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The new Industrial Revolution: manufacturing with 3D Printers and Polymer Materials in an Economy of Design, Innovation and Intellectual Property

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Abstract

In this paper, we analyze the function and applications of a 3D printer in the context of a modern economic landscape. While other papers delve into the topic of printers in which users can download 3D models from various websites and replicate them, they do so on a surface level. This paper delves deeply in the potential economic changes that these devices could create. Unlike in regular manufacturing, these objects, made mainly from plastic material, can have internal gears and pieces that make a fully working mechanical product, without the need to assemble the individual parts into a larger contraption, and have been used even for the creation of fire weapons. We discuss the implications in regulation and control of the population and their creations.

Keywords: 3D printers; Industrial revolution; Economic changes

Introduction

The principle behind a 3D printer is similar to that of a regular printer. It consists of an extruder that moves horizontally on an axis which is held on top of two axes that allow it to move back and forward. These two axes are attached to the sides of the printer. This allows the extruder to move freely in the plane like any conventional printer. A major difference is the 3D printer also has a base that moves vertically, to provide a third degree of freedom. When printing an object, the extruder remains at the top and moves in two dimensions while printing the first layer of material. The base that holds the printed object will decrease in height by a small amount, so that the extruder can print the next layer. This process will be repeated until the object is fully printed [1].

Methods for Sharing and Accessing Designs

Consumers can create or modify existing models. There are various modelling software's available. Popular ones for product design are Solid works or AutoCAD; however other 3D multipurpose programs can be used as well, such as Maya, the industry standard, 3D Max, Blender, Cinema4D and others.

There are multiple websites that allow regular users to download 3D files and print them. The biggest is the Thing verse which is the one that the makerbot is most compatible with [2].

For beginners or even consumers, downloading designs and printing them will be the most beneficial feature. This is expected to be the most popular option in the near future should this be a viable cost-effective way to replicate products. However, 3D printers are currently most useful for product designers, engineers, architects, and whoever needs to create a rapid prototype. This enables faster work iteration and also increases motivation within consumers especially in the learning stages.

The makerbot, as well as other 3D printers' uses a format called STL, which holds a 3D model describing only its surface geometry without any texture, color, or material attributes. This is an extremely basic model that can be edited with almost any 3D program, making it widely compatible and flexible [3].

Manufacturing Larger Structures

The makerbot's design is simplistic but allows building much larger structures by combining different small 3d-printed pieces.

3D printing can also be combined with other forms of production to make, such as, mass production chain molds which allows easy modification of the retail products the instant a problem is identified and the design is modified [4].

Decentralization of Production

The implications of 3D printing are obvious. Shipping costs will be reduced as manufactured products will be produced locally [5]. The business model-on-demand printing of customized products—has significant advantages over traditional retailing models [6,7].

The nature of Computer science is that it is extremely scalable specifically because though initial cost of designing is high, marginal production costs will eventually decrease. In Economics, as long as there exists a competitive market in production firms, the supply curve is mostly determined by the marginal costs [8] which set the price of products at the intersection with the demand curves. This means that, should marginal costs decrease, (due to 3D printers), only high fixed initial costs of designing remain, then the economy will evolve., Based on the theory of supply and demand goods could be provided on a larger scale especially to consumers who had no access to such products beforehand (Figure 1).

Moreover, centralization of production also implies centralization of power. This is reflected in the Communist movement decision's to centralize all production in the government and in current economic liberalism which also allows for a few corporations to buy smaller ones demonstrate the same effect: centralization of power in a few hands [9]. This centralization to a few people in the private sector is as dangerous as centralization of power in the public sector. 3D printers could potentially allow local empowerment [10] to occur,

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when citizens will be self-sufficient and eventually be able to stand up against monopolistic practices such as price fixing by big corporations easily. In addition, the wide application of 3D printing technology has separated product design and manufacturing, so designers need to constantly strengthen and improve their understanding of the design theory, its application and development creating a stronger interaction between designers and users [11]. A decentralized economy will be accompanied with globalization, increased communication, internet networks, free education and could lead to a freer society. Examples of this phenomenon can currently be seen since the introduction of computers and internet networks. It is expected that the advent of 3D printers will further amplify this decentralization.

Movement from a manufacturing-based society to a design-based society

Computer science has revolutionised the world through the lowering of marginal costs of replicating software. An increasing number of companies have been automatizing their systems, replacing low-skilled workers that were previously used to perform simple, repetitive tasks in the industry or company operations [12].

The Industrial Revolution saw manually-crafted products becoming industrialized and production efficiency improved tremendously, although not reflected into worker salaries. This revolution rendered many crafting jobs obsolete, and also created new jobs for workers to control machines and perform repetitive manual labor in a more efficient manner. However, the alienation of workers and the lack of necessary skill to produce, allowed salaries to decrease and being easily interchangeable. Human labor became part of a bigger mechanism which could not affect the system significantly.

Though 3D printers may aggravate this decentralization, further rendering manual labor obsolete, on the other hand, could lead to more jobs that reflect design-based production and the current consumption culture. Low-skilled workers will be rendered useless but production will be efficient that costs will decrease and will benefit even people who lost their jobs.

An issue that arises is that, newly unemployed workers will enter a new market for technically savvy designers and programmers having no prior education or related skills. Amplifying the income gap and create divergent income levels and inequality. Another potential consequence to consider is how this technology can prosper without hindrance of the law. Therefore technological advancement has to be accompanied by a system reform, unlike in the Industrial Revolution which can account for unexpected changes in the market and protect vulnerable people in the system. In addition, policy makers should carefully consider how the exclusive right of patent may apply to these new technologies [13,14]. Thingiverse, for example has imposed restrictions on intellectual property rights to ensure no liability [15].

As the market adapts, new generations of workers and students will self-educate due to widespread access to information online. With regards to physical 3d-printed tools, workers will learn how to design objects instead of how to manufacture them [16].

However, similar to the software development industry, the 3D design industry will allow for cheap replication of products. Consequently this will lead to a non-competitive market, one with conditions for natural monopolies to take place.

Competitive market firm

The above graph (Figure 2) reflects the typical production trend of companies in a competitive market in which an increasing marginal cost for each unit produced. This automatically regulates the amount of units or quantity produced, and allows other companies to provide the rest.

Monopolistic market firm

However individual producer graph (Figure 3) which shows every variable used to maximize profit and take decisions, depicts how the elimination of marginal costs will cause every design company's cost structure to mimic that of a monopoly and thus create an extremely high potential for monopolies taking over and setting higher prices for product designs, as experienced with some software companies.

Cultural Changes

Since the Industrial Revolution, cultures have evolved and shaped consumer demands. Consumers no longer value artisanal or hand-

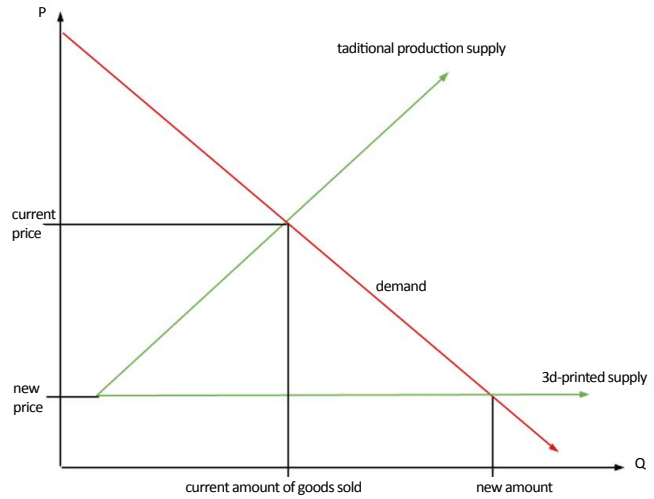

Figure 1: Graph representing centralization of production.

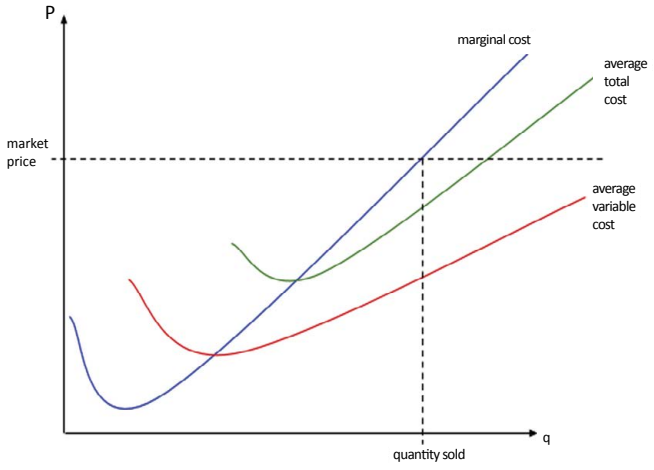

Figure 2: Graph reflects the typical production trend of companies in a competitive market.

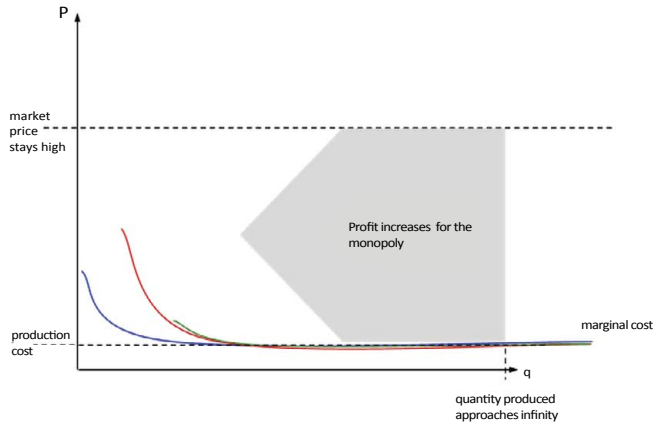

Figure 3: Individual producer graph which shows every variable used to maximize profit and take decisions.

crafted products. Popular culture seems to favour large multimillion dollar movies, video games or entertainment as well as any other form of industrialized art [17].

This is mostly due to the increased funds that can be invested in an industrialized product. It would not be surprising to find that 3D printers intensify this behaviour even more as many 3D artists have begun to include 3D printing in their art. Architects use printers to visualize their models and fashion artists are creating 3d-printed ornaments for dresses [18].

Another potential implication that 3D printing could have culturally is through history. 3d-printing has recently assisted in facial recreation of an Egyptian mummy [19]. Though the technology has not been perfected, it nonetheless opened up opportunities for archaeologists and historians to challenge and reinterpret existing narratives on history and culture.

Helping humans and the developing world

3D printers have already been used to produce customized prostheses, to print food [20], medicines [21], and to create human organs. Current experiments include printing proteins which could allow for DNA synthesizing, printing of biological materials for human [22] and animal enhancement. Firms are printing human lungs and liver tissue to run medical tests on them. The implication of this is that printing of stem cells could lead to complete organ reconstruction. In Sudan, the makerbot has allowed for customized prostheses to replace hands. This is a lot more affordable than the current alternatives that US citizens usually take [23].

With the use of 3D printers, a high school student was able to develop an inexpensive stethoscope from his smartphone. This would not have been possible previously, since the student would have had to invest large amounts of money to manufacture in a mass production chain [24] in order to make it an affordable product.

3D printing could improve sustainability of production, lessening the environmental impact [25] in developing countries which rely on heavy industrialization.

Weapons

The democratization of the means of production entails a widespread adoption of harmful tools. For example, there have been many incidents of releasing 3D plans for different kinds of weapons, from revolvers to machine guns. Mass media has over-exaggerated the implications, but in the near future it might be possible for the government to lose control over weapon ownership and thus could facilitate criminal activities [26]. Lawmakers have started the discussion whether to focus on gun control or narrow access to 3D printing technology [27,28].

On the other hand, weapons have been proven to allow oppressed populations to defend themselves and take over the government. Decentralization of weapons also decentralizes power, and minimizes the risk for totalitarian or oppressive governments.

Interviews

Chris Marion

Mechanical Engineering

(Dropped out of college and is currently working on a Startup making new 3D printer technology)

3/2/2014

What can you tell me about the history of the Makerbot, the most popular affordable 3D printer in the market today?

The patents for FDM technology expired around 2009. It made it possible for hobbyists to build 3D printers themselves. They stopped worrying about getting into legal trouble. In the beginning, the online community started making their own 3D printers. Makerbot has a long story. Founders of Makerbot (before 2010) were involved in a new open source community of hobbyists.

They were selling printers that were very similar to the ones you could assemble yourself. Makerbot started selling kits for DIY and also assembled kits that were all open source, which means anybody could modify the designs. They made a switch to closed source and a lot of people were frustrated. They became the “brand name” for DIY hobbyist type printers. They were selling them for $2000 and every other competitor was a lot higher in price. Now this has changed, and kits have become less popular as kickstarter played a big part on accelerating the 3D printer market.

What's good about the Makerbot?

The makerbot has a lot of added value for a newcomer. Experienced people will be disappointed by FDM technology (makerbot) and will prefer resin-based technology, which provides a much higher resolution.

Which other technologies exist and why are they better?

Stereolithography (SLA) is another technology that was originally invented by “3D systems”, one of the largest 3D printing companies - founded by Charles Hull, the inventor of SLA. In SLA, there is a resin or liquid based on polymers with certain properties such that when light at a certain wavelength hits the liquid, it solidifies. That is the basis of SLA 3D printing.

One of the problems that big printers have is that the object, once printed, might stick to the bottom of the glass, and the bigger the printer, the more force it will have and the harder it will be to take it off that surface. This is a big problem for scaling. We need to print bigger products.

I know that you are currently developing a new 3d-Printer product. How is this different from the already existing ones?

Our product prints faster, and allows more scalable versions. It does not have the suction issue, which means you can print products as large as you want and you don't run into sticking issues.

No matter the size of the object, as long as it fits inside the printer, it will take the same amount of time, because printing each layer projects an image into them to solidify some parts of the layer. No other technology can do all of this together. This printer allows for a much higher resolution: 20 microns. The smallest object that a human eye can see is 100 microns.

What are the best future uses of 3D printers that you know of?

Boeing is using 3D printers to make titanium parts for jet engines. This has reduced their production costs by significant amounts.

How did you come into this industry?

I was originally involved in the DIY 3D printing and fabrication Yahoo Group, an online hobbyist community, developing software that would make it easy to print 3D models in different printers without any kind of specialized programming knowledge that was necessary at the moment for most kits.

I made this software open source and a lot of people started using it around the world to create different projects. My partner Kurt met me through this group and community and asked me if I wanted to do this for money, I visited him in Los Angeles and when he showed me the proof of concept, I knew I had to work in this area, and agreed to stay. I'm now working in Los Angeles with him and another partner.

Do you think 3D printers will be the next revolution?

I don't think it is realistic to think there will be a 3D printer in every household in the next 10 years. There will be decentralized manufacturing. Maybe smaller factories spread all over the place. Products will be printed in shops.

In order to reach mass consumption, we need to print with multiple materials at once, in color and objects that are big enough to be useful. Once those are done, and it's easy enough to use, then it will become mainstream in households. The ability for people to create content quickly and easily is going to be a killer feature.

Will 3D printers replace traditional production chains?

It is very possible, especially because 3D printers use additive manufacturing, which means we only use as much material as is going to make up the model. Injection molding is efficient, but you still have to produce the molds. Molds are expensive. The cost of setting up a production chain is high.

Making changes in designs are more expensive. With 3D printers, you could create molds and modify them at a much faster speed. In the future, I think we will not be seeing additive manufacturing at high quantity. It shines at low quantity and up to mid quantity. 10000 units or above will be for conventional manufacturing only.

In your opinion, will 3D printers make our society focus more on design than production chains?

There's gonna be a point where the common user is not gonna be able to produce quality 3D design in the same way as a professional. There will be increased demand for freelancing 3D design, just like there was an increased demand for computer science after the computer revolution.

Do you believe 3D printers could be used for biotechnology or genetics, or making other kind of products?

Biotechnology and genetics are a lot more challenging. One, the typical materials you would use for an SLA is not biocompatible because they're toxic. You need to come up with new materials. There is a new research paper where people were using a vitamin as the photoinitiator to make it biocompatible and insert it into people. This could lead to more research in the area.

One of the experiments in biology gathered a team that took a pig's heart and removed all of the cells. All that was left was bone and cartilage. They added stem cells to it, and if you have the right hormone, they will attach themselves to the cartilage and remake the heart. The way the cells know how to attach themselves to the cartilage and bone is that there are markers in the cartilage that cells recognize and helps them understand what they should become.

We need to embed protein markers into the 3d-printed model so that stem cells know what to do. You can currently build organs that don't require a support (bones), such as liver or bladder. There is currently at least one company that supplies 3D printed tissues to pharmaceutical companies who need to try medicine on a human organ. This company prints a small section of a human liver to perform tests on, instead of going through the papers to perform tests on real humans. A high precision syringe can pop one cell at a time where they want it, similar to FDM technology.

You need to have a support system that holds the cells in place. This company is using biodegradable dissolvable sheets and they lay cell sheets and support sheets between each other to keep them isolated. You take that and put in an incubator at the optimal temperature and with the necessary nutrients. Cells will grow and join together, forming a cohesive tissue. The sheets are dissolvable and are no longer there. You could theoretically be producing complex human organs with that.

Also, when it comes to genetics, there is another method of SLA printing: two-photon stereolithography. It allows for much higher resolution, in the order of nanometers. The previous method used a single laser. In this, we use two lasers that make two photons hit simultaneously to trigger the chemical reaction to solidify the resin, It becomes more precise and uses a different kind of resin that allows it get smaller features. This has allowed printing proteins and could allow for printing our own DNA.

What cultural changes might we see with the popularization of 3D printing?

There are two schools of thought. The traditional artists, who want to stick with traditional media: sketch, paint, etc. where they say all forms of art should be coming directly from the human. The other school says “it doesn't matter what your medium is” as long as you're creating something that you see in your mind.

This other school is a lot more about creative expression in any form. I think 3D printers will help the current trend of moving towards the second school.

What are the risks of 3D printers in your opinion?

Some SLA chemicals are carcinogenic. If you come into contact with them too much, you'll become sensitized. You will develop a rush and can have an allergic reaction to them. These materials will be regulated by the FDA, right now it's unregulated. Those are the risks to consumers.

When it comes to social risks, there's this controversial area around weapon printing. 3D printing got bad publicity because the media

blew this out over proportion. The first story was about some group that released plans for making weapons, using either 3D printers or conventional manufacturing techniques.

Those plans were taken down but you can still find them on torrents or different parts of the internet. For a lot of those parts, you will still need an expensive high precision printer, and it would be cheaper for criminals to go buy a gun. The second story is somebody also developed plans that could be made with a $1000-printer, and could fire once.

There's always going to be crazy people trying to kill others, and they will always be trying to find a way to do so. There's really no way right now to prevent people from printing some parts.

Do you think 3D printers also pose a risk in the labor force, decreasing demand for low-skilled workers?

As this takes hold more and more in the manufacturing world, we won't see this right away, but a decade from now, we'll definitely see an impact. Factory workers will be replaced with manufacturing techniques.

You will be able to make items that previously required assembly in just one shot. It's going to change the way jobs are distributed and it's going to push more towards technical and design jobs rather than unskilled workers. Right now it's not an issue, but maybe in the future.

When computers were coming out, people were afraid of them stealing their jobs, but if you look at it, they created way more jobs than they stole. The current distribution of 3D printers is: majority in the USA, Europe is second, and developing countries almost don't have any, which means there could be a greater divergence in wealth and industrialization.

Matt Ridder, Political Science, Stanford University.

2/15/2014

What do you think is going to be the relevance of 3D printing?

I think 3D printers are gonna have a large impact. I don't think it will be cheap enough for most people to use it, but at this point in time it's pretty much unattainable. Down the road it will be more accessible. In the immediate, wealth concentration is a problem that affects 3D printing because not everybody can own one.

Do you believe 3D printing will help move towards decentralization of production, which could, for example, discourage monopolies and encourage innovation?

I don't think 3D printers will encourage innovation much, because people are already drawing plans, and making them is not a big impediment to their process. 3D printers might encourage students to pursue different academic paths because at an early age they might be able to see their inventions come alive.

In your opinion, will 3D printers make our society focus more on design than production chains?

I think we have been moving towards a design-based society for a long time. I don't think 3D printers are the piece that is gonna help us move in that direction. If 3D printers become more widespread, we might see a decrease in the employment of low-skilled workers, as 3D printers might create already-assembled objects and therefore make it unnecessary to hire low-skilled workers to assemble a product once the parts are produced.

What cultural changes might we see with the popularization of 3D printing?

I don't think we can predict cultural changes by looking at 3D printers. They usually rest upon many things that could contribute to the cultural change. 3D printing may very well be one of those factors. I think you'll see a group of society that feels more empowered, with computer science growing in popularity, and especially with the proliferation of the internet, this series of improvements in technology, including 3D printers, will contribute to the same empowerment than computers.

Is there a potential for this technology to help developing countries in, for example, health?

As far as biotechnology and medicine, I don't know enough to predict whether 3D printers could help in those areas. If 3D printers become very cheap, they could help in the third world. By making production cheaper, causing independence in households. More developed countries will get access to this technology first, so it could even widen the inequality gap between developed countries and underdeveloped ones.

What are the risks of 3D printers in your opinion?

The most obvious risk is the printing of guns, down the road. At this time, it doesn't seem to be an issue. I don't believe 3D printers will make it that much easier for terrorists to create dangerous weapons, because they need to be of a decent size, a lot bigger than what 3D printers can achieve.

Todor Markov, Symbolic Systems, Stanford University.

3/15/2014

What do you think of 3D printers?

3d printers have the potential to make the manufacturing cost for different vital objects smaller and vastly increase our production capabilities and GDP. It also has the ability to create things in a really small scale such as cells and circuits and opens new possibilities in things such as electrical engineering or computer science and synthetic biology.

Do you think 3D printers will make production decentralized?

For some materials, yes. If the material you're using is common, you can download the design and print anywhere, but if it requires rare metals or special biological materials, obtaining them might be difficult, so even if the design is online, only a specialized lab will be able to create the product.

What impacts do you think decentralization of production could have in the world?

It would put out of business a lot of big retail chains and food, cosmetics, clothes or common items will become obsolete because people will be able to download the design and 3D print it. It will also mean that lots of people who are working in low-middle jobs in these areas might lose their job. That sector is going to decrease a lot and there will be a bigger market for design rather than manufacturing.

Do you think that's similar to the Computer revolution?

I think so, but a better comparison would be the first or second industrial revolution, because both of those massively increased our manufacturing capacity, which is also what well-made 3D printers are going to do, while computer mostly increased our capacity to process information. 3D printers have obvious applications in designing smaller circuits which production of smaller and more compact computers and

smart devices, and also computer software will most likely make design creation much easier.

What cultural changes do you think might happen?

I think that mass proliferation of 3D printing will lead to, on the one hand, mass increase in production, and on the other hand a big reduction in the basic and middle level jobs that most people are employed in right now which will necessitate the government system to change to something with more wealth fare and help like the Scandinavian government, where even people who are unemployed have a fairly high standard of living, and it would also mean that a lot of people would be working on creative design for different fields. I think it will also lead to a more decentralized state because people will be able to provide their basic needs by themselves.

Do you think printers could be used for biotechnology or genetics?

I think so. Even now we have examples of 3D printers being used to create lung and liver tissue, so I'm thinking that this application is only increasing in prominence as the technology improves. One possible application would be to use a person's own tissue as a sample and from it, grow different organs for transplants, which would make the whole process much cheaper. It would also eliminate donor versus receiver compatibility issues. Rich people are going to have an advantage initially, but history has shown that technology eventually spreads top-down and it's more efficient to use this technology, for example, to make someone live from 50 years to 90 years instead of applying it to someone who's 90 to make him live until 130.

You get diminishing returns the more you try to push the boundaries, and since people's quality of life are closer to that boundary, it will be harder for them to push it using this technology, while it will be a lot easier for poor people to catch up.

Do you think 3D printers can help developing countries?

I think 3D printers offer an opportunity for developing extremely cheap food and medicine, and will help a lot in regions that are suffering from different epidemics that will be prevented if there is enough medicine.

What are the risks that you see in 3D printing?

One potential risk is it being used for manufacturing weapons, which is actually already happening. This would increase the possibility for regional conflicts around the world, especially in the third world, and would most likely increase the percentage of violent crimes, but on the other hand, wide availability of fire weapons can also in a way help people increase their safety with collective militia-type organizations, where people work in their local community to oppose the order, so there's uncertainty about what effect cheap-manufacturing of weapons is going to have on society as a whole.

Conclusion

Although traditional forms of manufacturing will likely remain necessary for mass manufacturing, 3D printers has allowed for designers to prototype products much faster and innovate without the need for a factory. In addition, the introduction of 3D printers has changed how conventional innovation occurs, creating opportunities for a wider public change. Therefore, it is expected that large improvements in designs will occur, and society will continue relying on large-scale manufacturing factories for mass production, a shift to a new Industrial Revolution.

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