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Proceedings to the 7th International Conference on Appropriate Technology, November 23rd – 26th, 2016, Victoria Falls, Zimbabwe.

Open Source 3-D Printers: An Appropriate Technology for Developing Communities

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Abstract

The recent introduction of RepRap (Self-Replicating Rapid Prototyper) 3-D printers and the resultant open source technological improvements have resulted in affordable 3-D printing, enabling low-cost distributed manufacturing for individuals. This development and others such as the rise of open source-appropriate technology (OSAT) and solar powered 3-D printing are moving 3-D printing from an industry specific technology to one that could be used in the developing world for sustainable development. In this paper, we explore some specific technological improvements and how distributed manufacturing with open-source 3-D printing can provide sustainable development by creating wealth for developing world communities through the ability to print less expensive and customized products. Conclusions on the technical viability of 3-D printing to assist in development and recommendations on how developing communities can fully exploit this technology have been outlined.

Keywords

3-D printing, appropriate technology, OSAT, economic development, Recyclebot, developing communities, distributed manufacturing, solar powered 3D printers.

1.0 Introduction

Although proprietary and expensive 3-D printers have been available for decades, only recently has the introduction of the RepRap (Self-Replicating Rapid Prototyper) 3-D printing project [1-3] radically reduced the costs of 3-D printers and made them available for entry level markets [4-5]. Free and open-source hardware (FOSH) developed along with the RepRap 3-D printer models have asserted 3-D printing as not only an innovation platform for promoting distributed manufacturing systems, but also as a novel form of localized and customized production [6]. Using computer aided designs, it is now possible to fabricate and customize products cheaper, faster, and from the comfort of the user's home. Additive manufacturing in the form of open-source 3-D printing, combined with distributed generation through solar powered 3-D printers, has the potential to alleviate poverty in impoverished rural communities. Price declines and technological improvements are moving 3-D printing from an industry specific technology to one that could be used in the developing world [7-12]. For example, 3-D printing may radically improve access to eye care, and may be used to manufacture livestock feeding stations that reduce disease transmission and improve agricultural productivity [6,13]. In 2010, Pearce et al. [7] proposed a research plan for enabling people to print themselves out of poverty with open source 3-D printing and Gebler et al. have argued 3-D printing can aid in global sustainability [14].

This paper will review the current status of 3-D printing for sustainable development by evaluating the technical and economic viability of 3-D printing in the two main categories; 1) technological improvements, which includes a) RepRap evolution and its features appropriate for development, b) recyclebots and availability of local 3-D printing materials, c) off-grid solar-powered 3-D printing and, 2) applications for development. Necessary further development will be outlined and conclusions will be drawn on the technical viability of 3-D printing to assist in development.

2.0 Technological Improvements

2.1 *3-D printers: RepRap Evolution and Features Appropriate for Development*

The RepRap project was started by Adrian Bowyer at the University of Bath [3] in 2004 as the idea to make a 3-D printer that could self-replicate. Specifically, it was made to be a fused filament fabrication (FFF) rapid prototyping machine (RP) that could make most of its own parts [1]. FFF is an additive manufacturing technology—material is deposited in layers which are joined to each other through heat [15]. When it was first introduced, all the RepRap designs and software were made open-source for the world to have and improve upon [3]. The first RepRap produced was called Darwin, a box-like 3-D printer made of mostly metal and 3-D printed parts [1]. To fix problems Darwin was experiencing, the next RepRap 3-D printer was built—Mendel. Mendel improved upon Darwin by decreasing the weight of the printer, increasing axis efficiency, making assembly simpler, and allowing for extruder head change [7]. The RepRap machine has started the open-source 3-D printer community [15] and is now the most widely-used 3-D printer among the maker community [1,16].

Table 1. Market survey for some entry level FFF open-source 3-D printers showing the cost, build volume, print speed, print materials, OS supported, and ability to print without a computer.

Characteristics	**LulzBot Mini 3-D Printer**	**LulzBot TAZ 6**	**Ultimaker 2+**	**Ultimaker 2 Extended+**
Cost	$1,250.00	$2,500.00	$2,499.00	$2,999.00
Build volume	3,650 cm³	19,600 cm³	10,194 cm³	15,167 cm³
Print speed	Up to 275 mm/sec	Up to 200 mm/sec	Up to 300 mm/sec	Up to 300 mm/sec
Print materials	ABS, PLA, HIPS, PVA, wood filled filaments, Polyester (Tritan), PETT, bronze and copper filled filaments, Polycarbonate, Nylon, PETG, conductive PLA and ABS, UV luminescent filaments, PCTPE, PC-ABS, Alloy 910	ABS, PLA, HIPS, PVA, wood filled filaments, Polyester (Tritan), PETT, bronze and copper filled filaments, Polycarbonate, Nylon, PETG, conductive PLA and ABS, UV luminescent filaments, PCTPE, PC-ABS, Alloy 910	PLA, ABS, CPE	PLA, ABS, CPE
OS supported	Mac OS X, Windows, Ubuntu, Linux	Mac OS X, Windows, Ubuntu, Linux	Mac OS X, Windows, Linux	Mac OS X, Windows, Linux
Ability to print without a computer	No	Yes	Yes	Yes
Characteristics	**Rostock MAX v2**	**Printrbot Play**	**Printrbot Simple**	**mElephant**
Cost	$999	$399	$599	$600
Build Volume	92,363 cm3	1,300 cm3	3,375 cm3	5,760 cm3
Print speed	Up to 300 mm/s	Up to 80 mm/s	Up to 80 mm/s	General print speed 50 mm/s
Print materials	PLA, ABS, PETG, Nylon	PLA	PLA	PLA
OS supported	Linux, Mac, Windows	Linux, Mac, Windows	Linux, Mac, Windows	Linux, Mac, Windows
Ability to print without a computer	Yes	Yes	Yes	Yes

Table 2. Market survey for entry level FFF open-source 3-D printer kits for cost, showing build volume, print speed, print materials, OS supported, and ability to print without a computer.

Characteristics	Ultimaker Original+	Printrbot Simple	Original Prusa i3	MOST Delta II (Athena)
Cost	$995.00	$599.00	$599.00$500.00	
Build volume	9,040.5 cm³	3,375 cm³	8,000 cm³	11,781 cm³
Print speed	Up to 300 mm/sec	Up to 80 mm/sec	Up to 200 mm/sec	110 mm/sec
Print materials	PLA, ABS, CPE	PLA	PLA, ABS, PET, HIPS, Flex PP, Ninjaflex, Laywood, Laybrick, Nylon, Bamboofill, Bronzefill, ASA, T-Glase, Carbon-fibers enhanced filaments	PLA without alterations anything with upgrades [17]
OS supported	Mac OSX, Windows, Linux	Windows, Linux	Mac, Windows, Linux	Mac, Windows, Linux
Ability to print without a computer	Yes	Yes	Yes	Yes.

2.2 Recyclebots and Availability of Local 3-D Printing Materials Feedstocks

3-D printing filament is traditionally manufactured from raw virgin materials, which is generally landfilled at the end of the life cycle of the 3-D printed product. This filament is also expensive, with minimum costs of about $20/kg for PLA in the Internet [18]. However these costs are significantly inflated as the cost of resin pellets ranges from $1-4 per kilogram [19]. In addition, these prices can be further reduced by obtaining filament using recyclebot technology. Recyclebots are open-source waste plastic extuders capable of turning post-consumer thermoplastic containers into 3-D printer filament [20-21].

The Ethical Filament Foundation is a member-owned, not for profit organization, whose goal is to grow the waste plastic recycling industry through the underdeveloped world [22]. The people in the underdeveloped world could benefit greatly from 3-D printing by having the means to produce needed tools on their own time [7]. However, to do this, communities need reasonably priced filament. The Ethical Filament Foundation promotes having waste pickers—who now earn pennies a day—take plastics from landfills and use recyclebots to make low-cost filament while being paid fairly for their work. This will benefit both those people whose only job is to pick out waste from landfills and the environment, since these plastics will be used again instead of decaying over the centuries in landfills [23]. After the filament is produced, it will be tested for quality and given the Ethical Filament stamp of approval, which shows that the filament was ethically produced and is of high quality [24]. This allows people living in underdeveloped countries to have plastic filament without procuring additional costs from importing materials [24].

2.3 Off-Grid Solar-Powered 3-D Printing

Most communities in developing countries are generally remotely located and isolated without access to a reliable road network or electricity grid. To address the challenge this poses to embracing 3-D printing technology in these remote rural areas, off-grid solar-powered 3-D printers were developed [25-27]. The most recent version of this technology was equipped with a battery that would charge during times of excess power being supplied by the solar photovoltaic (PV) modules and would discharge during times of low power output [25]. This new version, which uses a MOST-delta solar-powered RepRap 3-D printer is light to transport as a single unit. All the components including the printer can fit in a duffle bag for easy transit. Therefore, solar-powered 3-D printers have the technical potential to enable local customization of complex designs, whilst ensuring uninterrupted supply of essential needed parts for rural remote communities. Prototypes of solar powered 3-D printing systems have already been demonstrated for semi-mobile systems [27] and a highly mobile system [25]. The latter could be used to make, for example, replacements parts at any rural development center, school or even home. The former system is designed to become a permanent fixture at rural schools that are not connected to the electrical grid. Thus, the solar-powered 3-D printer could be used to make high-value products such as scientific tools for research or education [28-29], equipment for use in medical clinics [30], and other items which can be used for disaster relief [31]. Thus, this will help alleviate the problems of science equipment shortages in the developing world schools and medical centers by making available the much needed hardware at a fraction of a cost [32]. Solar-powered distributed manufacturing allows off-the-grid rural communities to leap to a more sustainable method of production.

Fig. 1. Solar Powered MOST-delta 3-D printing, 3 x 12 V, 24 W solar panels, and printer with panel mounted in a duffel bag [25]. The PV modules are clipped to the frame of the RepRap for shipping.

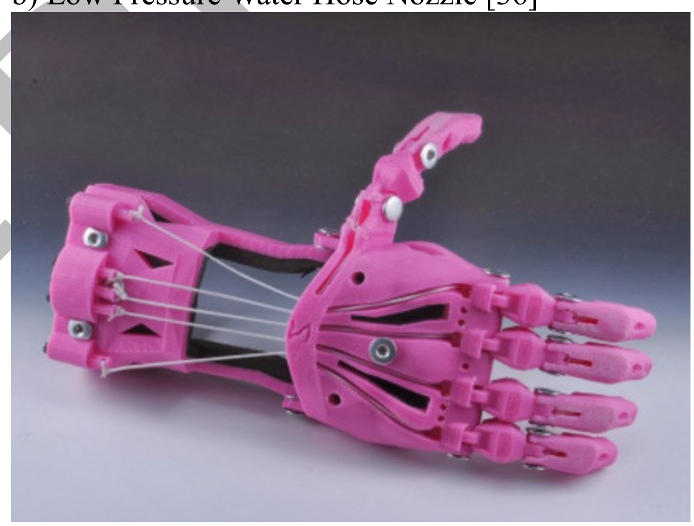
3.0 Application for Development

The technical development of the open-source 3-D printer enables low-cost distributed production, which can be a key ingredient for economic emancipation of underprivileged resources starved developing communities. Distributed manufacturing with 3-D printing can empower communities through the ability to print less-expensive and customized products. The capacity to locally fabricate and optimize products such as the chicken feeder and other open source appropriate technology (OSAT) [33] products will be of great economic value to rural communities. Previous work has analyzed the case of organic farmers [34]. However, OSATs can be developed for any particular type of community or means of employment and can be easily printed by people in the developing world who have access to an open source 3-D printer. Examples are shown in Fig. 2.

a) Hammer [35]

b) Low Pressure Water Hose Nozzle [36]

c) Chicken Feed Holder [37]



d) Cyborg beast [38]

Fig 2. Sample OSATs for economic empowerment of communities in the developing world

Table 3 shows the economic comparison for the 3-D printed OSATs products in Fig. 3. As can be seen from Table 3, locally 3-D printed items are much more cost effective than buying them on the market or importing them from other countries. These and other similar tools could help transform resource constrained communities for the better since they are required for daily chores/tasks such as construction (i.e. the hammer), farming and agriculture (i.e. low pressure water hose nozzle, and the chicken feed holder).

3-D printing can also be used in medical applications in the developing world. One example of this is an organization called Enabling the Future. Enabling the Future is a global community of people owning 3-D printers who volunteer to print low cost prosthetics for children around the world. All of their hand designs are open source for anyone to print and further improve on. For children with partially functioning wrists, the wrist actuated designs including the Raptor Reloaded, Raptor, Talon, Cyborg Beast (Fig. 3), Ody Hand, Flexy Hand, Phoenix Hand, and Osprey Hand are ideal. There are also designs available for children without a functioning wrist such as the Team Unlimited Arm and the RIT Arm. The community has grown to over 7,000 online members [39-40]. These 3-D printable prosthetic hands have the potential to help many people—especially in developing countries—that do not have enough money to pay for expensive prosthetics sold commercially. They can give some people the opportunity to do work and make money in a way that they were not previously able to before because of physical constraints.

Organizations like Field Ready and iLab Haiti have already started bringing 3-D printing technology to disaster struck places and the developing world and providing technical training in that country. These organizations have shown that training people to use 3-D printers in the developing world is possible. Furthermore, Michigan Tech's project with Enabling the Future volunteers from Nicaragua also successfully brought 3-D printing to the developing world by first training people in the U.S. to provide technical support in country. These projects have helped people with a real need, and can be expected to increase utility in the future as additional OSATs are designed.

Table 3. Economic Comparison for Selected 3D Printed OSATs Products

Design	Amount of filament needed (grams)	Approximate capital costs (US$)	Total retail cost low (US$)	Total retail cost high (US$)	Percent change low	Percent change high
Hammer	235	6.31	7.31[41]	199.97 [42]	-58%	-3,069%
Cyborg beast prosthetic hand	70	36.61	225 [43]	100,000 [44]	-515%	-273,049%
Low Pressure Water Hose Nozzle	53	1.22	3.14 [45]	19.99 [46]	-157%	-1,539%
Chicken Feed Holder	290	6.66	12.23 [47]	28.95 [48]	-84%	-335%

This need for more designs also makes clear the primary current limitation to this approach. Although there are several million free and open source designs available, only a small fraction are of high-quality OSAT like those shown in this paper. This is a tiny fraction of the products normally available to consumers anywhere in the world. To put this into perspective in 2013 Amazon sold over 230 million products in the U.S. [49]. Many freely available designs are simply customized derivatives, or poorly executed non-functional designs, which are partly due to changes in the goals and license agreements for the largest design repository [50]. In order to make this method of OSAT deployment viable more and better (improved) designs are necessary in a wide range of products that would be of service for developing communities of any level of sophistication. Ideally, these free designs would be vetted, tested and housed in a reliable centralized repository [50]. Future work is needed in this area.

4. 0 Conclusions

This paper have presented some of the technological improvements and innovations of 3-D printing and how an open source-based distributed manufacturing technology can benefit resource-constrained developing world communities. Highlights on how these innovations have ignited the transition of 3-D printing technology from being sorely industry-based to being home-based technology are also presented. Cost reductions coupled with technological improvements such as open source highly portable 3-D printer models capable of operating off the grid can be the key drivers for the adoption of 3-D printers by individuals. Various examples presented in this paper on the use of 3-D printers for development suggest that there is a great potential for 3-D printing technology to be used as a tool for sustainable development in the developing world. This technology will enable developing-world communities to locally customize and fabricate need-driven OSATs for their day to day use and by so doing empower them to create wealth through establishing small sustainable enterprises. The use of appropriate 3-D printed OSATs has the potential to result in better products and improved agriculture yields, which will help reduce poverty, hunger and improve the general life style for many. There is however, the need for further research to improve and customize open source 3-D printers, recyclebot technology, open source photovoltaic powered 3-D printing, and the designing of more useful OSATs for the developing world. The ability to locally fabricate both 3-D printers and the printing filament using local materials is a key to the successful adoption and implementation of the 3-D printing technology in the developing world. Current work in these areas show enormous potential for bringing 3-D printing to the developing world in the near future.

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