Digital Revolution 2.0: The new era in fabrication

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ABSTRACT

In the wake of the second digital turn in architecture (Carpo, 2017), this talk questions the opinion of Gershenfeld (2012) that ‘’ a new digital revolution is coming, this time in fabrication.’ ’ It questions the widespread use of digital fabrication from industry and investigates the impacts on architecture and society. It is not a pure architecture lecture but multidisciplinary research, which tackles the 3D printing industry, as we know it today. The lecture debates the above phrase through different approaches towards digital materiality, the use of digital tools in fabrication, the goal of mass customization-collaboration and the relation of design with making. Moreover, It searches the origins and the development of the idea of digital fabrication from antiquity to 21st century. Specific examples are presented towards the prospects of digital fabrication regarding its opening to the society, its further development of embodied technology, and the overcoming of temporal limitations of cost, speed, and quality. Finally, it concludes with useful findings and questions for further research in the field.

Good morning everyone,

I would like to speak you about the second digital revolution, which opens a new world in fabrication, as technologies like additive manufacturing are continuously gaining momentum and challenge the way we design and make things.

So let me start.

1. INTRODUCTION

According to Carpo (2012), electronic technologies in the early 1990s changed society, economy, and culture to such an extent that some architects began thinking that design and making should change as well. During this period – the first digital turn– digital tools started being widely used in architecture mainly as supplement of human hand. For example, designers used CAD in order to develop and finish faster the same designs that they were doing previously by hand. Nowadays, Carpo (2017) has noted that society, is currently learning that computers are better and faster at solving problems by themselves using artificial intelligence. In a metaphorical sense, computers have begun to develop their own science (Carpo 2017).

The emergence of such technologies has created designs with many, complex curves that are widely produced and digitally manipulated. In the new millennium, digital tools have begun to function in new ways and are following new and apparently inscrutable logic (Carpo 2017). The construction industry has developed exceedingly complicated buildings, as new machines, materials and techniques are continuously evolving. Furthermore, the genesis of open source software and platforms has created a worldwide network of makers-developers-architects who exchange ideas about various projects, in order to overcome difficult issues and develop even more complicated machines, such as open-source 3d printers. Just as the digital revolution of the 1990s begot a new way of making, today's computational revolution-the second digital turn- is begetting a new way of thinking (Carpo, 2017). The Director of MIT's Centre for Bits and Atoms, Gershenfeld (2012), in his article, how to make almost anything, demonstrates that 'a new digital revolution is coming, this time in fabrication'. The purpose of the following lecture is to question that point in an attempt to find answers by analyzing different approaches. Its goal is to study and evaluate the possible perspectives of fabrication in the 21st century.

2. MAIN BODY

2.1 DEBATES ON ''THE NEW DIGITAL REVOLUTION IN FABRICATION''

According to Gershenfeld (2012), "digital fabrication" is a manufacturing process in which the materials are digital. Evens (2010) has argued that digital materiality is deeply problematic, because anything digital warrants its own ontology, consisting of a series of 0 and 1. However, Picon (2010) has demonstrated that digital materiality will remain a pervasive concern: while the content changes constantly, its meaning remains undecided.

In addition, Frampton (1995) has widely criticized the use of digital tools in fabrication; He considers them to be a threat to the material application as architects apply materials ignoring their properties such as strength. Although Gershenfeld (2012) understands the issues with digital tools in fabrication, he considers them-the issues- to be an opportunity for the future development of tools. More specifically, Gershenfeld (2012) believes that digital tools are shaping new structures and propelling the progress of fabrication machines.

Moreover, Gershenfeld (2012) supports the prospect of mass cooperation and mass customization in digital fabrication. Indeed, individuals would be able to design, produce and customize tangible objects on demand, wherever and whenever they needed them (Gershenfeld, 2012). Carpo (2017), however, has argued that the transition from mass customization to mass collaboration is not yet possible in architecture and design. Even though important steps have been taken toward mass customization worldwide, design professionals such as architects have rejected the prospect of mass collaboration (Carpo, 2017).

Another concern in digital fabrication is the relationship between design and making. Bacharidou (2018) has demonstrated that design concerns how an idea develops, whereas making refers to how the same idea is implemented. Gershenfeld (2012) has found that digital fabrication technologies narrow the gap between design and making as, for the first time in history what is programmed is the physical word- the prototypes - rather than the virtual one. Nevertheless, Bacharidou (2018) believes that interaction with design prototypes remains a conceptual and technical challenge in fabrication. Brandt (2012), however, has noted that it is the responsibility of designers-makers to drive the applications of these technologies in architectural artefacts and urban environments.

2.2 ORIGINS AND DEVELOPMENT OF THE IDEA

Gershenfeld (2012) has defined the digital revolution in fabrication as the ability of things be turned into data and data into things. Thus, although many years of research remain to complete that vision, the radical turn is already well underway (Gershenfeld, 2012). Is the transition between data and things totally new idea in the 21st century? How was that concept developed over the centuries?

According to Smith (1992), in ancient Greece, philosophers like Aristotle learned much from visiting workshops as everything about the behavior of metals was already known to craftsmen and blacksmiths. As a result, specific theories were created on the relationship between ideas and matter. The most dominant one, Aristotle's concept of hylomorphism, regards creation as the imposition of an idea of form upon passive material or matter (Knight and Stiny, 2015).

During the Renaissance, hylomorphism was reincarnated in Alberti's distinction between designing – as a pre-ordering of the lines and angles conceived in the mind – and building (Knight and Stiny, 2015). In Alberti's theory, a building was the identical copy of the architect's design: with Alberti's separation between design and making came the modern idea of the architect as author, in a humanistic sense of the term (Carpo, 2011). Moreover, in the 16th century, alchemists respected the direct interaction between matter and energy (DeLanda, 2004). Their respect was based on the misconception that the conversion of metals to gold was possible.

Regarding the first half of the 20th century, the idea of mechanization affected the thought processes of philosophers and architects. The connection between design and making in that period was ''the machine'' that could be used to materialize radical ideas and build a new industrial society. In his book, Towards an Architecture, Le Corbusier (1931) has described the concept of a house-engine, an idea that architecture can be produced industrially worldwide.

Kwinter (1992) has found that, after the Second World War, significant scientific breakthroughs, like the genesis of nuclear weapons, the invention of computers, the first missions of satellites in orbit, the research of complex biological structures and the discovery of deoxyribonucleic acid (DNA) led scientists to study exceedingly complex systems that had hitherto been unknown to humanity. Consequently, human culture was moving decisively away from classical mechanism and reductionism, as the physics model-the machine- was giving way to a biological model-the system- (Kwinter, 1992). As a result, scientists built computational workflows to study complex systems without having to simultaneously convert data into real models, as the design and making processes were independent of each other.

That goal of a closer relationship between design and making was partially achieved after the discovery of additive manufacturing-3d printing in the 1980s, with really small steps forward in the first three decades due to patent restrictions. Improvements to computer-aided design software and the availability of lower-cost fabrication systems gradually spurred the field into new applications of fabrication (Keating, 2014). Currently, digital fabrication products, such as the MakerBot and the Ultimaker, are on the market and permit modifications to be made by users as their plans are openly shared on the internet (Gershenfeld, 2012). Hence, the expanding limitations of fabrication are only beginning to be explored, and novel approaches to design are being discovered (Keating, 2014).

2.3 PROSPECTS OF DIGITAL FABRICATION

The potential of digital fabrication is a serious concern for research institutes, universities, communities, and industry. The main directions, based on the findings of the articles 'how to make almost anything' (Gershenfeld, 2012) and 'beyond 3d printing' (Keating, 2014), are divided into three general categories (figure 2): i) the further familiarization of society with digital fabrication, ii) the development of embodied technology in digital fabrication devices and iii) overcoming temporal limitations like cost, time, quality. Consequently, digital fabrication will challenge future mass manufacturing techniques, enabling the industry to use it (Keating, 2014).

i) The wide familiarization of society with digital fabrication means that, ideally, in the future, everyone could make anything anywhere (Gershenfeld, 2012). Indeed, in the last decade, many digital fabrication workshops – fab labs, Hackerspaces, Makerspaces – have been established worldwide, participating in an international community -the Fab Academy- organized by M.I.T and directed by Gershenfeld. Inside these digital fabrication workshops, makers can acquire high skills about various digital fabrication techniques or even do research and develop more specific machines and devices. These workshops many times communicate with other word wide, exchanging knowledge and skills. However, even fab labs are open to everyone there is a degree of inaccessibility to them as the above skills tend to be time consuming and people many times prefer ready industrial products rather that DIY ones. Sanchez (2016) also believes that one of the most radical innovations of digital fabrication is its distribution: makers can create, use and send digital files through the internet, print them on local machines, bypassing the traditional distribution procedure, which is both time-consuming and inefficient. These new ways of distributing data and making things can benefit communities, making the real potential of fabrication laboratories not only technical but also social (Gershenfeld, 2012).

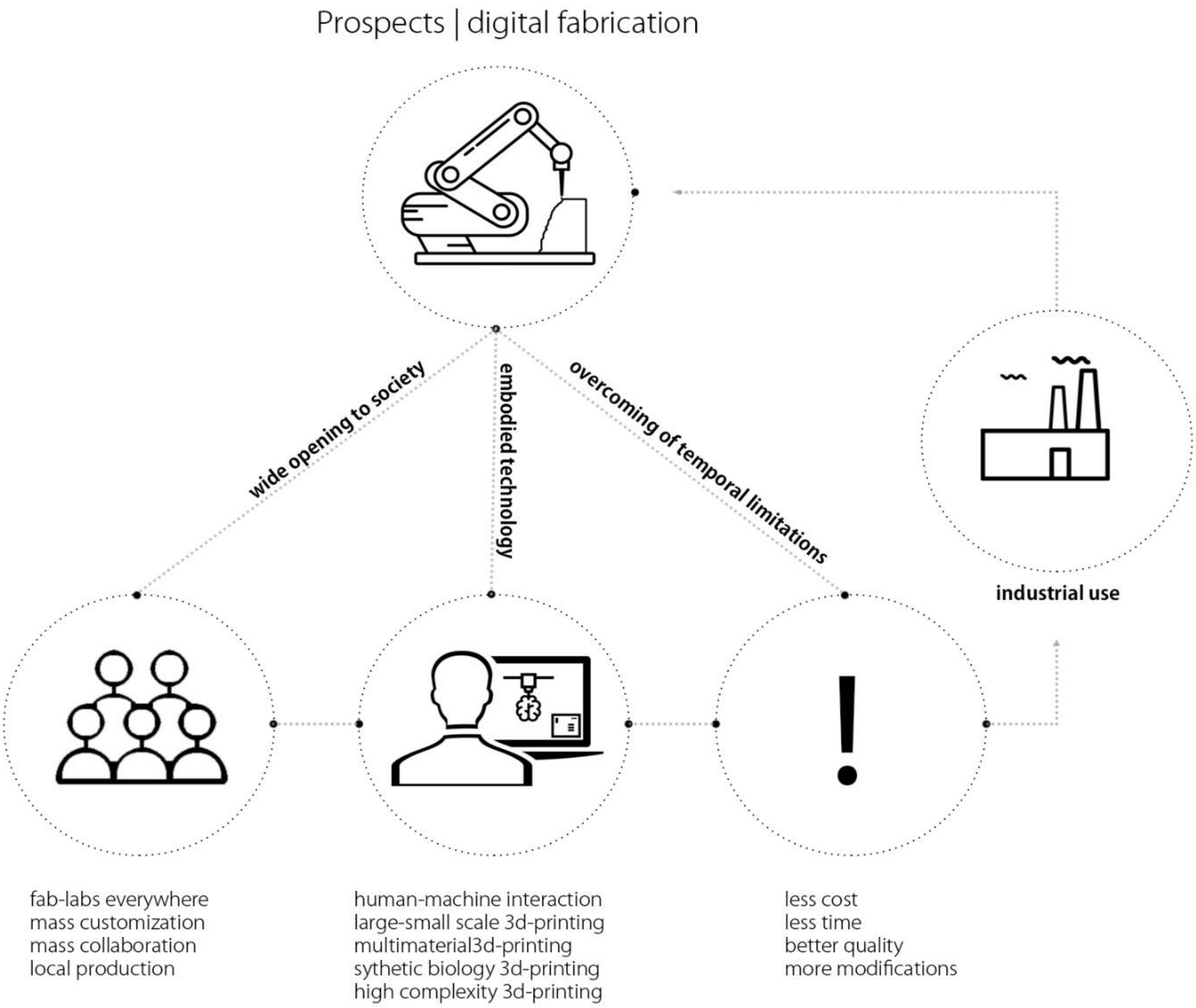


Figure 2. Prospects of digital fabrication

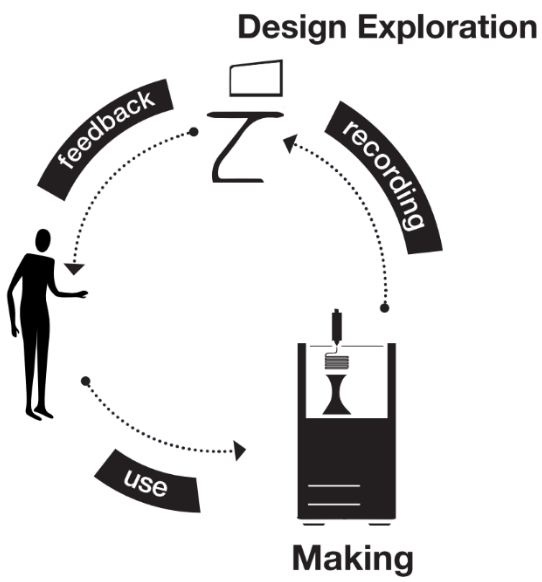
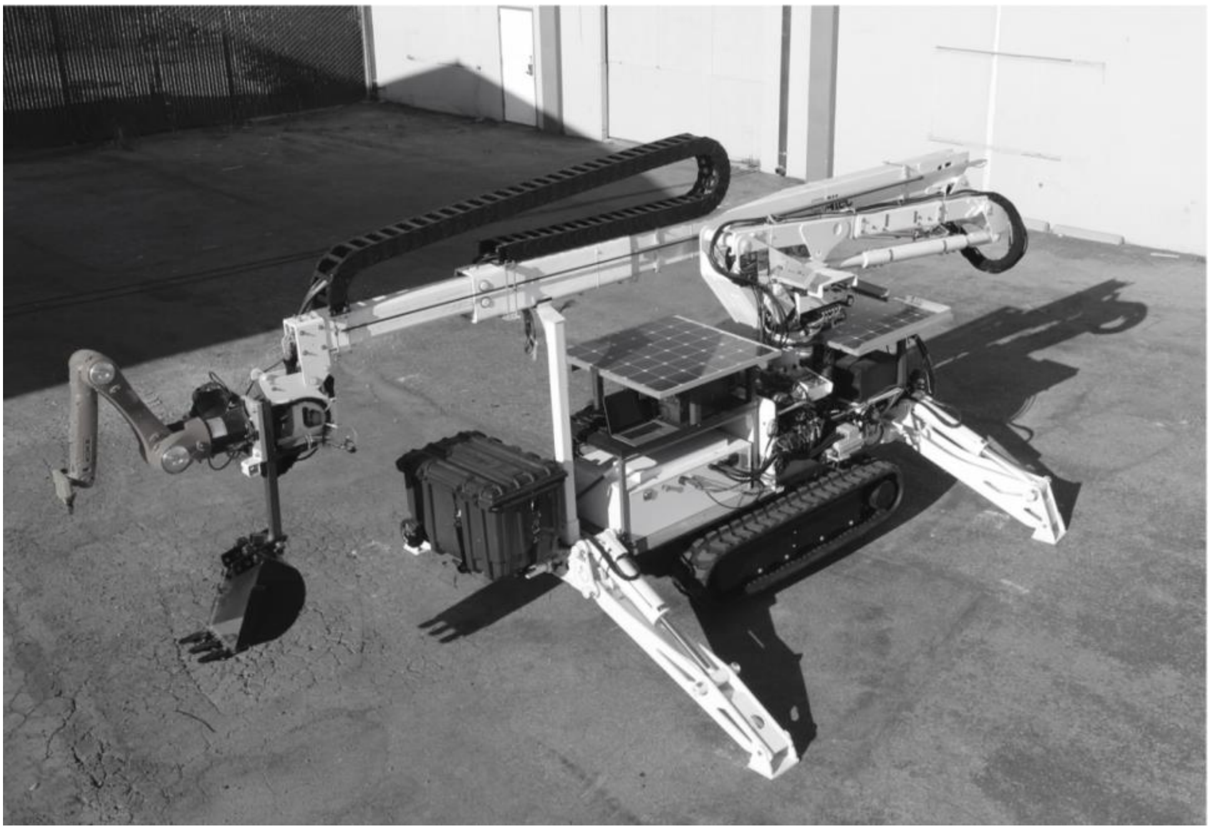


Figure 3. Active Prototyping framework, introduced by Bacharidou in M.I.T, 2018.

ii) Another aspect of digital fabrication is its further development in embodied technology. Recent studies at M.I.T. have demonstrated that improving the connection between design and making creates real potential for digital fabrication. Bacharidou (2018) has demonstrated that the concept of continuous interaction with computational fabrication tools is gaining impetus in computational design research and human-computer interactions. She has introduced a computational framework called "active prototyping" (figure 3), which aids the designer to project the impact of tools on design outcomes and explore possible design solutions while making (Bacharidou, 2018).

Furthermore, the Media Lab at M.I.T is currently studying small- and large-scale applications for digital fabrication technologies (Keating, 2014). The mediated matter group of the lab has developed a system called "Digital Construction Platform" (figure 4), which is capable of on-site design, sensing, and fabrication of large-scale structures (Keating, 2014). Various start-ups, such as AI build, have also accomplished large-scale 3d printing of complex structures in their attempt to use digital fabrication technologies in the industry (figures 5, 6). The same time, another start-up company, the MX3D has accomplished to 3d print in large scale metallic structures such as bridges and benches (figures 7, 8). On the other side of the spectrum, micro-scale 3D printing also has significant applications in micromechanical devices and optics, despite several limitations, such as material restrictions (Keating, 2014). Gershenfeld (2012) has noted that many labs worldwide are developing assemblers-instead of printers- capable of producing complete functional systems, like microfluidic devices and nanostructures, in a single process (figures 9, 10). In regard to material selection, many companies, like Stratasys and Ultimaker, are developing machines capable of printing multiple materials simultaneously such as the Ultimaker 3 (figure 11). Keating (2014) believes that that multimaterial and biological material printers are on the near horizon.

iii) Lastly, limitations regarding cost, time and quality appear to be temporal constraints of digital fabrication (Keating, 2014). Indeed, the new devices like the Ultimaker 3, have improved in regard to quality, printing times and cost. Improvements to open-source electronic platforms, like Arduino and Raspberry Pi, can reduce costs and provide new capabilities for the modification of digital fabrication devices. Keating (2014) has further noted that synthetic biology printing can contribute to reductions in time and costs, as 3d printing biological structures can grow by themselves or by living organisms. For example, in the silk pavilion project, silkworms created silk patterns over a pre-designed structure (figures 12, 13, 14).



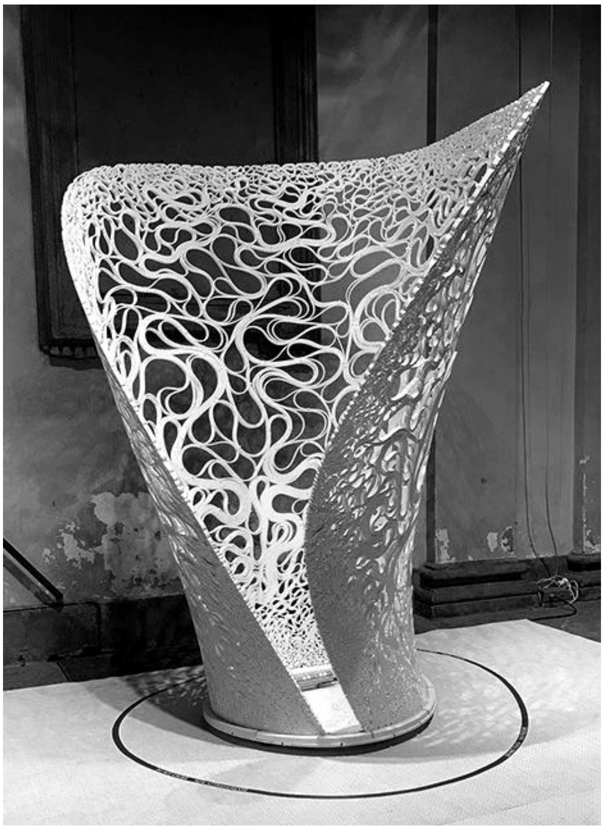


Figure 4 (top). Digital construction platform for large scale 3d printing, media lab, M.I.T 2016.
Figure 5 (left). Thallus large scale 3d printing project, AI Build, Milan 2017.
Figure 6 (right). Daedalus large scale 3d printing Pavilion from, AI build, Amsterdam 2016.

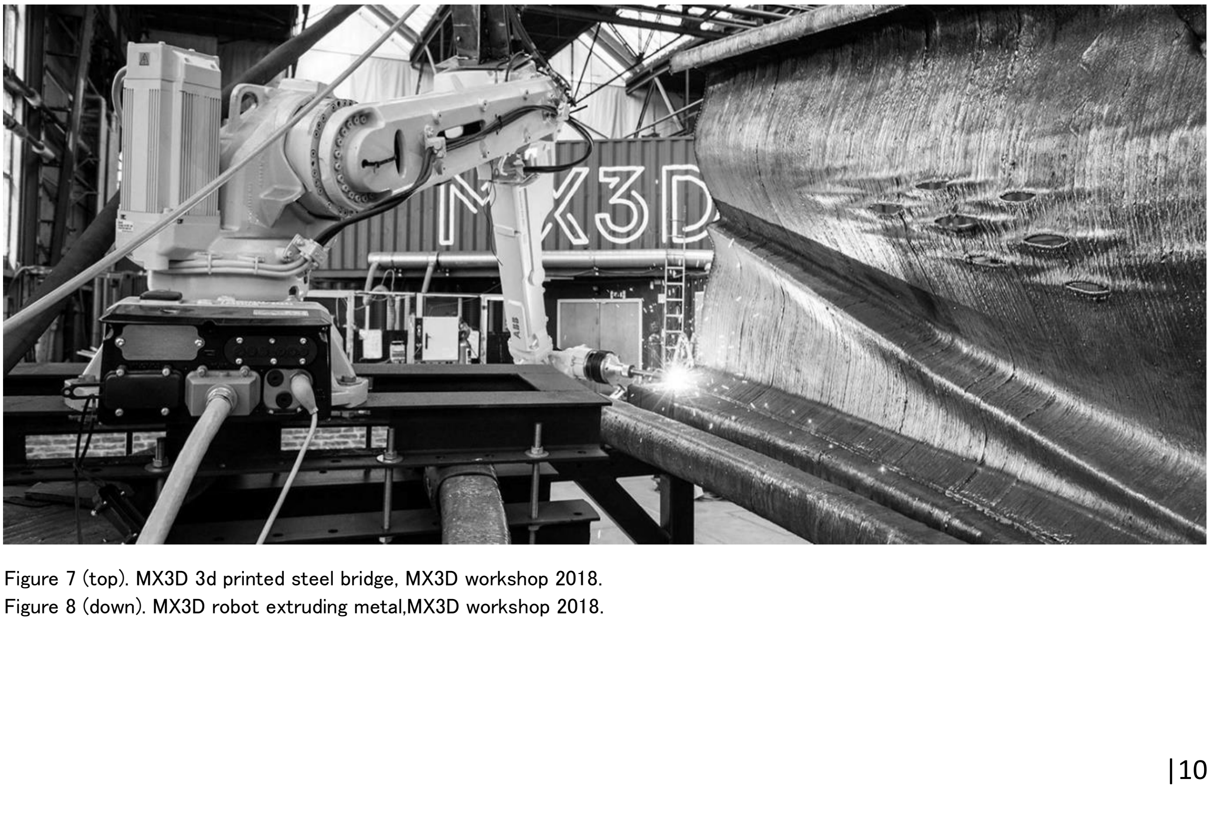
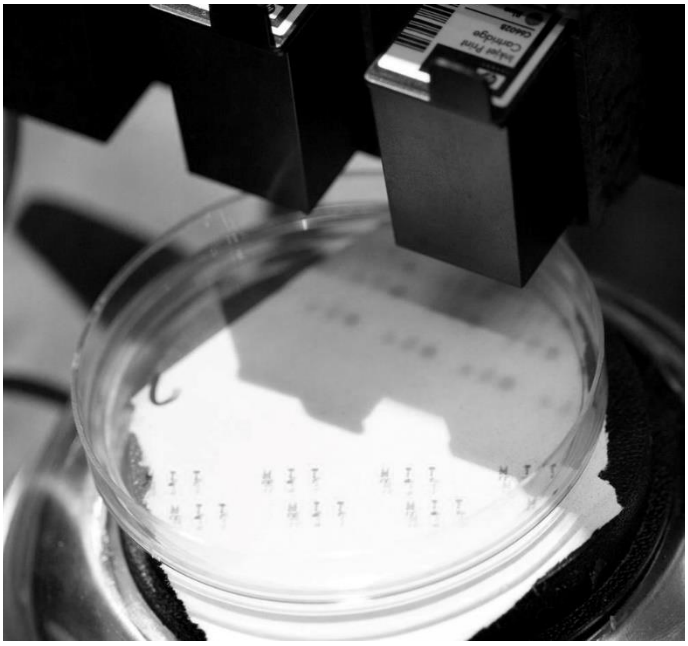


Figure 7 (top). MX3D 3d printed steel bridge, MX3D workshop 2018.
Figure 8 (down). MX3D robot extruding metal,MX3D workshop 2018.



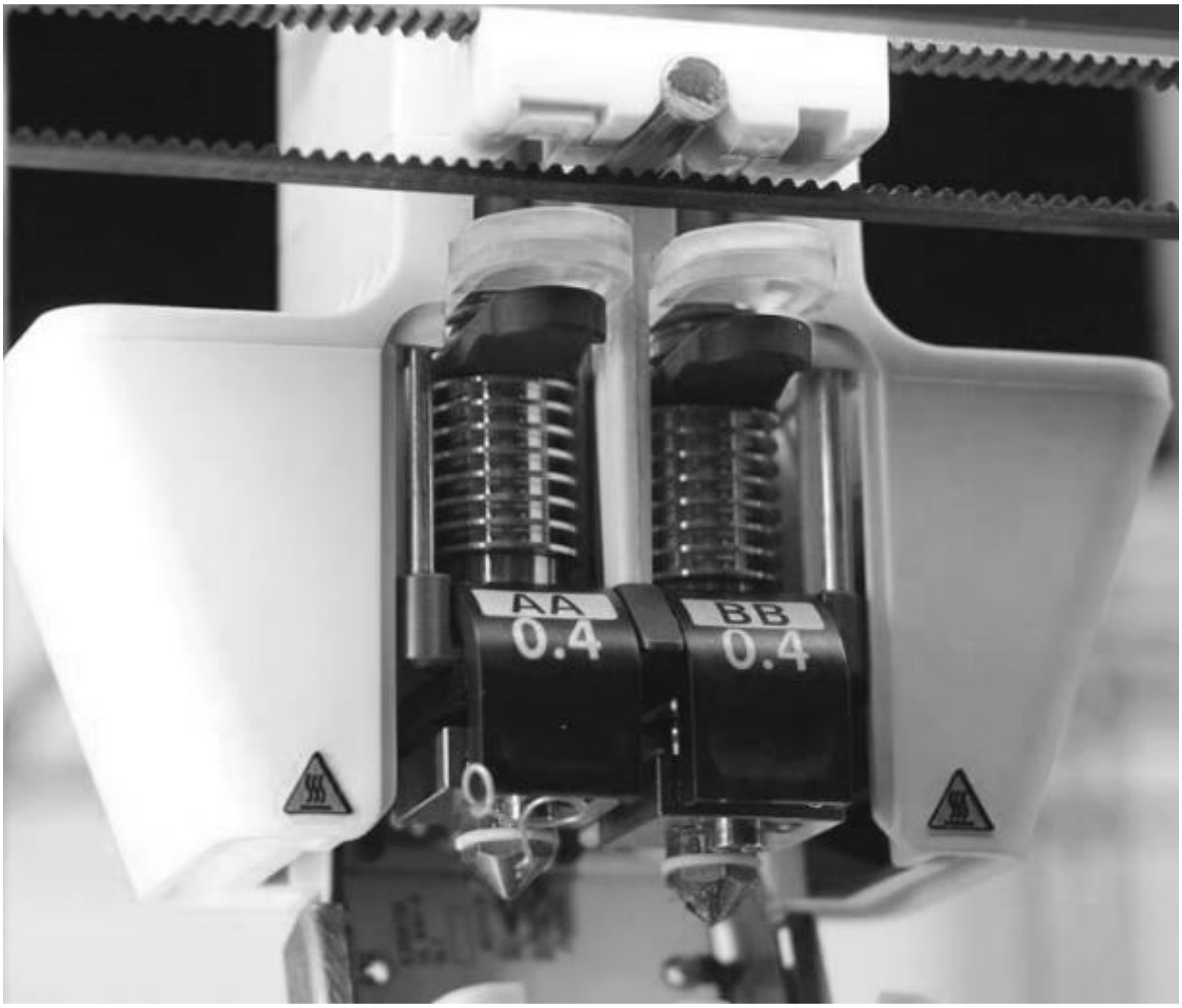


Figure 9 (left). Small scale 3d printing of Escherichia coli cells with a fluorescent tag, media lab M.I.T, 2014.
Figure 10 (Right). Small scale 3d printing of microfluidic devices, media lab M.I.T, 2014.
Figure 11 (Bottom). Multimaterial extruder of Ultimaker 3, with open designs on internet.

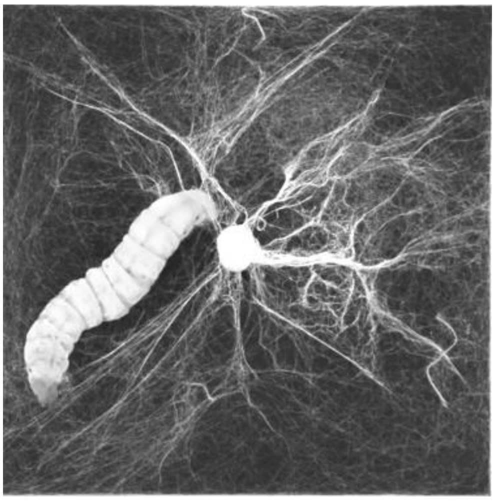


Figure 12 (top). Silk pavilion project, a mixture of digital fabrication techniques with biology, media lab M.I.T.
Figure 13 (left). Detail of structure producing by a silkworm.
Figure 14 (right). Detail of the final surface of silk pavilion.

2.4 THREATS

Despite the prospects of digital fabrication, there are rising threats about its wide use in the future. For instance, should everything be accessible to everyone, or new rules and restrictions should be regulated?

Gershenfeld (2012) concerns about the theft of intellectual property in a framework of replicating designs worldwide without permission. He supports that patents should be protected while simple designs should remain free to the community. On the other hand, Anderson (2012) has criticized that the copy of designs in open source environments has its positive aspects, as it proves that a design was successful, the competition between designers for the same design can be creative and what starts as a simple copy it has the potential to be developed in a real innovation. He has also highlighted that even companies whose data are sensitive, choose to participate and trust open source communities in order to find new talents and develop their concepts fast and without extra cost.

Another aspect of digital fabrication is the rising questions towards intellectual property, authorship and ownership. As regards authorship, Rui (2016) has noted that it requires originality, because in open source communities it’s very difficult or even impossible to identify the owner of a project. Fok and Picon (2016) have criticized that nowadays there are many rising questions towards ownership especially in open source environments. Consequently, these terms have to be redefined after all these tremendous developments in digital fabrication. New types of ownership towards open source environments have become possible using digital technologies in a way that society has just beginning to comprehend their consequences (Picon, 2016).

Crucial threat of the wide use of digital fabrication is the production of weapons or other dangerous tools individually (Gershenfeld, 2012). Indeed, even in open source communities, access restrictions or protection over specific designs should happen for protection of public safety. As it was described before, the advances in speed, quality and materiality towards 3d printing can challenge current legal framework of guns as they can be produced and distributed locally, with materials-thermoplastics- that cannot be identified by metal detectors in airports and other public spaces.

2.5 DISCUSSION

After analyzing the prospects and the threats of digital fabrication, it would be vital to criticize them.According to Anderson (2012) digital fabrication inverts the economics of traditional manufacturing. Indeed, Carpo (2017) has demonstrated that in traditional manufacturing, economies of scale are proportional to the number of identical products produced, as the profit is rising when items are distributed to more customers. However, these rules cannot be applied to digital fabrication products. Even from 1990s, people understood that digital mass customization can lead to economies without scale, today's aggregations of supply and demand does not make the production process cheaper (Carpo, 2017). This happens as in digital fabrication variety, complexity and flexibility is free (Anderson, 2012), as everyone can modify a digital file and produce it locally. Standardization is not a condition as in digital fabrication the products, which used to be expensive with traditional techniques are now becoming free (Anderson, 2012).

However, the examples presented about large scale 3d printing of AI- build and MX3D remain time consuming and not affordable for the buildings of tomorrow. The current limitations of additive manufacturing prevent its further adoption from the industry. Even though many startups, labs and companies have started to study these limitations, until now additive manufacturing hasn't achieve to challenge the current subtractive manufacturing techniques intensively and decisively in order to illustrate the real future of making. It is still enclosed in small scale and in prototyping uses.

The same time, the current advances of artificial intelligence seem to create a new dynamic towards their applications to additive manufacturing. More specifically, Using AI, additive manufacturing can be developed faster, in an affordable way, defining the future of both design and making. In the second digital era, AI has started to be developed and we are in the very beginning of that process. Machine learning can empower not only additive manufacturing but also the way that design is conceiving and happening. For example, in the Autodesk Dreamcatcher platform design is defined from designers through specific goals and contains whereas the same time many variations are produced without extra cost (Autodeskresearch.com, 2019).

Furthermore, the rise of the usage of industrial robots and the ability of users to make their owns end effectors applied to these robotic arms can be enforced by Ai algorithms and create real innovative projects. Standardized 6-axis robots with their own extruder can be used to shape the future of making. Ai algorithms can identify the most effective toolpaths or even supervise the printing process and adjust it through feedback while extruding.

Moreover, the cost of the printing is affected not only from the cost of the machine-the robot- and materials but also from the possibility of printing errors. For example, if a maker knows that an industrial robot can extrude a complex structure without printing errors and quite fast, the cost of the final piece would be seriously lower, compare to printing more than one time in order to achieve an acceptable result. The same time, if this maker could inform other makers into her community about the settings she mastered, it can be assumed that large scale 3d printing could be seriously advanced.

Consequently, the rise of open source platforms, the wide use of industrial robots, the computational power and the algorithmic innovation are shaping a new future of making, the future of AI applications on it. In my point of view, now is the momentum in which designers and makers should take the chance and make communities, sharing information and data about these prospects. Although Ai creates new routes to digital fabrication, the complexity of the algorithms and computational intensive processes demand specific research on well-defined topics; otherwise it can be a waste of energy.

One prospect of the future of making in my point of view could be the integration of AI with additive manufacturing because it would help humanity to gain knowledge about 3d printing quickly and challenge all the other traditional subtractive techniques which are known to humanity for centuries. I think that this prospect can be developed even more through open source communities as more people from different backgrounds can solve faster and better a problem that a single human or a single company can.

Bearing these points on mind, these days in Bartlett school of Architecture I start to develop my thesis, which is based on the above arguments. I study an open source machine-learning framework for large-scale additive manufacturing, as I believe that it can push both design and fabrication out of their current limits.

3. CONCLUSION

The development of digital-computational tools has changed the design and making processes so radically that Gershenfeld (2012) is referring to a new digital revolution in fabrication. There are valuable doubts towards this idea regarding the challenge of digital materiality, the use of digital tools in fabrication, the goal of mass collaboration, the relationship of design with making processes. However, Gershenfeld has described the revolution as a dynamic and changing procedure, not as a static fact, in which every issue is solved. While he clearly understands the many problems, he also demonstrates the real prospects of them, making his arguments convincing and his vision possible.

As regards the basic roots of digital fabrication as a concept – i.e., the transitions of things into data and data into things – emerged centuries ago. Indeed, Aristotle's theory of hylomorphism, Alberti's distinction between designing and building, Le Corbusier's vision of the house-engine and Kwinter's biological model were all stepping stones to the present conception of digital fabrication. Even though historical periods were changing, the relation between, information-ideas and matter was a fundamental concern for many philosophers-architects throughout the centuries.

In the 21st century, however, digital fabrication products are on the market and have great potential for development (Gershenfeld, 2012). The explosion of international fab labs indicates that the familiarization of local communities with digital fabrication workshops is imminent. Studies in M.I.T about human-computer interactive frameworks, such as the 'active prototyping', and investigations into large- and small-scale 3d printing machines, further prove the significant progress of digital fabrication devices. Multi-material extruders, such as the Ultimaker 3, electronic platforms, such as Arduino and synthetic biology printing, demonstrate the progress being made in overcoming the temporal limitations of cost, time and printing quality. However, several threats regarding digital fabrication need to be addressed, including the public's authority to use information without regulations, authorship and ownership issues the theft of personal property and the development of guns (Gershenfeld, 2012).

Overall, the significant interest in digital fabrication research at universities and industries alike, the emergence of numerous start-ups and digital fabrication workshops worldwide, the progress made in regard to large- and small-scale, multi-material and biology printing, the development of open source software platforms and AI algorithms, the limitation of the cost of fabrication devices, all indicate the emergence of a new digital revolution in fabrication. Hence, according to Gershenfeld (2012), the main question for future research is how people will live, work and play when digital fabrication is a commonplace reality.

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