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INDUSTRY 4.0

Additive Manufacturing as a New Digital Technology for Private and Businesses

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ECONOMIA - *Ricerche*

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SUMMARY

INTRODUCTION

The world has started to speak about a possible new revolution that would change radically the way in which the entire economic system will be managed: Additive Manufacturing, together with the other enabling technologies of the industry 4.0, has the potential ability to change the traditional concepts of manufacturing and the way in which the production is managed throughout its supply chain.

Even Jeremy Rifkin, one of the sharpest and recognized analyzers of socio-economic scenarios, believes that the phase of digitization, the Third, has just begun and has yet to fully show all its implications and its potential.

On the contrary Klaus Schwab, a German engineer and economist, best known as the founder and executive chairman of the World Economic Forum, in his book "The Fourth Industrial Revolution", argues that the first three revolutions are the transport and mechanical production revolution of the late 18th century; the mass production revolution of the late 19th century, and the computer revolution of the 1960s. He accepts that some people might consider the fourth revolution just an extension of the third but argues that the scale, speed and impact of the latest technologies mean they deserve a revolution of their own.

Whether the revolution in act today is in the Third or the Fourth, while the old way of making things involved taking lots of parts and screwing or welding them together, now a product can be designed on a computer and "printed" on a 3D printer, which creates a solid object by building up successive layers of material. This new way of producing objects, that is called Additive Manufacturing (AM), is considered to be revolutionary.

This study, divided in four chapters will analyze the changes that the Industry 4.0 is making to the whole economic system focusing on the manufacturing technology of Additive Manufacturing (AM) and analyzing the

Italian economic context of reference, in the wood-furniture manufacturing sector. It will consider the supply side, that is the propensity of businesses to use 3D printers in the prototyping and subsequent production phase and the role of Fab Labs as mediators for the use of the technology between private consumers and businesses; the demand side and therefore Italian consumers knowledge of AM, 3D printing technologies and Fabrication Laboratories (Fab Labs), their perceptions about products made using 3D printers, their propensity to buy products made with these technologies and to use these ones to create their one products. Finally it will consider also environmental aspects related to the "indoor air quality" and 3D printers melting techniques when printing for example plastic filaments of materials.

In detail chapter 1 investigates, through a literature review, what is Additive Manufacturing, starting from its origins, trying to outline its developments over time and understanding its future lines of development. After the description of the Additive Manufacturing technique and of its application fields, the chapter deals with the analysis of the international significance of the phenomenon and then focuses on the Italian situation, investigating the presence of a potential gap between the International and Italian economic system.

Chapter 2 deals with the places where digital manufacturing technologies and 3D printing take shape, that is, Fabrication Laboratories (Fab Labs). They are defined as a platform for learning and innovation: a place to play, to create, to learn, to mentor, to invent. After describing the born of the International Maker Movement, the chapter describes the typical layout of these digital manufacturing spaces, where makers operate; the tools and machines used in it and the people that appeal to it. Subsequently the main Fab Labs realities are taken into account, through an empirical research, describing the diffusion and typology of laboratories present in the Italian territory and making a comparison between this reality and the other main European and American ones, highlighting their potential strength and weaknesses and identifying their role both towards consumers and businesses in the Industry 4.0 era. The aim of this second chapter is therefore to analyze where Do Ii Yourself (DIY) comes to life; these laboratories work with the typical mechanisms of the sharing economy: they provide a space with tools and equipment for digital manufacturing, making them available to individual users, small businesses and schools.

As for chapter 3, this takes into consideration the analysis of the perception and development of Additive Manufacturing techniques in the Italian market. To do this, the results of three research works are presented. The first tries to investigate the knowledge and perception that Italian consumers have of 3D printers, and their propensity to use these manufacturing technologies in order to evaluate how much Italian consumers are near to the definition of the new consumer called "Prosumer" given by Alvin Toffler (1980).

Subsequently it has been investigated the role of businesses in investing in this new manufacturing technology. The research focus was the Italian wood-furniture industry, solid pillar of the Made in Italy, where design is the first element of importance. The aim was to understand if companies in this sector were investing in digital technologies and in particular in AM techniques, to remain competitive in their reference markets. The research also attempted to investigate the potential sustainable benefits and barriers to the implementation of AM in this specific sector, trying to identify the gaps in perception between "traditional companies", which have never implemented AM techniques and those "innovative", which have implemented these technologies yet.

Finally chapter 4 deals with Additive Manufacturing and the possible problem of Indoor Air Pollution due to the melting process of 3D printers, during which materials such as plastics emit gaseous substances, commonly called Volatile Organic Compounds (VOCs). Assessing that the quantity of substances emitted does not exceed threshold levels is important for the health and safety of those using such digital tools.

The chapter starts defining the concept of Air Pollution, and distinguishing between Indoor and Outdoor Air Pollution. It continues describing what VOCs are and the guidelines for Indoor Air Quality defined at an European and Italian level. The chapter ends with the description of the results of the research, which performed air sampling of indoor air environments, while a 3D printer was under function, with different types of plastic materials (PLA, ABS, PET) in order to understand and assess the potential dangerousness to human health of this technological tool. Non-manufacturing environments such as offices, homes, classrooms, and libraries are usually designed for occupant comfort, not exposure mitigation. Hence, use of 3D printers in non-manufacturing or private settings potentially represents another contribution to VOC exposure for indoor workers and the general public to particles with potential dangers for human health. Since most desktop 3D printers are not equipped with exhaust ventilation or filtration accessories and users in home and public settings typically do not utilize appropriate personal protective equipment, it is important to characterize the physicochemical properties of 3D printer emissions to understand exposure potential and risk as early on as possible in the adoption of this technology to non-industrial settings. To this end, in collaboration with laboratory Cosmob Spa, this research performed air sampling of indoor air environments, while a 3D printer was under function, with different types of plastic materials in order to understand and assess the potential dangerousness to human health of this technological tool.

1. ADDITIVE MANUFACTURING: IS IT THE FUTURE?

Abstract

The world has started to speak about a possible new revolution that would change radically the way in which the entire economic system will be managed: Additive Manufacturing has the potential ability to change the traditional concepts of manufacturing and the way in which the production is managed throughout its supply chain. The aim of this chapter is to investigates what Additive Manufacturing is, starting from its origins, trying to outline its developments over time and understanding its future lines of development. After the description of the Additive Manufacturing technique and of its application fields, the chapter will deal with the analysis of the international significance of the phenomenon and then will focus on the Italian situation, investigating the presence of a potential gap between the International and Italian economic system.

1.1. Additive and Subtractive Manufacturing

Currently the world economy is going through a period of transition and change that the journal *The Economist* has defined as "The Third Industrial Revolution":

> The first industrial revolution began in Britain in the late 18th century, with the mechanisation of the textile industry. Tasks previously done laboriously by hand in hundreds of weavers' cottages were brought together in a single cotton mill, and the factory was born. The second industrial revolution came in the early 20th century, when Henry Ford mastered the moving assembly line and ushered in the age of mass production. The first two industrial revolutions made people richer and more urban. Now a third revolution is under way. Manufacturing is going digital (The Economist, April 21st, 2012).

Even Jeremy Rifkin, one of the sharpest and recognized analyzers of socio-economic, technology and production scenarios, believes that the phase of digitization, the Third, has just begun and has yet to fully show all its implications and its potential (Rifkin, 2011; Carlucci, 2015; Ruffilli, 2015).

On the contrary Klaus Schwab, German engineer and economist, best known as the founder and executive chairman of the World Economic Forum, in his book "The Fourth Industrial Revolution", argues that the first three revolutions are the transport and mechanical production revolution of the late 18th century; the mass production revolution of the late 19th century, and the computer revolution of the 1960s. He accepts that some people might consider the fourth revolution just an extension of the third but argues that the scale, speed and impact of the latest technologies mean they deserve a revolution of their own. "The changes are so profound that, from the perspective of human history, there has never been a time of greater promise or potential peril" (Schwab, 2016; Thornhill, 2016).

Whether the revolution in act today is in the Third or the Fourth Industrial Revolution, while the old way of making things involved taking lots of parts and screwing or welding them together; now a product can be designed on a computer and "printed" on a 3D printer, which creates a solid object by building up successive layers of material. This new way of producing objects, that is called Additive Manufacturing (AM), is considered to be revolutionary.

The AM technique is a production mode that, even using very different technologies, allows the creation of objects (components parts, semi-finished or finished products) generating and adding successive layers of material (Additive Manufacturing) rather than by subtraction from the full (Subtractive Manufacturing), just as it is in many of the traditional technical production (turning, milling, etc.) (Centro Studi Confindustria, 2014). It is an important evolution in the context of the broader trend of the digitalization of manufacturing that takes place through dialogue between computers and machines thanks to the sharing of information (among machines, people and between people and machines) made possible by the spread of the Internet.

AM is a radical innovation, capable of producing profound changes in the economy and society from many points of view. There is the possibility of creating objects with new geometries, reducing the stocks, achieving a "mass customization" of many products, redefining the location processes of production activities with different logistics, a new work organization, new professional figures in the field of manufacturing and crafts and new spaces for creative action of individual citizens. The revolutionary aspect of AM consists in the fact that the objects are not realized by removal of material, as it is in the case of operations with computerized numerical control machines

(CNC) such as milling machines, lathes, presses, machining centers, or for welding of separate pieces; on the contrary, the objects are generated for stratification and addition of material directly into a single piece. AM allows to produce items with complex geometries not otherwise achievable in a single piece with the traditional techniques and ensures that the development of variants of costs compared to a basic model are substantially zero. For these reasons this technique is currently used mainly in the following cases (Centro Studi Confindustria, 2014):

> productions in which it is the technology of choice, that is, when it allows to reduce the costs and made objects with equal or greater technical characteristics to obtain unique qualitative standards, not achievable with traditional techniques;
>
> productions where technology is cost competitive only if you change the object's design that has to be realized. Changes in design allow to maximize the potential of AM without compromising (or improving) the technical characteristics of the object;
>
> productions where technology is not competitive in absolute terms but may be economically advantageous because:
>
> – the piece printed in 3D is more expensive, but AM (due to its flexibility, the speed of production without the need for molds or other tooling) allows you to "store" files instead of products, thereby reducing the capital tied up in inventory and stock costs;
> – AM can allow to withstand sudden and unanticipated lack of components for in-line production;
> – AM allows the constructive reengineering of more efficient pieces (and more expensive) that help increase the productivity of existing industrial facilities.

The sectors most involved today are, in addition to prototyping in general, aerospace, automotive, biomedical, packaging and it is widespread in jewelery. While some areas will see rapid and disruptive changes, such as those just mentioned, others will change slowly and steadily. Either way we are going to the so-called "New Normal" (Potti, 2015), that is to say, this is already the new world in which physical objects are perfectly integrated into the network of information.

In this new world, manufacturing has an important role due to the fact that it is the main engine of economic growth because it generates productivity gains which then are spread, through the goods it produces among the other sectors; it creates skilled jobs and better paid; it makes the most part of research and innovation, making benefits to the whole system through new innovative content of manufactured goods used from the other sectors (Paolazzi, 2015).

Technological developments, together with those of the production allow products and machines to communicate with each other and exchange commands wirelessly, directly or via the Internet of Things. The result is a much more flexible production environment, with less central control and more integrated intelligence locally in equipment, able to optimize the efficiency of processing.

In this production scenario, the strategic challenge of companies that aim to be part of the future of European manufacturing is grafted: understanding how to plan the development paths that promote technological advancement in production systems, based on the diffusion of the key technologies of this new Industrial Revolution in its production structure.

1.2. The road towards Additive Manufacturing

Additive Manufacturing has roots in topography and photosculpture which date back almost 150 years. Both of these early technologies might be categorized as manual "cut and stack" approaches to build a freeformed object in a layerwise fashion. The first successful AM process was effectively a powder deposition method with an energy beam proposed by Ciraud in 1972. Over the last 20 years increasingly sophisticated technologies have been developed to produce complex, freeform solid objects directly from computer models without part-specific tooling; these are often labeled "solid freeform fabrication" (SFF) technologies. Until recently they have been applied principally to prototype models and have encompassed predominantly additive or layered manufacturing techniques. These technologies are evolving steadily and are beginning now to encompass related systems of material addition, subtraction, assembly, and insertion of components made by other processes. Furthermore, these various additive/subtractive processes are starting to evolve into rapid manufacturing techniques for masscustomized products, away from narrowly defined rapid prototyping (Beaman et al., 2004).

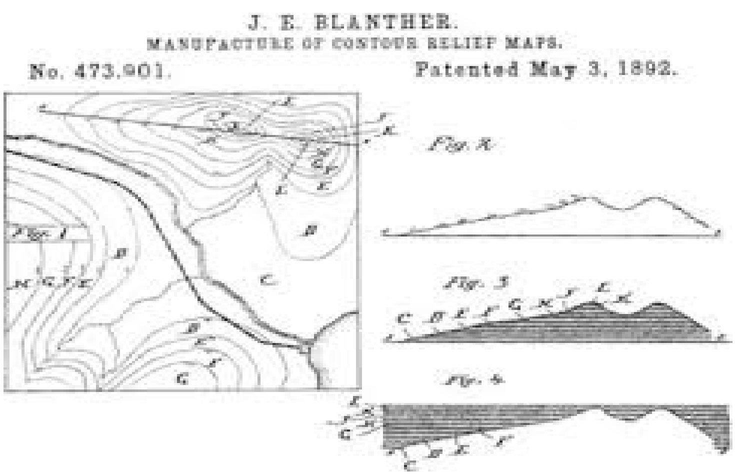
1.2.1. Prehistory of AM

An essential element of AM is layerwise creation of a part. From a review of the US patent literature, Bourell et al. (2009) identified two early roots of the modern AM technique that is to say topography and photosculpture.

Topography

Topography is the study of the shape and features of the surface of the Earth and other observable astronomical objects including planets, moons, and asteroids. It involves the recording of relief or terrain, the three-dimensional quality of the surface, and the identification of specific landforms. This is also known as geomorphometry. In modern usage, this involves generation of elevation data in digital form (DEM). It is often considered to include the graphic representation of the landform on a map by a variety of techniques, including contour lines, hypsometric tints, and relief shading. Topography is considered a precursor of AM since Blanther (1892), suggested a layered method for making a mold for topographical relief maps. The method consisted of impressing topographical contour lines on a series of wax plates and cutting these wax plates on these lines. After stacking and smoothing these wax sections, one obtains both a positive and negative three-dimensional surface that corresponds to the terrain indicated by the contour lines. After suitable backing of these surfaces, a paper map is then pressed between the positive and negative forms to create a raised relief map (Figure 1.1).

Fig. 1.1 – Blanther's layering method for producing topographical maps



Source: Bourell et al. (2009)

In a similar way, Perera (1940) proposed a method for making a relief map by cutting contour lines on sheets (cardboard) and then stacking and pasting these sheets to form a three-dimensional map. In 1972, Matsubara (1974) of Mitsubishi Motors proposed a topographical process that uses photo-hardening materials. In this process, a photopolymer resin is coated onto refractory particles (e.g., graphite powder or sand). These coated particles are then spread into a layer and heated to form a coherent sheet. Light (e.g., mercury vapor lamp) is then selectively projected or scanned onto this sheet to harden a defined portion of it. The unscanned, unhardened portion is dissolved away by a solvent. The thin layers formed in this way are subsequently stacked together to form a casting mold. Subsequently DiMatteo (1974) recognized that these same stacking techniques could be used to produce surfaces that are particularly difficult to fabricate by standard machining operations. In one embodiment, a milling cutter contours metallic sheets, these sheets are then joined in layered fashion by adhesion, bolts, or tapered rods. This process has obvious similarity to the earlier 19th century work, and are forerunners techniques of the recent AM technique.

Photosculpture

Photosculpture arose in the 19th century as an attempt to create exact three-dimensional replicas of any object, including human forms (Bogart, 1979). One, somewhat successful realization of this technology was designed by Frenchman François Willème in 1860. A subject or object was placed in a circular room and simultaneously photographed by 24 cameras placed equally about the circumference of the room (Figure 1.2) An artisan then carved a 1/24th cylindrical portion of the figure using a silhouette of each photograph.

In an attempt to alleviate the labor-intensive carving step of Willème's photosculpture, Baese (1904) described a technique using graduated light to expose photosensitive gelatin that expands in proportion to exposure when treated with water.

In some of the earliest work in Japan, Morioka (1935, 1944) developed a hybrid process between photosculpture and topography. This method uses structured light (black and white bands of light) to photographically create contour lines of an object. These lines could then be developed into sheets and then cut and stacked or projected onto stock material for carving.

Fig. 1.2 – The photosculpture method of François Willème using cameras surrounding the subject

Source: Bourell et al. (2009)

1.2.2. First attempts to modern AM

The first step towards the modern AM was made in 1956 from the mind of John Munz, who developed a method to "register" solid objects in a resin by ultraviolet light, baptizing "photo-glyph recording". Munz (1956) proposed a system that has features of present day stereolithography techniques. He disclosed a system for selectively exposing a transparent photo emulsion in a layerwise fashion where each layer comes from a cross section of a scanned object. Subsequently in 1968, Swainson (1977) proposed a process to directly fabricate a plastic pattern by selective, three dimensional polymerization of a photosensitive polymer at the intersection of two laser beams, while Ciraud (1972) proposed a powder process that has all the features of modern direct deposition AM techniques. This disclosure describes a process for the manufacture of objects from a variety of materials that are at least