to develop. As development actors consider incorporating 3D printing into their work, it is important to identify and engage local innovation and manufacturing ecosystems, in which 3D printing may be one valuable component.

When considering using 3D printing as part of a development solution, it is critical to assess the systems and institutions in the area, such as local makerspaces, universities, businesses, and other communities. These entities may already have the tools, expertise, experience, or interest to engage in the project at hand, potentially improving outcomes and sustainability. Development actors can maximize resources and impact by engaging existing innovation ecosystems and broadening their focus to include other production tools in addition to 3D printing. These may include digital fabrication tools, such as laser cutters, as well as traditional artisanal forms of production. At times, it will be likely that engaging the skills of a local welder or artisan will be a better approach than relying on a 3D printer. When digital fabrication tools are not present, if the digital ecosystem context is well-suited to their adoption, it may be worth considering whether to support the development of a makerspace in a community.

Innovative communities like makerspaces that focus on hardware and parts manufacturing, while admittedly accessory to digital ecosystems, are often overlooked in development as important contributors to the digital and innovation economy. These spaces can offer communities meaningful jobs, opportunities to network, and actionable skills. Donors and implementing partners can better support, engage, and leverage existing manufacturing innovation ecosystems in developing countries to augment or amplify development and humanitarian assistance. Donors, NGOs, and other development actors would benefit by better engaging with these local innovation hubs and supporting and leveraging them to drive wider economic and social gains in our work.

IS 3D PRINTING RIGHT FOR MY DEVELOPMENT PROJECT?

This is a list of the factors that should be considered before undertaking a 3D printing project. While not an exhaustive list, these should help development practitioners assess whether 3D printing is relevant, appropriate, and feasible for a given project.

RELEVANCE: Can 3D printing add value in your situation?

1. What is the problem you are trying to solve?
2. What is the status quo solution to this problem?
3. How could a 3D printed piece or a 3D printer address the problem at hand?
4. In what other ways can you address this problem?
5. How does this 3D printed product compare to its next best alternative, especially in terms of functionality, safety, and durability?
6. Do the benefits of using 3D printing technology make it better than the next best alternative solution? Consider the functionality, safety, and durability of a 3D printed product, as well as overall cost, flexibility, and time.

APPROPRIATENESS: Is 3D printing right for these circumstances?

1. What criteria will be used to evaluate the product design and assess the safety of a 3D printed item? Who is qualified to make that assessment?
2. Does the 3D model meet necessary specifications for the product to function as intended?
3. How many 3D printed items are needed? Considering the quantity of needed parts, is 3D printing a cheaper, faster, or more durable option than acquiring the part through a traditional supplier?
4. Who is the product for? Who benefits from this use of 3D printing? Is this solution inclusive? Were end users engaged in design and adoption, where appropriate?
   To what extent does this application of 3D printing reflect the Principles for Digital Development?
5. How does this solution impact the job market in local communities?
6. How will you assess impact post-construction?

Photo Credit: USAID El Salvador

FEASIBILITY: Do you have the necessary resources for successful implementation in your context?

1. What resources do you need to implement your 3D printing solution? (e.g., printers, printing materials, designs, software, electricity, internet, and expertise for printer operation, finishing touches, and use of the final product)
2. Do you have access to the necessary resources? What barriers to access, if any, exist (e.g., custom duties for importing printers, lack of local talent to operate and maintain printers, etc.)?
3. Is it possible to access an existing Fab Lab or makerspace, or create a 3D printing community?
4. What local constraints do you face operating the 3D printer, such as unpredictable power, lack of technical assistance, power outages, dust, and moisture? How will you face these challenges?
5. What aspects of the local legal or policy environment may impact your ability to implement your 3D printing solution (e.g., shipping and customs, trade restrictions, etc.)?
6. What local partnerships or government relationships do you need in order to implement and sustainably integrate this solution?
7. Are there additional parts, materials, or finishes needed to make the 3D printed part fully functional? Does the product require post-processing or finishing touches?
8. Are there permits required in order to print or distribute these parts?

Photo Credit: USAID El Salvador

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APPENDIX A: UNDER THE HOOD

"3D printing" is an umbrella term for several methods of additive manufacturing. In traditional methods of manufacturing, objects are created by boring, drilling, grinding, or cutting material. These methods are subtractive because they are processes of removing material. In contrast, additive manufacturing methods create parts by adding material layer by layer. Different 3D printing technologies use different materials, vary in dimensional accuracy, and are used for different purposes.

The most common 3D printing method is Fused Fabrication Modeling (FFM), also known as Fused Deposition Modeling (FDM). FFM printers use a type of material called thermoplastic filament, which is a term to describe polymers that are solid at cool temperatures and pliable at high temperatures. The printing process begins by pushing the solid filament into a heated nozzle, much like a glue gun. The nozzle deposits the now-pliable filament on a build platform, following a path determined by the digital 3D model. Each layer becomes solid as it cools. The printer builds objects from the bottom up by repeating this process until all layers have been made.

Unlike FFM printers, vat polymerization printers use a type of material called photopolymer resin. These are liquid polymers that harden when exposed to specific kinds of light. To begin, the printer lowers a build platform just under the surface of a basin of resin. Following the digital 3D model, a laser selectively "cures" the resin where needed to create one layer of the object. After each layer, the platform lowers slightly and a blade sweeps over the hardened layer to recoat it with resin. The laser builds the next layer by selectively curing the resin where needed and the process repeats. Once all the layers have been added, the part is removed from the vat, cleaned of excess resin, and then recured and sanded.

3D printers vary significantly in terms of technical processes, cost, and speed. The quality, material, and size of the printed objects also vary (see Appendix B).

APPENDIX B: COMPARISON OF 3D PRINTING PROCESSES[18]

COMPARISON OF 3D PRINTING PROCESSES

Process	Technology	Materials	Dimensional Accuracy	Common Applications	Strengths	Weaknesses
Material Extrusion	Fused Deposition Modeling	Thermoplastic Filament (PLA, ABS, PET, PETG, TPU)	±0.5% (lower limit ±0.5 mm)	Electrical housings; Form and fit testings; Jigs and fixtures; Investment casting patterns	Best surface finish; Full color and multi-material available	Brittle, not sustainable for mechanical parts; Higher cost than SLA/DLP for visual purposes
Vat Polymerization	Stereolithography (SLA), Masked Stereolithography (MSLA) Direct Light Processing (DLP)	Photopolymer resin (Standard, Castable, Transparent, High Temperature)	±0.5% (lower limit ±0.15 mm)	Injection mold-like polymer prototypes; Jewelry (investment casting); Dental applications; Hearing aids	Smooth surface finish; Fine feature details	Brittle, not suitable for mechanical parts
Powder Bed Fusion (Polymers)	Selective Laser Sintering (SLS)	Thermoplastic powder (Nylon 6, Nylon 11, Nylon 12)	±0.3% (lower limit ±0.3 mm)	Functional parts; Complex ducting (hollow designs); Low run part production	Functional parts, excellent mechanical properties; Complex geometries	Longer lead times; Higher cost than FFF for functional applications
Material Jetting	Material Jetting (MJ), Drop on Demand (DOD)	Photopolymer resin (Standard, Castable, Transparent, High Temperature)	±0.1 mm	Full-color product prototypes; Injection mold-like prototypes; Low run injection molds; Medical models	Best surface finish; Full color and multi-material available	Brittle, not suitable for mechanical parts; Higher cost than SLA/DLP for visual purposes
Binder Jetting	Binder Jetting (BJ)	Sand or metal powder: Stainless / Bronze, Full-color sand, Silicia (sand casting)	±0.2 mm (metal) or ±0.3 mm (sand)	Functional metal parts; Full-color models; Sand casting	Low-cost; Large build volumes; Functional metal parts	Mechanical properties not as good as metal powder bed fusion
Powder Bed Fusion (Metals)	Direct Metal Laser Sintering (DMLS); Selective Laser Melting (SLM); Electron Beam Melting (EBM)	Metal Powder: Aluminum, Stainless Steel, Titanium	±0.1 mm	Functional metal parts (aerospace and automotive); Medical; Dental	Strongest, functional parts; Complex geometries	Small build sizes; Highest price point of all technologies

18 "The Types of 3D Printing Technology."

APPENDIX C: COMPARISON OF LOW- TO HIGH-END 3D PRINTERS[19]

Comparison of low- to high-end 3D printers				
Grade	**Budget**	**Entry Level and Hobbyist**	**Professional and Performance**	**Business and Industrial**
Printer Cost	$100-$300	$300-$1000	$1000-$10,000	$10,000+
Characteristics	• Sold as kits; assembly required • Regular calibration required • Limited material selection • Small print volume • High noise level • Low speed • Lower quality prints	• More reliable • Increased capabilities • Better suited for frequent use • Few modifications or repairs required	• Precise, fast • Increased print sizes • Enclosed printing bed • Improved interfaces and ease • Difficult to self modify • Phenomenal quality • Some only accept manufacturer's materials	• Possible materials include carbon fiber and metal • Come in multiple large units • Used for prototypes, functioning parts, part of the manufacturing process of commercial items • Become more expensive overtime

Sample printers in these ranges								
Printer	**Phrozen Sonic Mini**	**Creality Ender-3 V2 3D Printer**	**Original Prusa Mini**	**Creality Ender 5 Pro**	**Peoply Phenom**	**Tiertime UP300**	**Rize One**	**Markforged Mark 2**
Cost	$199-269	$262	$906	$389	$1,999	$2,169	$26,000	$13,499
Process	MSLA	FDM	FDM	FDM	MLSA	FDM	FDM/Material Jetting	FDM
Speed	80 mm/s		200+ mm/s	60 mm/s		200 mm/sec		280mm
Print Size (in)	4.7 x 2.6 x 5.1	8.6 x 8.6 x 9.8	7 x 7 x 7	8.6 x 8.6 * 11.8	10.9 x 6.1 x 15.7	8 x 10 x 8.8	11.8 x 7.8 x 5.9	12.5 x 5.1 x 6
Materials	Resin (Recommended Phrozen's Aqua-Gray 4K)	PLA/TPU/PETG 1.75mm	PLA, PETG, ASA, ABS, Flex 1.75mm	PLA, ABS, PETG, TPU 1.75mm	Resin (manufacturer's "Deft Resin" recommended)	UP Fila ABS, ABS+, PLA, TPU and more	Rizium One, Release One, Marking Ink	Nylon, Carbon Fiber, Fiberglass, Kevlar, etc

19 "How Much Does a 3D Printer Cost?"; "Best 3D Printers 2021 (April)."

APPENDIX D: COMPARISON OF 3D PRINTING MATERIALS[20]

Comparison of 3D printing materials		
Material	**Cost**	**Qualities**
PLA	$15–$20 per kg	• Easy to print
ABS	$15–$20 per kg	• Heated build required
PETG	$16–$19 per kg	• Stronger, higher temperature resistance, and easier to use than ABS
Nylon	$50–$73 per kg	• Flexible • Chemically resistant • Good for modeling functional parts
TPU, TPE, Soft PLA	$87–$110 per kg	• Flexible • Used for "RC car tires, shoes, and rubber-like models"
Polycarbonate	$30–$93 per kg	• Strong • Transparent • Good electrical insulation properties
ASA	$30–$50 per kg	• Good for some outdoor applications; UV and moisture resistant • Electrically Insulating
SLA: Resin	$40–$300 per liter	• High resolution
Specialty materials include wood, glitter, glow-in-the-dark compounds, carbon fiber, stainless steel, magnetic iron powder, kilnable metal filament		

APPENDIX E: 3D PRINTING IN DEVELOPMENT (NON-USAID)

APPENDIX F: 3D PRINTING IN DEVELOPMENT (USAID)

20 3D Printer Filament Buyer's Guide.


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