

## **3D Printing for Sustainable Industrial Transformation**

Thomas S. Woodson,

Email: thomas.woodson@stonybrook.edu

Running Header: **3D Printing for Sustainable Industrial Transformation**

Abstract 3D printing has been hailed as a technology that will usher in a new industrial age. The technology has many advantages over traditional manufacturing and proponents of it say that 3D printing could bring sustainable industrial transformation by altering supply chains, manufacturing jobs, and production. But like all technologies, 3D printing is bound by a complex socio-technical system that could limit its growth and further increase inequality.

**Keywords:** 3D printing; additive manufacturing; development; sustainability; industrial change; technology policy

### **Introduction**

The literature on 3D printing paints vivid pictures of a society transformed by this technology. Authors give scenarios where mothers print new toothbrushes for their children from the comfort of their own living room and husbands print personalized gourmet cakes by simply pressing a button (Lipson and Kurman, 2013). World leaders talk about the potential of 3D printing to revolutionize manufacturing and reinvent industries and development scholars write things like ‘the rise of 3D printing could do for Africa what semiconductors did for Taiwan in the 1960s’ (Juma, 2014). With all the publicity around 3D printing, how will it ensure sustainable industrial transformation and what are some potential consequences of this technology for development? 3D printing offers many advantages over traditional manufacturing that could allow it to disrupt the current hegemony of industrial manufacturing. However, 3D printing is embedded in socio-technical systems that may prevent the technology from producing sustainable industrial transformation. This article briefly discusses the potential of 3D printers to transform industry and some of the factors that could hinder its growth.

### **What is 3D printing?**

3D printing, or additive manufacturing, refers to a process that prints three dimensional objects by stacking layers of materials. Basic 3D printers extrude melted plastics to build an object, while more expensive printers may use lasers and chemical binders to heat and solidify chemicals to make an object. Even though 3D printing only recently became widely discussed, the technology is not new. The early stages of 3D printing began in the late 1970's with photopolymer processing, and in the 1980's, scientists developed methods that use lasers to selectively cure polymers and build layers (Weber *et al.*, 2013). Since the 1980s, scientists and engineers developed a myriad of other 3D printer technologies to improve their size, speed, and accuracy. They have also developed printers that print in colors and print one object using different materials. All these improvements have made it possible for the consumers to own 3D printers and for companies to use them for large scale production.

3D printers range in size, cost and performance. Small 3D printers can fit on a desk while industrial scale printers can cost thousands of dollars and are the size of small cars. There are even new 3D printers that print large structures like homes and office buildings. The highest quality printers are primarily used by large corporations. These printers often print a single object using different materials and they have a high resolution so that the final printed object requires very little post-production processing. The smaller, lower quality printers are mostly used by individual consumers and they have received a lot of publicity recently (Weber *et al.*, 2013).

Today, 3D printers are compared to the personal desktop computer in the 1980s because, like the first personal computers, 3D printers are primarily used by technically savvy, early adopters and the current printers are slow and unwieldy (Finocchiaro, 2013). Despite their current limitations, there is a large and growing market for 3D printers. In 2013, it was estimated

that 3D printing was a US\$2.5 billion market, and it is estimated that it will have grown to a US\$ 16.2 billion market by 2018 (Canalys, 2014). To further increase the market for 3D printers, corporations want to make them a product that every household needs. 3D printing companies, like 3D Systems, have built user friendly 3D printers to reach the mass market and some large companies, like HP, are entering the market to further expand the supply of 3D printers around the world. In the future 3D printer enthusiasts envision that the technology will be used ubiquitously by every company and consumer. Instead of going to the store to purchase a new outfit or toy, the person can simply download the blueprints and print the product at their house.

### **How will 3D printing cause industrial transformation?**

The proponents of 3D printing point to several unique features of this technology that can make it a catalyst for altering global manufacturing. First, 3D printers allow designers to quickly develop prototypes, which allows them to design products at lower cost and get them to market quicker. This feature is especially important for small firms that do not have access to large design studios. With 3D printers, small firms can better compete with larger firms, increase competition and provide more choices for consumers.

3D printers can also spur industrial transformation by allowing manufacturers to print assembly free final products (Lipson and Kurman, 2013). Directly printing a final product is a large departure from current manufacturing practices that often require companies to outsource manufacturing to other firms. Many companies do not have the resources to both design and manufacture a product and even large firms rely on manufacturers for actual production.

Manufacturers are key actors of industry because they have advanced assembly lines and access to cheap labour in order to make large batches of a single product. Batch processing produces thousands of identical products more cheaply than making a few individual units and the shift to

mass production is a major factor that created the current industrial system (Kreiger and Pearce, 2013). In order to support mass production, companies ship materials around the world to be fabricated and assembled at a central location. The finished products are then shipped back to distributors to be sold. The financial sector developed markets, insurance programmes and banking services to support large scale manufacturing. However, 3D printing could potentially break the traditional model of manufacturing by allowing customers to directly print a product that they purchase. This allows product designers to bypass manufacturers and distributors and sell designs directly to consumers for them to print.

Another distinct feature of 3D printing is that the cost of operating the printer is the same regardless of the complexity or the shape that is printed (Diegel *et al.*, 2010; Lipson and Kurman, 2013). In traditional manufacturing, complex shapes can be more expensive or even impossible to manufacture because they require extra steps and special skill to craft. In contrast, 3D printing complex shapes cost the same and take the same time to print as simple shapes. The main variable that increases the cost of 3D printing is the amount of material that is used in the design. The complexity free nature of 3D printing allows firms to increase the intricacy of their designs without increasing their costs, and as a result, firms can enhance the designs and functionality of products. Proponents of 3D printing believe that this will unleash a wave of new designs that were previously impossible to manufacture (Lipson and Kurman, 2013).

Finally, 3D printing allows items to be tailored with minimal impact on the cost (Lipson and Kurman, 2013). For example, in the healthcare sector 3D printers have custom built prosthetics and medical devices for patients (Huang *et al.*, 2012). The tailored prosthetics are cheaper than previous devices and they are more effective because they match the patient's body. In commercial retail, customers can emblaze their initials on a product or change the color of the

components to match their particular tastes without incurring any extra expenses. For developing countries, the potential to customize things is especially beneficial. Many of the current products are designed by engineers in wealthy nations to solve their problems. 3D printing will allow designers in emerging economies to create and alter products to fit their needs.

All the changes from 3D printing could ripple across the industrial system and have impacts on jobs and supply chains. 3D printing will change employment and create careers for highly skill engineers and designers that know computer aided design (CAD). New industries that support 3D printers will spring up generating 3D printer technicians, feedstock suppliers and copyright lawyers.

With regards to supply chains, 3D printers open the possibility that companies do not need to maintain warehouses of extra inventory. Rather, a company can print the necessary parts when they are needed, which allow firms to operate lean organizations and respond quickly to changing markets. Similarly, companies do not have to outsource manufacturing to different regions and have parts shipped to a central location for assembly. Again, companies could just print the necessary parts in their own factories or have consumers directly print the objects themselves. A world without long supply chains will especially benefit remote places that have hitherto been held back because they did not have access to essential materials. If a small, landlocked country can simply print a new part to fix a machine, it could improve that region's productivity and living standards.

### **Will the transformation be sustainable?**

This issue focuses on sustainable industrial transformation. Sustainability is a major concern for the world given that there is an increasing demand for a finite amount of resources. The world's resource constraints will be especially high as low income populations enter the

middle class and demand more resources, like energy, food, and consumer goods, to sustain their middle class lifestyles. It is possible that 3D printing can make future industrial transformation more sustainable, but it will not be the silver bullet to solve all the world's problems.

3D printing, unlike other industrial processes, has the potential to be more sustainable because it uses less material than subtractive manufacturing. In subtractive manufacturing, parts are created by removing material. Unfortunately, the excess material is often wasted. 3D printers use less material because it builds structures instead of removing material and some estimate that 3D printing uses 90 percent less raw materials than other manufacturing process (Lipson and Kurman, 2013). Also, 3D printers use less material because the technology can print hollow structures. By decreasing the fill of objects, 3D printers create lightweight materials without sacrificing too much strength.

Life cycle assessments of 3D printing find that it is more environmentally friendly than traditional manufacturing techniques under certain circumstances. In one study researchers found that 3D printing small devices made of acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA) can reduce energy usage by 41-64 percent and greenhouse gas emissions by 27 percent-58 percent depending on the fill of the printed object (Kreiger and Pearce, 2013).

Another benefit of 3D printing that makes it more sustainable is that personalized products are less likely to be discarded (Diegel *et al.*, 2010). Mass manufacturing produces a glut of one-size-fits all products, but no product fits the specifications of a particular customer. Customized products, on the other hand, tend to have more value for people because they meet their exact needs, and as result, they are less likely to dispose of them (Diegel *et al.*, 2010). This will increase the life span and sustainability of 3D printed products over mass produced items.

However, in order for this technology to be really sustainable, 3D printers must use sustainable feedstock. Engineers are already developing feedstock recycle kits that have the potential to reduce material waste and increase the sustainability of the technology. One study estimates that it takes half of much energy to create recycled 3D printer feedstock as to create new feedstock from virgin materials (Baechler *et al.*, 2013). In addition, recycled feedstock makes 3D printing more self-sufficient, and therefore, the technology becomes even more useful for remote locations that do not have access to materials.

### **Challenges for 3D printing**

Despite the optimism of 3D printing, there is no guarantee that this new technology will alter industries. The technology is embedded in a social framework and much of the literature does not consider the contextual factors that could impact it.

#### *Advantages of large-scale manufacturing*

Since the first industrial revolution in the 1800's, small manufacturers have merged and clustered together to form bigger firms with higher output. The economies of scale of large industries has pushed down prices by allowing manufacturers to buy cheap bulk materials, increase worker efficiency through specialization, and give them more access to capital to fund big projects (Kreiger and Pearce, 2013). Small scale manufacturing does not have these benefits, and therefore, it will be difficult for the current industrial system to be completely replaced by distributed, small-scale 3D printing. Rather, it is more likely 3D printing will be another tool used by the large manufactures to become more profitable.

#### *Persistence of supply chains*

One of the major arguments used to justify the importance of 3D printing is that the technology will shorten supplies chains by letting the end consumer directly print the product.

However, 3D printing will not erase supply chains. The 3D printer materials, like the feedstock, have to be shipped and new supply chains will develop to meet the demand for 3D printer supplies. Also, altering supplies chains will have negative consequences for ports, and transit stops. Much of the developing world can be bypassed because all the manufacturing will take place at the end location and the materials do not need to be shipped around. As a result, those countries will be further marginalized because they are not necessary for global manufacturing and trade.

#### *Not sustainable*

A proposed benefit of 3D printing is that it can be more sustainable than current manufacturing. However, the ease of 3D printing may encourage greater consumption. If a consumer makes a mistake on a 3D print, then the low cost of printing another object may encourage them to print a new copy instead of being satisfied with the undesirable print. A similar phenomenon arose with paper printers and over the past century the U.S.A. annual paper consumption per pound per capita increased from about 100 pounds to over 700 pounds (Liu and Stork, 2000).

#### *Health and safety*

There are health and safety concerns associated with widespread 3D printing. 3D printers emit high rates of ultrafine particles and toxins while they are operating (Stephens *et al.*, 2013). This particulate matter and toxins can cause a variety of respiratory health illnesses (Stephens *et al.*, 2013). Also, there are increased pollution risks from widespread distributed manufacturing. At large manufacturing facilities, the pollution is concentrated and can be managed more easily than pollution that is spread across sites. If there are no robust pollution controls with 3D



printing, then the technology could cause new types of environmental pollution that are harder to clean up.

### *3D printing will not follow Moore's Law*

3D printers have been compared to computers, but it is unlikely that 3D printing will see exponential growth as did personal computers. Computing power had massive growth due to the miniaturization of the transistor. The rise of computers is often said to follow Moore's law, which is a trend that the number of transistors on an integrated circuit doubles every 2 years. This allowed computing power to have exponential growth (Moore, 1965). However, it will be difficult for 3D printers to follow Moore's law because 3D printing is based on mechanical movement. Mechanical printing will get faster, but it cannot increase exponentially fast (Finocchiaro, 2013). For example, industries like transportation and food production have gotten quicker, but they did not have exponential growth like Moore's law because of the physical limitations of the technology. As a result 3D printing has technological limitations that will mitigate its impact.

### *Legal and social battles*

3D printing will face many legal battles that will slow its adoption. Like digital music files, 3D print designs are digital files that can be easily copied, shared, and distributed; therefore, like music, they can be illegally obtained. There have already been small legal battles between 3D printing hobbyist and firms over copyright violations and this tension is likely to grow as the technology becomes more ubiquitous (Finocchiaro, 2013). Another legal challenge facing 3D printing is that it is not clear who is liable for flawed 3D printed objects. Badly printed objects could have dire consequences if they are used in machines, equipment and medicine.

Solving these legal hurdles is not impossible but governments will need to develop laws to regulate copyright infractions and liability lawsuits arising from 3D printing.

A widely discussed risk of 3D printing that will hinder its use is that the technology can be used to create dangerous items like weapons and drugs (Lipson and Kurman, 2013).

Hobbyists have already created 3D designs for guns, and as the technology spreads, it is likely that weapons and other socially undesirable products will be created. In order for 3D printers to be accepted by society, policymakers must create guidelines for 3D printing. that allow the technology to be used safely, 3D printing has an uncertain future.

### *Impacts on development*

3D printing, like other technologies, are not neutral artifacts that only induce economic growth and development. Rather, it is embedded in social systems and the impacts of the technology will be diverse. One negative consequence of 3D printers is that the technology could leave millions of workers unemployed. Instead of having a plethora of assembly line jobs, those workers will be replaced by a handful of 3D printers. Factory jobs have been lifted millions of workers out of poverty by giving them a steady income. If 3D printers destroy manufacturing, it could have deleterious impacts on development.

Finally, despite the optimism that developing countries can develop customized 3D printed objects to fit their needs, there are barriers that prevent these countries from using 3D printers. First, this technology requires good infrastructure, like an electricity grid, to operate. In extremely poor countries, 3D printing is not a viable technology unless the country has a minimal level of infrastructure. Second, it takes expertise to create useful CAD designs. One problem for poorer nations is that they do not have a skilled workforce to design products that fit their needs, and as a result, they rely on products designed for affluent consumers. Until these

nations develop a skilled engineering and technology design workforce to make 3D print designs, it is unlikely that the technology will provide any widespread benefit for them.

## Conclusions

Very few technologies caused major sustainable industrial transformation. Many technologies, like space travel and nuclear technologies, were hailed as revolutionary, but those technologies never induced industrial transformation. Will 3D printing be different than previous technologies and catalyze sustainable industrial transformation? As shown, 3D printing solves many unique problems that can make it transformative. However, it is not a forgone conclusion that 3D printing will cause sustainable industrial transformation. Much of the current literature does not fully consider the socio-technical system that surrounds 3D printing and will impact the technology's adoption. For 3D printing to induce sustainable industrial transformation, policymakers and engineers must actively study the technology's adoption in order to improve the technology and develop policies that make 3D printing more equitable and sustainable.

**Acknowledgements:** I would like to thank Noela Invernizzi, Joan Horvath, Gary Halada, and Hailemichael Demissie for their advice on the paper.

## References

- Baechler, Christian, Matthew DeVuono and Joshua M. Pearce (2013) 'Distributed Recycling of Waste Polymer into RepRap Feedstock', *Rapid Prototyping Journal* 19(2): 118–125.
- Canalys (2014)'3D printing market to grow to US\$16.2 billion in 2018', Available at: <http://linkinghub.elsevier.com/retrieve/pii/S0026065714701389>.
- Diegel, Olaf, Sarat Singamneni, Stephen Reay and Andrew Withell (2010) 'Tools for Sustainable Product Design: Additive Manufacturing', *Journal of Sustainable Development* 3(3): 68–75.
- Finocchiaro, Charles (2013) 'Personal Factory or Catalyst for Piracy? the Hype, Hysteria, and Hard Realities of Consumer 3-D Printing', *Cardozo Arts & Entertainment Law Journal*, 31(2010): 473–509.
- Huang, Samuel H., Peng Liu, Abhiram Mokasdar and Liang Hou (2012) 'Additive manufacturing and its societal impact: a literature review', *The International Journal of Advanced Manufacturing Technology* 67(5-8): 1191–1203.
- Juma, Calestous (2014) 'It Will Take More Than Natural Resources for Africa to Rise', *Aljazeera*, 22 October.

- Kreiger, Megan and Joshua M. Pearce (2013) 'Environmental life cycle analysis of distributed three-dimensional printing and conventional manufacturing of polymer products', *ACS Sustainable Chemistry and Engineering* 1(12): 1511–1519.
- Lipson, Hod and Melba Kurman (2013) *Fabricated: The New World of 3D Printing*, Indianapolis: John Wiley & Sons.
- Liu, Ziming and David G. Stork (2000) 'Is paperless really more?', *Communications of the ACM* 43(11): 94–97.
- Moore, Gordon E. (1965) 'Cramming more components onto integrated circuits', *Electronics*, April, 38(8): 114–117.
- Stephens, Brent, Parham Azimi, Zeineb El Orch and Tiffanie Ramos (2013) 'Ultrafine particle emissions from desktop 3D printers', *Atmospheric Environment* 79: 334–339.
- Weber, Christopher. L., Vanessa Pena, Maxwell Micali, Elmer Yglesias, Sally Rood, Justin Scott, and Bhavya Lal. (2013). 'The Role of the National Science Foundation in the Origin and Evolution of Additive Manufacturing in the United States', *IDA Science & Technology Policy Institute*.