3D Printing and its Regulation Dynamics: The World in Front of a Paradigm Shift

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Abstract

3D printing is increasingly being considered capable to do for manufacturing what the Internet did for information. While the technology is already being deployed, limited studies have been advanced on its anticipated effects. After offering a "primer" of the emerging technology in question, this paper continues by elaborating on its possible impacts in architecture, aesthetics and design. It then attempts to map its impact in the political, economic, industrial and social spheres. The paper concludes by advancing a discussion on the different regulatory approaches that could be adopted, along with the relevant key concerns.

Keywords

3D Printing; Additive Manufacturing; Architecture; Creative Destruction; Design; Paradigm Shift; Regulation; Safety; Security; Social Transformation.

1. 3D Printing: Upcoming Industrial (R)Evolution?

It is impossible to fully foresee the implications of any emerging technology ex ante. For instance, it would have been impossible for the creators of ARPANET to envision the current state of the Internet and the way in which it has affected almost every aspect of our daily lives, let alone its economic impact. 3D printing (or additive manufacturing), a technology which was previously used for modeling and prototyping, is now considered by many to be a "physical analog" of the Internet, in the sense that has the potential to usurp traditional production.

As Campbell et al (2011) note, 3D printing is a truly revolutionary emerging technology that could up-end the last two centuries of approaches to design and manufacturing, with profound implications in the geopolitical, economic, social, demographic and security spheres. Many claim that 3D printing makes it equally cheap to develop single items as it is to create thousands, and thus manages to undermine economies of scale, causing dramatic changes in social and economic evolution. It may, thus, have as profound an impact on the world as the coming of the factory, bringing forth a new industrial revolution.

Of course, competing claims exist, often included in the very same studies. Susson (2013), for instance, while initially forecasting a new industrial revolution because of additive manufacturing, then goes on to claim that “3D printing is not likely to replace traditional manufacturing methods for most applications - it simply takes too long to print individual objects to make it cost effective on a sufficiently large scale”. This might initially seem problematic, however it is quite normal to witness such discrepancies for a technology in its initial stages.

How initial, of course, remains to be seen. A 2010 Ganter report identified 3D printing as a “transformational technology” in the Technology Trigger phase of the Hype Cycle, i.e., only 5-10 years from mass adoption (Fenn 2010). Thus, 3D printing is indeed *ante portas*. However, only a limited number of studies have focused on its potential implications from a political, regulatory, and social standpoint.

2. Additive Manufacturing and 3D Printing: A Primer

Traditional manufacturing was the driving force behind the industrial revolution, while, as Ashford et al (2010) note, the industrial revolution was the historical turning point in sustained increases of GDP per capita, which up until that point fluctuated instead of increasing. Of course, manufacturing has in itself progressed significantly in the previous decades, significantly “detaching” it from its French etymology, which literally means “made by hands”. Today’s manufacturing increasingly involves the use of machinery, robots, computers etc. What is essential to understand is that these technologies are “subtractive” techniques, which means that objects are created through the subtraction of material from a work-piece (Campbell et al. 2011). Thus, final products are dependent on the capabilities of the tools used in the subtractive manufacturing processes (see Table 1).

Additive manufacturing is a group of emerging technologies that make objects from the “bottom-up”, by adding layers of material in cross-sections, a process similar to creating objects by blocks of Legos (albeit, smaller). The process starts by having a 3D model of the object that will subsequently be printed, typically through the use of computer-aided design (CAD) software. Thus, 3D printing, in simple terms, is a technology that allows one to transform a digital file to a physical object. Thus, we can now print real objects in three dimensions, depending of course on the capabilities of the printer.

So far, several additive manufacturing processes have been advanced, differentiated by the manner in which they create each layer. Campell et al. (2011) include a series of such techniques. “Fused Filament Fabrication”, for instance, involves extruding thermoplastic or wax material through heated nozzles to develop a part’s cross-sections (Campbell et al. 2011).

3D printed shoe by Z Corporation

3D print context models by AEC

3D printer designed by E. Dini, capable of creating buildings from stone

Monumental Architecture with 3D printing by N. Ervinck

3D prosthetic limbs by S. Summit and K. Trauner

Red rock guitar prototype by D. Manson

3D printed headphones by B. Garret

3D printed models of dental parts by Glidewell Labs

Full size 3D printed polymer motorcycle

Le Mans race engine built by Aston Martin using 3D printing technology

3D printed bicycle by EAD

Table 1: Indicative samples of 3D printing

Other technologies range from jetting a binder into a polymeric powder (3D printing), using a UV (ultraviolet) laser to harden a photosensitive polymer (Stereolithography), to using a laser to selectively melt metal or polymeric powder (Laser Sintering) (Campbell et al. 2011).

The key lies in the capabilities of the printer to make use of certain materials, and in what level of craftsmanship. Recent developments in the synthesis of end-use products indeed allow for increasing numbers of materials to be used simultaneously. One could think of a normal printer with several different cartridges, printing simultaneously, but instead of ink making use of materials, such as metals, plastics, etc. in each cartridge.

Additive manufacturing processes, of which 3D printing is a subset, offer significant advantages. First, they entail reduced waste, when compared to subtractive manufacturing. Second, additive manufacturing makes it possible to create functional parts in a decentralized fashion, without the need for assembly, thus offering distinct advantages in time and cost. Finally, additive manufacturing processes have the capacity to create advanced geometries that are not feasible by any other means, thus offering significant geometrical freedom in engineering design (Campbell et al. 2011).

While initially additive manufacturing and 3D printing were considered emerging technologies mainly used in prototyping, i.e. the fabrication of conceptual models of new products for form and fit evaluation, such as 3D models of buildings by architects, processes appear to have already drastically improved, and 3D printing is increasingly being used for the creation of parts for functional testing but also even end-use parts. Furthermore, 3D printing is used for the development of automobile and aircraft components but also in custom orthodontics and in the creation of custom hearing aids. Generally, most of us have already encountered 3D printed objects, even if we do not yet quite know it (Susson 2013).

A basic 3D printer is currently less expensive than what a laser printer was in the 80's. Currently, one can purchase a desktop 3D printer for less than $1000 (Susson 2013). Because of this low price, interest in 3D printing has escalated as an increasing number of hobbyists are able to interact with the technology. In essence, this process is democratizing manufacturing in a way similar to how information was democratized in the Internet.

3. Design, Aesthetics, Architecture

3.1 Society and Space from a New Perspective

3D printing, as a new form of manufacturing, will cause various changes to social balance and, consequently, to the way we perceive space. The beauty of this technology is that it does not need a factory to be deployed. Small items can be made by a machine like a desktop printer in the corner of an office, a shop, or even a house. Bigger items (bicycle frames, panels for cars, aircraft parts, etc.) need a larger machine and a bit more space. Therefore, industrial space may no longer exist in the currently known form.

This is a disruptive and transformative technology, because it means that as 3D printers develop, big factories will be rendered gradually obsolete; production can be localized - if not domesticated - instead. Many goods that have relied on the efficiencies of large and centralized plants will be produced locally and we might possibly witness the rise of 3D printing shops, where anyone can get their design ("product") printed. Eventually, rapid prototyping technology has the capability to undermine the need for centralized mass production.

All above mentioned observations lead to the conclusion that 3D printing has the capacity to decentralize business, perhaps reversing the urbanization that accompanies industrialization. Furthermore, additive manufacturing will affect the relation between public and private space. Production areas will no longer involve mass spaces, such as factories, but small businesses, offices, and houses. Manufacturing will further enter the private space, thus creating a new perception of working and personal places. This fact might agitate the balance between public and private space.

This revolutionary technology offers infinite opportunities and makes production easier, but at this point it appears to be rather anarchic. Manufacturing requires security, thus printers and 3D printing machines have to be regulated if not controlled, so as to avoid creation of products harmful to the society. Therefore, production security will have to enter the private space, creating a system where private life - which will be inextricably connected to manufacturing - might end up receiving a new set of potential threats (see Fig. 1).

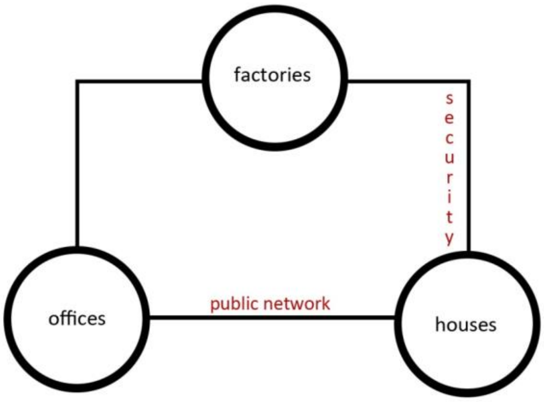

Figure 1 A generic perception of an alternate manufacturing Space

As design is the key to unlocking the potential of this technology, information needed for the production of objects will be found on computers. That creates the need of a network that contains designs and software, a public network that will be used by every small or big business and individuals, introducing a huge public digital space.

3.2 3D Printing: Revisiting Aesthetic Values

3D Printing is expected to create innovative products with new shapes and forms, influencing strongly the aesthetic values of our society and - in the long run - expanding the realm of industry and imagination. With this new technology, if you can design a shape on a computer, you can turn it into an object. Additive manufacturing enables designers to experiment with new bespoke solutions for products, because trying out new products will become less risky and expensive. Therefore, it improves the ideation process, which before was constrained by costs.

Companies, too, can make experimental investments without having to do full return on investment cost benefit analysis. Therefore, creativity will be further developed allowing us to explore human needs at a deeper level. Consumers could no longer be regarded as a mass. Personal needs will be emphasized, which leads to a new and personalized type of industry.

Creativity in meeting individuals' needs will come to the fore, just as quality control did in the age of rolling out sameness. Home users will have all they need to develop prototypes. People will be able to design new products just by using their 3D printers and software, so mass and social orders will be undervalued and, instead, we will view an emphasis to individuals' personality, needs and aesthetic values. Furthermore, goods will be infinitely more customized, because altering them will not require retooling but only tweaking the instructions in the software. Each item can be made slightly different at almost no extra cost, because each is created individually, rather than from a single mould, changing the impersonal face of nowadays industry. Consumers' ideas can come to life through 3D printing and allow them to fully illustrate their ideas to companies via feedback.

3D printing allows new unusual shapes to be made. We will be able to build shapes that you could not mould cast or forge - pieces that we could not make in any other way but through additive manufacturing. Additive manufacturing allows the creation of objects in shapes that conventional techniques cannot achieve, resulting in new, much more efficient designs. It can, actually, achieve fine detail and difficult geometries inconceivable with old-fashioned "subtractive" methods such as woodcutting or carving and it affords possibilities not available through conventional fabrication methods. Therefore, it enables designers to experiment with new bespoke solutions for products.

3.3 3D Printing in Architecture

The emerging technology in question is also ushered in Architecture, changing completely everyday life. We are introduced to a new way of creating not just scale models of buildings, but also the actual structures themselves. Additive manufacturing offers the opportunity to print whole buildings. 3D printed buildings not only are made based on a new revolutionary technology, but also their structure is innovative.

With this large-scale technology we will be able to build whole buildings including all the conduits for electrical, plumbing and air-conditioning, at one time. Furthermore, by taking out the need for extensive labor printing could cost about a fifth of what traditional construction methods cost today.

Imagine if this technology were applied in developing countries, especially where lumber is scarce. Slums could be eradicated. Instead of living in tents or cardboard boxes when natural disaster strikes, victims could be provided what is described as "dignified housing" - and fast. With poor communities particularly vulnerable to destructive natural disasters, and about one billion people already living in slums, 3D printed homes could be a dignified solution to an increasingly desperate global situation.

3D printing could not only offer relief to millions of urban dwellers, but even empower the architect by liberating her from the traditional restrictions of reality. This technology is an additive (formative) rather than a subtractive process. It does not wastefully chip away at existing material - it forms impossible materials in impossible geometries. We are now confronting a future where homes themselves respond naturally to the environment around them, whose energy-efficiency and sustainability are a natural consequence of their form.

Figure 2: Design of a 3D printed house (www.dezeen.com)

Therefore, design and architecture appear to face a new era, where designers will have to evolve. The increased ease and decreased cost of construction could mean that the design itself will determine the value of the home, which the customer could purchase online and download.

4. 3D Printing and Social Transformations

One may claim that 3D printing includes several characteristics which tend to maximize social benefit (Portes 2000). The question that arises refers to the facts that could turn 3D printing into a hegemonic form of production. First of all, an individual shall be able to produce everyday items by utilizing solely the triplet "3D printer - raw material - digital design of the product" while this could take place domestically. Second, it is possible to personalize each object and, thus, highlight each person's individuality, which could further motivate an individual towards utilizing the 3D printer at its full potential (Reeve 2001).

3D-printing could be accused or favored on the basis that it further promotes individualism. However, this is partially true, since one may detect circumstances and parameters that could promote social collaboration or even utilization of this technology in a collective manner. Given the fact that the possibility of printing a house does exist, one could propose a municipal or even ad-hoc collaborative environment of a housing 3D printer usage. Taking into consideration that an individual, or a family need one house to live in, the cost of owning a house 3D printer may sound irrational. However, in a municipal scale, this could maximize societal gain. Under the prism of collaborative 3D printing technology exploitation, one could easily detect issues that would promote democracy, since small communities owning large house 3D-printers have to agree on the usage priority, cost management, aesthetics of the public space etc.

With regards to the economic aspects of 3D printing, the first consequence of the analysis above entails the transformation of tradable goods into commodities. For example, there would be no need for someone who owns a 3D printer to buy plates, bottles or other everyday objects, unless if there is a specific property about a certain commodity that justifies it, such as its sentimental value, branding issues etc. Thus, several areas of traditional manufacturing and trade will struggle to survive, causing a snowball effect on international political economy and the society more broadly.

The exact nature of social transformations that 3D printing will entail will most certainly be extremely interesting to watch and even more difficult to predict. Furthermore, several questions arise, such as the evolution of the working environment after a collapse of the traditional labor paradigm. Society may face the further emergence of new classes, like the *precariat* (Standing 2011). This could be closely linked to the issue of the availability of 3D printing, raw materials and designs.

5. Political, Economic and Industrial Impact

5.1 Geopolitics

Since it is extremely difficult to foresee the micro-implications of 3D printing beforehand, one could claim that such an approach would be even harder for the macro-implications in economics and geopolitics. Nonetheless, some initial thoughts have started to emerge. Campbell et al. (2011) note that through the extensive use of 3D printing, manufacturing could be pulled away from today's traditional manufacturing states, such as China, and be brought back to the countries where the products are consumed. According to this line of thinking, such a development would play a significant role in reducing the economic imbalances (current account surpluses and deficits), because export countries surpluses would be reduced and importing countries' reliance to imports would shrink as well (Campbell et al. 2011)

However, while such a displacement could potentially be envisioned, in reality it would depend on two factors. The first one lies in the true potential of the technology with regards to its capability to sustain economies of scale. In the context of the same study, Susson (2013) makes two competing claims: While originally stating that "3D printing now makes it as cheap to create single items as it is to produce thousands, which may have as profound an impact on the world as the coming of the factory did", he then goes on to say that "3D printing is not likely to replace traditional manufacturing methods for most applications – is simply takes too long to print individual objects to make it cost effective on a sufficiently large scale". So, which is it? Is 3D printing a proper means for prototyping only or could it really displace the factory and have significant macro-effects in the economy? One could make the case that the former claim describes the contemporary reality, however as the technology advances it could be expected that 3D printing becomes increasingly cost-effective.

The second factor involves the availability of material inputs for production. If we attempt to envision a future where 3D printing becomes the norm and production is brought back from the East to the West, for the current account imbalances to fully recede one would need to guarantee the availability of material resources domestically. Currently, commercial 3D printers can utilize only certain materials: plastics, resins and metals, and print with the precision of approximately a tenth of the millimeter (Susson 2013). However, many scholars increasingly make the case that in the future there are going to be 3D printers that will allow one to create 3D structures out of living cells, building rather complex structures, such as blood vessels, skin tissue or even heart valves and organs, while researchers from MIT are working on printers that allow users to print food. It thus becomes clear that for 3D printing to fully roll-back current account imbalances, the availability of material resources that will be used in additive manufacturing will be critical, and might create its own new set of imbalances as needs shift.

5.2 Production and Manufacturing

Even though additive processes have been available in the market for decades, we are seeing their widespread adoption only recently. With the capability to efficiently manufacture customized goods through 3D printers, one might envision that local manufacturing could start making a return to developed countries. Indeed, 3D printing has the capacity to dramatically reduce costs related to production, packaging, distribution and overseas transportation (Campbell et al. 2011). The process itself, however, has the capacity to drive a change in tastes, namely a transition from mass production to mass customization, in which each item produced is customized for the end user at little or no additional production cost.

The pace in which the technology is expected to develop is, of course, uncertain, and it will probably vary widely for different types of products (Campbell et al. 2011). This means that many consumer products may still be cheaper to mass produce through traditional methods and shipped to points of consumption for a long time, despite the introduction of 3D printing.

The key question here is at which point will a product as complex as a laptop or an engine will be printed in a single process? Campbell et al. (2011) note that for such products, the shift will be in spurts, as certain parts are increasingly being printed and then assembled in a traditional fashion, but with a declining number of individual parts to be assembled. This process will gradually lead to a decline in the costs of production, and, thus, supply chains will increasingly be simplified and shortened.

Furthermore, the increasing adoption of 3D printing should be expected to lead to less unnecessary products, as most products will increasingly be printed on demand. This will significantly resemble the «Just-In-Time» management philosophy of making only «what is needed, when it is needed and in the amount needed». Rendering inventories unnecessary will lead to having fewer of a final product printed, with important monetary and environmental benefits. Printing will, thus, be on demand, in a fashion similar to the transition from traditional books to e-books (Campbell et al. 2011).

As we increasingly speak about printing large items, such as a house, the key question will lie in the size of the printer. There are already companies working on printing small residential buildings, while Airbus is developing 3D printing to print entire wings of airplanes (Campbell et al. 2011).

5.3 Employment

Creative destruction is a well-known term, coined by Schumpeter, in order to describe how innovative products and processes displace old ones in the context of a dynamic market economy. In reality, Schumpeter considered the forces of technological competition and innovation to be the locomotives of capitalism, contrary to the traditional model of price competition and equilibrium, advanced by traditional economics (Ashford et al. 2011).

As Ashford and Hall (2011) note, in the classical literature one meets two types of innovation, i.e., product and process innovation. A product innovation occurs when a new product is developed and launched in the market or an old product is changed in a radical way. A process innovation involves an improvement in a product without significantly changing its final characteristics (Ashford and Hall 2011).

The distinction between product and process innovation is very significant vis-à-vis their impact to employment. Namely, in the context of the impact of creative destruction with regards to employment, product innovations destroy jobs but also create new jobs, as new products are advanced that require new talented workers. To the contrary, process innovations typically destroy jobs, even though they can have positive microeconomic effects, possibly through more competitive prices. Nonetheless, the effect of process innovation on employment can be very significant.

In this context, is additive manufacturing, and more specifically 3D printing a product or a process innovation? While a 3D printer does indeed constitute a new product, the function that 3D printing can serve in the future can fully displace a series of employments in the manufacturing sectors, thus destroying a significant amount of jobs. The limited literature on this seems to concur: Campbell et al (2011) claim that "reduced need for labor in manufacturing could be politically destabilizing in some economies while others, especially ageing societies, might benefit from the ability to produce more good with fewer people while reducing reliance on imports". Thus, it seems that 3D printing might have a similar effect to the one that computers did with regards to displacing labor.

More broadly, it can be expected that 3D printing will boost the direct relationship between the designer and the product, a relationship that was strained after the industrial revolution, and will render it similar to the relationship between software developers and their products. As a result, this might spur interest in engineering and industrial design, in a similar fashion to what happened in the field of computer science over the past decades. Simultaneously, 3D printing is expected to create new industries and professions, such as the production of printers itself, from the production of individual home printers to the creation of manufacturing centers, printers in local stores and relevant government agencies (Campbell et al. 2011).

5.4 Health and Nutrition

The medical implications of 3D printing technology appear to be astounding. Susson (2013) notes that in February 2012, the Belgian firm LayerWise announced that doctors successfully implanted an entire replacement titanium jaw it had produced for an elderly woman who suffered from progressive osteomyelitis. In March 2013, American medical doctors surgically replaced seventy-five per cent of a patient’s skull with a custom-made 3D printed implant (Susson 2013). At the same time, certain companies use additive manufacturing techniques in order to create custom braces for hundreds of thousands of patients across the globe. Specifically, osteolithography is used to fabricate molds from 3D scan date of each patient’s dental impressions (Campbell et al. 2011). Finally, other companies make use of laser sintering in order to quickly fabricate custom hearing aids, based on 3D scans of impressions of the ear canal.

Susson (2013) also notes that researchers at MIT are working on 3D printers that allow users to print food. The idea is that such a technology will employ certain input materials and will then be able to replicate the most elaborate recipe of the most famous chef. As the technology progresses and has the capability to include an increasing amount of input materials, produced recipes will become more sophisticated, thus potentially disrupting not only domestic food preparation but also, perhaps, the restaurant business more broadly.

5.5 Environment

3D printing might significantly help with regards to meeting environmental and resource preservation goals. First of all, as production is shifted to the places where consumption is occurring, it is expected that the transportation and manufacturing carbon footprint of many products can be reduced, as designs, rather than products, will now be shipped internationally (namely, digitally rather than physically). The carbon footprint will be further reduced by the diminishment of complex supply chains of parts produced by a significant amount of suppliers scattered around the globe, while the total energy required for the production of any final product may also be reduced, depending on the previous complexity of its manufacturing process (Campbell et al. 2011).

3D printing is also expected to reduce waste in the manufacturing process by the very nature of additive versus subtractive manufacturing, as the latter has lower resource productivity by definition. In fact, the printing process has almost zero waste. At the same time, the waste of excess or unsold production will also be eliminated, as well as the cost of storage of inventory (Campbell et al. 2011).

5.6 Security and Safety

Most of the headlines that 3D printing has produced thus far lie in areas relevant to homeland security. The reader must have already pondered on the capability of an individual to print potentially hazardous material. The simplest case would lie in printing a simple firearm, a case which appears to have already taken place in more than one occasions around the world, as several individuals have already printed and assembled firearm components (Susson 2013). Susson notes that a Texas resident and his nonprofit organization, Defense Distributed, 3D printed the lower receiver portion of an AR-15 rifle and successfully fired off over 600 rounds, while, within days, the man acknowledged that already more than 10,000 people had downloaded the CAD file with the blueprint for the AR-15 lower. So far, US Federal Law does not prevent an individual from manufacturing her own firearm for personal use.

Figure 4: A 3D printed gun

The discussion on 3D printed firearms raises the question of what different weapons could be developed through the use of 3D printers. How easy would it be to develop a traditional bomb, for instance? What about chemical or even nuclear weapons? The capacity to develop such capabilities would depend on the availability of relevant designs, along with that of material inputs.

However, the very notion that such technologies could become increasingly more accessible through 3D printers raises significant concerns about the proper monitoring and regulation of the technology. This might be also seen in connection and relation with the emerging threats raised by the wide use of social media (Kandias et al 2013).

6. Regulating 3D Printing

Thus, 3D printing introduces a series of vast transformations both in social and economic life. This technology offers the ability to build from trivial customs (commodities) to complex components, such as aerospace objects. It threatens to transform the industrial space and condemn big factories to cease to exist, at least in their current state. 3D printing shops along with the new personalized production could deter artisanship and threat the urbanization that accompanied industrialization.

Furthermore, public discourse has already pointed out a series of issues through which daily life can be affected by 3D printing, often in a manner that raises debates on whether this market should be regulated or not. As with any emerging technology, the manner through which it will be regulated by the state is expected to significantly affect the way in which the technology will develop. It is to be expected that 3D printing will surely spur wild streaks of innovation and creativity, alongside the protectionist and defensive efforts content creators and others will exert to protect their rights and their already established business models that will increasingly be put under threat.

6.1 Why Regulate 3D-Printing

Across the planet and especially in the citadel of capitalist economies, the United States, there are certain fields that showcase the demand for proper regulation. First of all, there is the area of health and nutrition, where, for example, the Food and Drug Administration (FDA) ensures the appropriateness of food and medicine sold and produced in the U.S. The FDA issues several doctrines and standards regarding food ingredients, dangerous compounds, medical efficacy and tobacco products adequacy. Furthermore, the airwaves, being treated as “public space”, are regulated by the Federal Communications Commission (FCC), both in terms of spectrum allocation and in those of the broadcasted content itself.

Another U.S. regulator is the Federal Trade Commission (FTC), which exists in order to protect consumers from unfair market practices, maintain competition and dissuade price-gouging and monopolies. Another such regulator Environmental Protection Agency (EPA) which deals with the safety of air and public waterways by preventing anyone from unleashing dangerous or hazardous material to the environment.

In order to generalize the above examples, the need for regulation emerges in free markets, when one or more factors of following exist (Dunford 1990): a) market failures such as monopolies, inability to provide public goods, inadequate information in the market, undesirable externalities and cartelization b) the problem of irreversibility, where a certain type of conduct from present generations could lead to irreversible results for the future generations, c) code of conduct and professional ethics, in order to set the barriers in certain professions and highlight a certain way of behavior and professionalism, d) public health, e) labor and workforce issues, f) environmental protection, g) national security and safety and h) several reasons per case, industry or societal parameters.

In the case of 3D printing one may spot that a lot of factors pointing towards regulation do exist. In the case of health and nutrition, as already mentioned, it will be possible for the users to manufacture medical instruments, food or even drugs. So what about these home brewed medical supplies? How can one be sure of their safety and suitability? What would happen with the phenomenon of drug overuse? What would be the implications in modern medicine?

Furthermore, in what concerns industrial relations along with the workforce and the labor code, a whole new world of transformations is enabled by 3D printing. As stated previously, it is possible for current industries to differentiate in a more decentralized fashion. Commercial goods will be transformed into commodities, new industries may rise and the phenomenon of creative destruction may be triggered. Regarding the affected industries, it is not clear yet which among then them will be disturbed, which form the market will adopt and what could happen with the unaffected industries. Interesting questions arise in terms of emerging monopolies, the ability to provide public goods, which good could be considered as “prime”, market information, externalities and cartelization. According to the analysis of section 5.1 concerning geopolitics, one is able to envision a domino effect in international affairs and the global economy.

In the areas of national security and safety, potential controversies become even more profound. Some US States have already started the process of regulating the 3D printing of guns, while some of the pioneers in 3D printing dictate the need for regulation in raw material (namely gunpowder) instead of printing designs or results of 3D printing per se. Another parameter, slightly harder to detect, is the repudiation of liability; namely when a 3D printed object causes injury to an individual, who is it to blame, the design, the 3D printer, the raw material, the manufacturer of the printer or the owner? What would be the results of a faulty but highly utilized design?

The analyses quoted in section 5 further highlight another series of life parameters that are affected either in an individual or in an international manner. However, they all lead to some core controversies; the decentralized way of production seems to be the essence of 3D printing. One may imagine the way of developing a municipal, for example, structure as a peer-to-peer protocol, where each of the citizens contribute one part of the structure in order to form the result. This way regulations seem to violate not only certain aspects of social benefit, but also the very essence of 3D printing. On the contrary, how could it be possible to protect all of the aforementioned aspects of daily life?

This question leads us to the second controversy, which is dictated by the demand for security and its conflict with freedom. Production security will threat entering the private space which could lead society to demand certain regulations in order to preserve the highest freedom/security ratio possible. This reasoning contradicts the need for a huge design repository which will broaden the public digital space along with societal collaboration.

6.2 Goals of Regulation

So, the initial view of 3D printing along with current concerns on security and safety do highlight a need for regulation, at least during its first steps or its prime adoption phase. In terms of the scale of the effects of 3D printing in science, knowledge, society and economy one may exclude quite safe results, however the results per se are hard to predict. This leaves open the question of how to approach this technology from a legal and regulatory basis. Tightening existing intellectual property protections vis-à-vis 3D printing may discourage innovation, while embracing an open-source laissez-faire ideology might promote piracy (Susson 2013). Thus, this entails a delicate balancing act, between intervention and laissez-faire, between innovation and security externalities. The 3D-printing activity of a single object demands the existence of a printer, raw material and the design. Thus, these are the parameters under regulation and a policy is to choose which model of regulation best fits it needs.

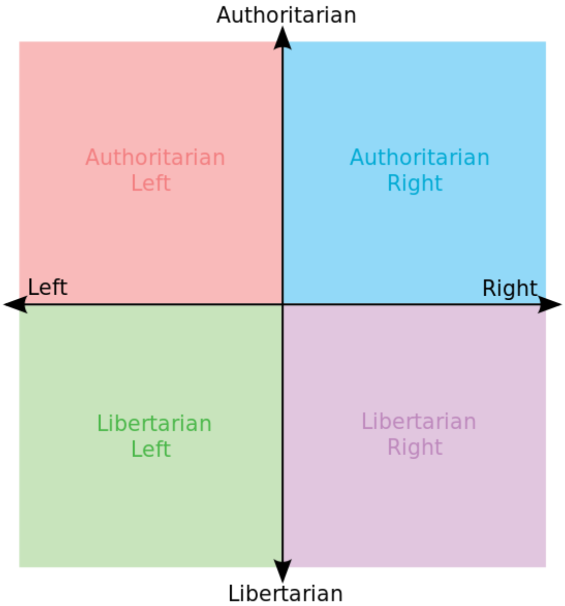

Figure 1 A generic modern political axis (Ray 2002)

With regards to the activity to be regulated and the available choices one may develop a certain set of “models” of regulation. Obviously, the choice is in reality a continuous challenge rather than a static result, driven by various variables such as economic growth, social benefit, historicity, ethnic differentiations, culture etc. Table 2 refers to a number of different social attitudes on how to regulate 3D printing based on existing commentary on regulation and deregulation which best fits the exquisite parameters of 3D printing (Jordana et al. 2004 ; Peltzman et al. 1989).

The innate reflexes of our society could be considered conservative in comparison with the transformations that 3D printing introduces. The most sensible reaction from our society would be a harsh and restrictive regulatory frame, in order to preserve homeostasis. Given the aforementioned radical changes, it is possible, if not certain, that strict rules will be proposed in order to confine the usage of this technology.

However, the complexity, the expected ripple effects along with the difficulty to predict societal responses forbids certainties and obliges the researchers to move towards trends or generic models. To this extent we utilize a modern political axis (Ray 2002) and existing regulation models in order to highlight tendencies that societies, regulators and industries could take into consideration in the process of regulating 3D printing.

The five general categories of 3D printing regulation rely upon specific parameters. The first is the level of interventionism from the authorities (authoritarian vs. libertarian point of view) which dictate the amount of liberty posed on the second parameter, which is the object of regulation; namely the triplet printer-material-design. Secondary parameters have “contaminated” the view of the basic parameters, such as the technological gap (technophobia vs. technocracy), social benefit, economic growth (development vs. depression) or even shadow prices (Heckman, 1974) as a derivative of the creative destruction, labor transformations etc.

	REGULATION FOCI		
SOCIAL ATTITUDE	**3D Printer**	**Raw Material**	**Designs**
Authoritarian-Technophobiac	Allowed only in mass production. Disallowed for individuals.	Allowed. Regulated only in mass production.	Allowed only after approval.
Libertarian-Unregulated	Not regulated. Ownership allowed. Unregulated for individuals and mass production.	Not regulated. Ownership allowed. Mater of demand and supply laws.	Unregulated. Unpatented. Free to use and produce.
Libertatian-Pro-Development	Not regulated. Ownership allowed and unregulated for both individuals and mass production.	Regulated only for hazardous materials	Regulated for illegal objects.
Authoritarian-Social-Benefit	Regulated. Personal usage limited to specific objects. Mass production limited to social demands. Municipal ownership only for specific purposes.	Regulated for hazardous material. Differentiated for ecological reasons.	Regulated to offer only the allowed according to the usage limitation of the 3D printer. Patent approval applies.
Mixed	Unregulated	Regulated for hazardous material. Laws of supply and demand apply.	Regulated only for banned objects (guns, patented objects, etc.).

Table 2: Social attitudes and 3D regulation foci

In terms of effectiveness, regulation is about producing the intended and desirable effects. To this extent, one is able to spot a series of tussles between the aforementioned regulation parameters. The classic model of production is in conflict with the forthcoming manufacturing transformation posed by 3D printing. Society is in front of a choice, will it value security over freedom or not? Every aspect of societal and economic life is to either battle towards homeostasis or accept the new and encapsulate it.

This reasoning highlights a serious challenge, that of democratizing manufacturing which, in an ontological level, is a commonplace and a challenge for all forms of economic and political systems from orthodox Marxism to Enlightened Liberalism and from Metamarxist Socialism to Neoliberalism.

The essence of self-realization is present in all the above mentioned systems and 3D printing enables the open debate and bridging of the differences, in the case that society choses to participate in the struggle and be active in the process of transformation. So, the intended effects of regulation, inductively the 3D printing regulation schema itself, is a stake for all the stakeholders and each individual separately.

7. Conclusions and Future Work

This work first performs a literature review, examining the contours of 3D printing and additive manufacturing, along with its impact in the selected areas of geopolitics, manufacturing, employment, the environment, health and nutrition, and its expected effects on architectural design, aesthetics, but also - and perhaps more importantly - regulation.

We have quoted a series of parameters that are able to render 3D printing a hegemonic technology globally. To this extent, this technological achievement may produce a ripple effect on innovation, research, daily life and thus to society, the economy and politics.

Furthermore, additive manufacturing encapsulates several controversies and raises the stakes even on ontological issues such as democracy, self-realization in the work place, the borders between the private and public spheres, the ratio between security and freedom and so on. Its essential nature relies upon the possibility of vastly transforming the market into a more collective and participatory level, enabling creative destruction and pervasively agitating the waters of societal homeostasis. The producer-consumer model is threatened the same way the client-server model was dethroned by peer-to-peer protocols.

As a result, societies will have to participate in the debate of 3D printing regulation, in order to maximize social gain or defend their historicity and culture. The stakeholders are many, thus the debate is expected to be fierce in order to balance either towards a libertarian or an authoritarian point of view, towards technophobia or technocracy, towards growth or depression. In the case of 3D printing, it would be safe to claim that there is no certainty, only opportunity.

As Bohr observed, “prediction is difficult, especially about the future”. 3D printing is expected to have ground-breaking implications, impossible to foresee at the moment. However, it does appear that the technology will have a disruptive power similar to that of the Internet, or perhaps even greater.

For future work we intend to revisit regulatory issues along with the political transformations and the contextual background of 3D printing. Another interesting issue is the diversification of social gratification models, under the prism of additive manufacturing. Finally, we plan to focus on relevant privacy and ethical issues that appear to eventually arise.

References

Ashford, N., Hall, R., “The Importance of Technological Innovation”, in Ashford, N., Hall. R., *Technology, Globalization and Sustainable Development*, Yale University Press, USA, 2011.

Ashford, N., Hall, R., Pierrakakis, K., “Economic Development and Prosperity: Current Theory and Debate”, in Ashford, N., Hall. R., *Technology, Globalization and Sustainable Development*, Yale University Press, USA, 2011.

Campbell, T., Williams, C., Ivanova, O., Garrett, B., *Could 3D Printing Change the World? Technologies, Potential and Implications of Additive Manufacturing*, Strategic Foresight Report, Atlantic Council, 2011.

Chad, “3D Printed “Strvct” Shoes by Continuum”, *Unfinished Man* Magazine, http://www.unfinishedman.com/3d-printed-strvct-shoes-by-continuum/ (last access 03.01.2014).

Dunford, M., *Theories of regulation. Environment and Planning*, D: Society and Space, Vol. 8, No. 3, pp. 297-321, 1990.

The Economic Impacts of 3D Printing, http://madameeureka.wordpress.com/the-economic-impacts-of-3d-printing/ (last access 06.01.2014).

Hall, K., “How 3D printing impacts manufacturing”, ComputerWeekly, http://www.computerweekly.com/feature/How-3D-printing-impacts-manufacturing (last access 06 .01.2014).

Printing me the head of Alfredo Carcia, *The Economist*, August 2013, http://textually.org/3DPrinting/cat_3d_printing_basics_explained.html (last access 06. 01.2014).

Heckman, J., “Shadow prices, market wages, and labor supply”, *Econometrica*, pp. 679-694, 1974.

Jordana, J., Levi-Faur, D., *The politics of regulation in the age of governance*, pp. 1-28, 2004.

Kandias, M., Stavrou, V., Bozovic, N., Mitrou, L., Gritzalis, D., “Can we trust this user? Predicting insider’s attitude via YouTube usage profiling”, *Proc. of 10th IEEE International Conference on Autonomic and Trusted Computing*, pp. 347-354, IEEE Press, Italy, 2013.

Kandias, M., Stavrou, V., Bosovic, N., Gritzalis, D., "Proactive insider threat detection through social media: The YouTube case”, *Proc. of the 12th Workshop on Privacy in the Electronic Society*, pp. 261-266, ACM, Berlin, 2013.

Kandias, M., Mitrou, L., Stavrou, V., Gritzalis, D., “Which side are you on? A new Panopticon vs. privacy”, *Proc. of the 10th International Conference on Security and Cryptography*, pp. 98-110, Iceland, 2013.

Kandias, M., Galbogini, K., Mitrou, L., Gritzalis, D., "Insiders trapped in the mirror reveal themselves in social media", *Proc. of the 7th International Conference on Network and System Security*, pp. 220-235, Springer, Spain, 2013.

Peltzman, S., Levine, M., Noll, R., “The economic theory of regulation after a decade of deregulation”, Brookings Papers on Economic Activity, *Microeconomics*, pp. 1-59, 1989.

Portes, A., “Social capital: Its origins and applications in modern sociology”, in E. Lesser, *Knowledge and Social Capital*, Butterworth-Heinemann, USA, pp. 43-67, 2000.

Ray, P., *The New Political Compass*, YES! Magazine, 30 June 2002.

Ratto, M., Ree, R., “Materializing information: 3D printing and social change”, *First Monday*, Vol. 17, No. 7, July 2012.

Reeve, J., Reeve, J., *Understanding motivation and emotion*, Wiley, New York, 2001.

Schueren van der, B., “3D printed buildings to become reality in the not-too-distant future”, *De Zeen Magazine*, September 2013, http://www.dezeen.com/2013/09/25/3d-printed-buildings-to-become-reality-in-the-not-too-distant-future/ (last access 10.01.2014).

The Societal Impact of 3D printing, http://madameeureka.wordpress.com/the-societal-impacts-of-3d-printing/ (last access 03.01.2014).

Standing, G., *The precariat: The new dangerous class*, A&C Black, USA, 2001.

Print me a Stradivarius: How a new manufacturing technology will change the world, *The Economist*, February 2011, http://www.economist.com/node/18114327 (last access 20.12.2013).

Susson, M., *Watch the World “Burn”: Copyright, Micropatent and the Emergence of 3D Printing*, Social Science Research Network, 2013.

Volner, I., “The 3D Printing Revolution”, *Architectural Digest*, October 2013, http://www.architecturaldigest.com/architecture/2013-10/3d-printing-dirk-vanderkooij–janne-kyttanen-article (last access 20.12.2013).