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L'impression 3D : tendances et discussion des implications sociétales, environnementales et éthiques

Dans ce papier, nous présentons l'étude d'un secteur technologique en plein développement – la fabrication additive (additive manufacturing). La fabrication additive, appelée aussi impression tridimensionnelle (3D), est un procédé de fabrication récent qui consiste à créer, grâce à une superposition de couches, un objet en trois dimensions obtenu à partir d'un modèle numérique. L'impression 3D est en passe de transformer complètement le domaine de la fabrication et de révolutionner les secteurs industriels associés. Ce thème a été particulièrement médiatisé lors de prospectives sur les domaines d'application de l'impression 3D. De ce fait, dans ce papier, nous discutons des opportunités offertes par la fabrication additive et nous en présentons les impacts sociétaux, environnementaux et éthiques.

Mots clés : innovation, gestion, impression 3D, technologie, implications

3D printing trends and discussing societal, environmental and ethical implications

In this paper, we present a study on a growing technological sector – additive manufacturing. Additive manufacturing, also known as three-dimensional (3D) printing, presents a novel manufacturing process that builds layers to create a three-dimensional solid object from a digital model. 3D printing stands to completely transform manufacturing industry as well as to disrupt related major industries. The topic has been surrounded with lot of hype when predicting future application scope, so in this paper we open discussion on the trends and present societal, environmental and ethical implications pertaining to this technology sector.

Keywords: innovation, management, 3D printing, technology, implications

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INTRODUCTION

We have entered in era of digital revolution which already affected and sparked changes in tourism, hotel industry, music and transportation, to name few. Digital revolution now presents potential to revolutionize the industrial world where postulates are to be reassessed, economic models to be rethought and processes to be reorganized.

In this article, we present a study on a growing technological sector – additive manufacturing. Additive manufacturing, also known as three-dimensional (3D) printing, presents novel manufacturing process that builds layers to create a three-dimensional solid object from a digital model (Birtchnell, 2013; Berman, 2012). Firstly dedicated to prototyping and modelling, the process of additive manufacturing has experienced considerable technological advances, and the materials that can be used for 3D printing have increased dramatically. This turned the interest of the industrial world, like for instance aerial, automobile or the rail industry, as well as medicine or consumer goods, to name few.

3D printing is considered as a game changer for manufacturing industry and to completely reconfigure business ecosystems. The topic has been surrounded with lot of hype when predicting future application scope and future revenue growth (Metal Powder Report, 2014a; Wohler's Report, 2014; McKinsey and Co., 2014). It has even been discussed that 3D printing will bring modern and developing societies to the doorstep of a new industrial revolution (The Economist, 2012).

Moreover, effects of this technical innovation have hardly begun to be taken into account (Gebler *et al.*, 2014; Le Bourhis *et al.*, 2014), and our intention is to study ongoing trends as well as to question *what are the societal, environmental and ethical implications of these (3D printing) trends?*

The study is motivated solely by the need to assess the technological advances and detect environmental, societal and/or ethical implications linked with 3D printing growth. Ethical and societal questions related to emerging technologies are not a new topic in scholar discourse, and have been discussed in works, for instance, of Van den Hoven *et al.* (2012) or Stahl *et al.* (2010).

Paper is organized as follows - 3D printing is introduced and characteristics defined in the next section. Problematic and socio-environmental implications linked with the use of 3D printing are presented in section 3. Concluding thoughts and limitations are presented in the final section of the paper.



Figure 1 – Use of 3D printing in different aspects (from prostheses and firearms, to consumer goods and in medicine).

3D PRINTING

3D printing has been developed during 1980s and 1990s to produce prototypes of an object. The goal is to produce three-dimensional objects from a digital model where layers are built one on top of other as the printer releases material from a container or cartridge. Every layer is a digital slice generated through Computer Aided Design (CAD). Each layer is added until the object is fully fabricated. Materials are fed to the printers in order to be made into objects based on extruder (fused-filament), chemical agent (binder) or a laser (sintering/melting) methods (Birtchnell, 2013). Common materials are resin, ABS, nylon, carbon, titanium or steel (Berman, 2012).

The manufacturing process is customizable and relatively fast to set-up. It implies on-demand, highly flexible production. Some future innovations are likely to include machines able to print mixed materials at the same time - for instance MIT printer prototype can use up to ten materials (Numerama, 2015).

Number of promising applications have expanded dramatically over the last few decades. Objects printed vary from medical implants (Petrovic et al., 2011) /organs (Atala, 2014), surgical instruments (Rankin et al., 2014), dental crowns, car parts, metal bicycle frame (Metal Powder Report, 2014b), jewelry, football boots, furniture (Harouni, 2014), batteries (Bradley, 2014), customized mobile

phones (Reichental, 2014), bionic arms, artificial blood vessels (Moskovitch, 2011), among others.

What is remarkable about this technology is that further advancements foster research and development in areas withheld by the previous traditional technologies.

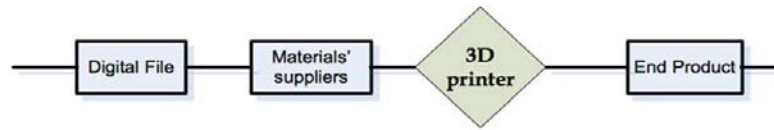


Figure 2 – 3D printing process (Mavri, 2015).

PROBLEMATIC ASPECTS

Although technology is more than 30 years old, it was not until recent decade that certain barriers regarding 3D printing made it more accessible. For instance, key milestone was 2009, the year when expiration of a key patent in allowed many startups to emerge offering cheap consumer-level 3D printers. A growing interest in media dating from 2012 put 3D printing into the spotlight, where various stakeholders are reporting dramatic growth in everything from consumer to high-end metal printers (Harop, Gordon, 2015).

The growth phase of 3D printing industry is threatening to change and disrupt the manufacturing as we know it. According to the *Semiannual 3D Printing Spending Guide* (IDC, 2015), 3D printing industry is going to be rapidly expanding in the next three years. Globally, it is expected to grow at a 27% compound annual growth rate. Report states that the nearly US\$11 billion industry in 2015 will balloon to US\$26.7 billion by 2019. This is one of the fastest rates of growth yet predicted for 3D printing, where West European, Asian and United States markets are expected to primarily drive the growth (IDC, 2015).

When discussing business opportunities lying in this industry sector, there is a notable number of about 30 innovative companies showcasing their latest advancements in 3D printing technology at the world largest Consumer Electronic Show 2015 in Las Vegas (CES Press Release, 2015). This showcase acknowledged that the 3D printing industry is far more segmented than most industry trend reports tend to recognize. The industrial 3D printing market, for instance, differs enormously from the desktop 3D printer market, where each represents varied growth rates.

Focusing on desktop 3D printer market, trend is moving toward development of more compact units, more suitable for consumers and capable of printing a variety of consumer goods, from toys and electronics to clothing, shoes and even food. Examples are the machines from companies who already are making

presence on the market, for instance *Makerbot*, *Dremel* and similar (Les Numeriques, 2015). As mentioned previously, some future innovations are likely to include machines able to print mixed materials at the same time (Numerama, 2015). On the other hand, this fact alongside aforementioned market reports, marks 3D printing as potentially disruptive technology that has been compared to emergence of personal computing in the late 1970s (Eisenberg, 2011).

This paper is not intended to go into details of describing 3D printing as a manufacturing method but to focus on examining societal, environmental and ethical implications linked with the growth of 3D printing industry.

SOCIETAL IMPACT

When speaking about societal impact and related implications of 3D printing, we must consider economic challenges lying afore, as well as the changes in business models.

Starting from changes in traditional economic model, we will witness shift from consumers to prosumers. Alvin Toffler (1980), in his book *The Third Wave*, argued that people in post-industrial age will start producing many of their own goods and services, likewise, shifting from pure consumer habits. In other words, consumers are no longer passive entities of the market, but becoming active in producing some of the goods and services entering their own consumption. With the emergence of *Maker* (Anderson, 2010) or *Hacker* (*Hacker space*, 2010) movements, rise of community-operated organizations like *fab lab* (Gershenfeld, 2010), growing number of community operated projects based on 3D printing – 3D printing technology is experiencing huge leap in democratization of accessibility to vast groups of users. This further reflects in enhancing the interest of users to produce and influence the community on local scale.

What conforms this logic is also cost of the printers. This cost has declined in price in recent decade. *RepRap* is an online community fostering information to get started with 3D printing, particularly with free desktop 3D printer (*RepRap*, 2015). Except that, easily portable and miniature 3D printing kits are available as of US\$270 (*3D Printers Online Store*, 2015), making 3D printers much more affordable to larger population of users.

Secondly, major factor when evaluating societal implications of 3D printing is the possibility of localized manufacturing of products on demand and closer to the consumer's location. Production chains, traditional way of converting available resources into products throughout phases like design, planning, manufacturing or selling, will be altered, wherein 3D printing technology is the transformation impulse in that change (Mavri, 2015).

Thirdly, when discussing the influence of 3D printing on societal aspect, as mentioned earlier, is the effect of wide spreading and impact on the global economy. 3D printing disrupts traditional product chains (Mavri, 2015) and this leads to deterioration (to a certain level) or eradication of the craft ships and skills of traditional manufacturing. Workforce requirements will only deepen the contrast between certain social groups influenced with further 3D printing industry growth. Even though it may lead to development of new skills and new job openings, transitional period, where 3D printing is fully computer-controlled technique, will inevitably lead to significant reductions in workforce requirements regarding the production, product delivery and manufacturing jobs (Alexandru & Petroşanu, 2013).

On the other hand, digitization fostered by 3D printing, Internet of Things (IoT) or virtual reality for instance, will give way to endless abundance of new job opportunities to be developed by new generations. Barack Obama, president of the USA, in his 2013 annual speech to the nation mentioned 3D printing as an opportunity to fuel new high-tech jobs in the country (CNN, 2013). This is later seen to result in creating new professions, jobs and industries related to the production of 3D printers, supply chains, materials and printing cartridges, product engineering and design and the software industry. For instance, one recent topic is the position of *manager of additive manufacturing and 3D printing*, as introduced by US Society of Manufacturing Engineers (Metal Powder Report, 2014c).

Side impulse of the wide spread of software and hardware related to 3D printing is open access to design. We are witnessing online repositories of open source designs (e.g. thingiverse.com) and development on materials easily accessible and locally supplied, which will only enforce localized manufacturing at customer's location. Having these characteristics of future trends in 3D printing on mind, we will probably witness increase in development of local solutions that serve the needs of many and increase the well-being.

For instance, one example is *Faircap*, a portable tiny water filter that could be screwed into any plastic bottle which would allow safer drinking at any available water source. 3D printing here enabled development of the model for a lower cost than with traditional mold production (Faircap, 2015). What it holds as the premise for the population that has lower access to the water is a cost of only US\$1 per model.

Moreover, Harouni (2014), executive of one company working with additive manufacturing, stated that we are on the tipping point since more and more software is being developed making data accessible to more users. The possibility of on-demand manufacturing products and at different locations than when using traditional techniques, could reduce actual economic imbalances and could modify the current hierarchy of the economic powers.

ENVIRONMENTAL IMPACT

A very important advantage of creating objects using 3D printing technology instead of traditional manufacturing methods is the waste reduction. As the construction material is added layer after layer, the waste is almost zero and during the production, it is used solely the material needed for obtaining the final object.

Many of the benefits of 3D printing relate to this additive rather than subtractive nature. This means that the material waste is kept to minimum, but also that complex shapes and forms can be produced without assembly. Berman (2012) mentions that when compared to traditional methods, 3D printing can reduce waste by 40% in metal machining for example.

Moreover, the 3D printing technology could use cheap recycled materials. This is still in early phase of vast application, but what it holds for the future is the reduction of cost concerning the waste management. 'Simple' materials, like use of resin and waste plastics as inputs for 3D printers no longer presents a threat that needs to deal with, but rather an opportunity and a valuable resource for re-use. There are several projects going on in developing countries where advantages of 3D printing are set to test.

For instance, Togolese entrepreneur and his team assembled 3D printer from electronic waste collected in dumpsites around the Togolese capital of Lomé (New African, 2015). What makes this single story interesting is, firstly, transformative power of 3D printing that demonstrates the advantage for latecomers in developing world to catch a wave of this technological innovation in the early phase. Secondly, this story present novel mind set in combating issue related to WEEE (Waste of Electric and Electronic Equipment) being shipped to developing world. Open access-enabled 3D printer designs allow their manufacturing in any environment using already existing equipment. This could be major breakthrough in Western societies and their standpoint to WEEE.

Positive environmental impact of 3D printing is also seen, except in the additive nature of production, in localized and on-demand manufacturing reflecting in lowered carbon footprint, rationalized use of resources (raw materials especially) and energy. This translates into production that is more efficient, flexible and adaptable (Connor *et al.*, 2014; Petrovic *et al.*, 2011).

Topic that, to our best knowledge, lacked proper analyses and scholar attention is the possible rebound effect to be expected by further growth of 3D printing technology (check for instance work of Gossart (2014) on the subject of rebound effect). It is not unreal to imagine that further deployment and mass customization of the machines would spur and heightened demand for

materials, increased error and number of faulty prints thus resulting in waste increase.

Moreover, increased deployment of 3D printers could result in increase of WEEE, by its own. Similar patterns of growth and deployment have been discussed ever since presentation of novelties with '2D' printers in early 1970s, or increase of home computer. This later resulted in WEEE being shipped from developed to developing countries in a form of second-hand goods (Rodhain & Fallery, 2011; McDonough & Braungart, 2002).

ETHICAL IMPLICATIONS AND SECURITY ISSUES

We are witnessing a growing number of websites offering repositories of design and online services in a range of possible materials for 3D printing (Metal Powder Report, 2014d). This opens questions on Intellectual property (IP), blueprints and moreover, security. In 2013 in USA, 3D design of a pistol was downloaded more than 100 000 times in 24 hours. This 3D design is example of revolution we may expect in the domain of criminal acts, where 3D printed firearms go beyond regular norms in weapon (Goodman, 2014; Daily Mail, 2014). For example, 3D printed firearms could be very easily disguised as non-hazardous products. Thus, 3D printing can become a potential danger when serving the needs of criminals or counterfeiters. 3D printing in the aspect of terrorism or other acts of violence against social norms present real threat.

Moreover, major ethical issue is the use of materials for 3D printing, or in this case, bio-printing. 3D printing has led to amazing advances in medicine, being capable of saving lives, lowering healthcare costs and improving human life's quality. For example, researchers have managed to create a 3D printer useful in creating low cost prosthetics (WAAG Society, 2015). Shocking novelties are concerning parts of the human body, organs and tissues being possible to reproduce with 3D printers. Firstly, 3D model of the final object is created using a scanner (computed topography or magnetic resonance imaging). Using 3D shapes, the organic material is printed and afterwards is implanted in the patient's body.

Japanese government announced in 2014 they will invest a massive sum of about US\$21 million in the development of transplantable human organ printing over the next five years. Russian scientists announced they will be able to 3D print human kidneys by 2018, and for instance, project of Yale School of Medicine aims to pioneer 3D bio-printed surgical tissues (3ders.org, 2015). The researchers from the Wake Forest University's Institute for Regenerative Medicine in North Carolina (USA) have successfully created a reduced size functional kidney. While these examples still remain in the domain of theory, we are on a tipping point of bio-printing where specific regulations for

producing biological materials from human cells still require thorough discussion.

Examples of 3D printing firearms or bio-printing clearly lead to the conclusion that there is a lack of legislation and regulations regarding 3D printing. For innovations to become successful they should, in general, conform three levels of filters – market, technology and society. The challenges related to these filters do not necessarily become obvious before introduction but rather they can emerge in correlation with adoption and uptake or success rates of the respective product or service. This seems to be the case with 3D printing and its societal aspect. The adoption of a technology requires a level of standardization that had not been integral part of the 3D printing.

Standardization of 3D printing was not deeply taken into consideration until recent years. In the European Union, the project SASAM (2015) was introduced in 2015 to promote the growth of additive manufacturing to become a family of efficient and sustainable industrial manufacturing processes by integrating and coordinating standardization activities within the European community and other stakeholders. One of the most interesting issues to monitor next is the progression and integration of all of the official policies – both on a national and an international level – as well as activities on the similar issue in the US and the rest of the world.

CONCLUSION

In this paper, we have presented 3D printing technology as a promising industrial sector. After brief introduction of 3D printing, we have dedicated section to examine actual trends and presented numerous societal, environmental and ethical implications of this growing technology, as far as we can anticipate them based on the current advancements.

Same like 3D printing, many significant technologies took off at some point of development as innovation's to become reality and changed who and what we are (Flanders, 2014). 3D printing is not an exception. Opening discussion on trends, anticipating impacts, reflecting on and disseminating policies related to 3D printing is expected to result in a more socially desirable and ethically acceptable technology. This would spur the development of new and sustainable products and services made possible with this technology.

Although it can be understood that the development of 3D printing as industrial sector is taking slow pace with many limitations to be overcome, we can conclude this paper stating that the 3D printing technology significance and social impact will gradually increase. This will question postulates of modern production, business models and of the modern society.

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