The Additive Manufacturing in the Industry 4.0 Era: The Case of an Italian FabLab

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Abstract
Nowadays it is possible to create a flexible, automated and agile production, implementing complex technologies, combining physical objects and information systems. Machines and robots are able to communicate each other, to take decisions in an independent way, to self-update and to self-adapt to changing context. The introduction of new automated techniques, the development of sophisticated and autonomous devices and machineries allow the creation of smart factories, giving origin to the Smart Manufacturing phenomenon. Additive manufacturing (AM) is one of the most widespread technologies in operational practices that with rapid prototyping and 3D printing, has revolutionized the production. It is an advanced technology to produce parts, using advanced computer-aided design software. As a consequence, the affirmation of digital fabrication labs, which aim is to promote digital culture, providing innovative tools and sharing knowledge, creating customized products. The present work provides a theoretical contribution to the extant literature of additive manufacturing technology and a practical example to encourage companies to adopt innovative tools. From a practical point of view, it is examined the characteristics and applications of 3D printing in a FabLab in the South of Italy. The methodology used is the case study technique, where information are collected through descriptive survey. The aim of this work is to investigate about the use of additive manufacturing technique, putting in evidence benefits and limits of this technology. In this way it is possible to understand about the development of Industry 4.0 in our country, in particular giving attention to the application of Additive Manufacturing technologies.

Keywords: Additive Manufacturing, 3D printing, Smart Factory, Smart Manufacturing, Digitalization.

JEL classification: O14

1. Introduction

The development of digital innovation, thanks to the smart manufacturing technologies, represents a new production paradigm, based on the interaction between man and machines: it is an opportunity for production, technology and communication development, thank to which it is possible to interconnect human resources and ICT technologies, improving efficiency, product quality, productivity, business strategies, analyzing a significant amount of data in "clouds".

In this sense, it is possible to guarantee the immediate measurement of parameters and the traceability of products or components: the use of sensors, placed directly on products, allows the reduction of structural complexity, realizing a more agile supply chain.

The new production paradigm is called "fourth industrial revolution" or "Industry 4.0".

The manufacturing revolution has begun in 2011, when the German government promoted the Industry 4.0 initiative, in cooperation with industrial and scientific organization. The promotion of the industrial change and the acquisition of a leadership position in manufacturing sector in the world, were the main objectives of the country (Bartodziej, 2017). At the same time, USA developed the Advanced Manufactured Partnership, a re-industrialization plan, aimed at innovating manufacturing through the adoption of intelligent production systems and improving the occupational level of the country. In 2011, the United States launched the "Advanced Manufacturing Partnership" plan, in order to innovate the manufacturing system of the country, increasing productivity and reducing costs. With a greater delay, in 2015, France launched the "Alliance for the Future" program, to implement the digitization process for support innovation, and in 2016, Italy, approved the "Industry 4.0" plan (http://www.economyup.it).

The originality of the work is to provide a theoretical contribution to the extant literature of additive manufacturing technology, providing a practical example of the application of 3D printing, presented the case of a FabLab in the South of Italy. The aim is to investigate about the widespread of additive manufacturing technology, trying to put in evidence the advantages, the disadvantages and the future development of the phenomenon.

2. The Industry 4.0 technologies

According to a study conducted by the famous American consulting firm, the Boston Consulting Group, the enabling technologies of Industry 4.0 are the follows:

- Augmented Reality, which are a set of tools that allow you to add information to those actually feel;
- Simulations, aimed to optimize products and processes, minimizing the number of errors. The need to specialize in methods and tools, such as analytics and data visualization, simulation and forecasting, is considered vital for taking correct decisions in real time, improving critical situation;
- Vertical / Horizontal integration of information throughout the entire value chain, from the supplier to the consumer. The industry 4.0 allows the business functions union, both from an internal perspective and in a vertical direction;
- Cybersecurity, which represent the ability to achieve a complete connection due to the use of standard communication protocols;
- Big Data and Analytics, which are the collection and analysis of large amounts of data to improve products and production processes;
- Cloud computing, which represents the ability to obtain a set of data or IT resources, available by the Internet and accessible at all times;
- Industrial Internet of Things, which are a set of technologies and sensors that enable communication between the artificial world and people, including products and production processes. It defines the attitude on the part of the objects belonging to the business world to develop its own intelligence, qualified in terms of self identification, location, status diagnosis, acquisition / data processing and implementation;
- Additive Manufacturing, which refers to the development of processes capable of creating objects using additive manufacturing processes through 3D printing. The additive manufacturing allows companies to produce prototypes, finished products directly on the market, or producing individual components capable of enhancing the products also in terms of design. At the same time a number of indirect benefits, such as lower stock of raw materials and the reduction of costs associated with transport and logistics;
- Autonomous robots, which operate in the business world to carry out complex nature of tasks. Robots are autonomous, flexible and cooperative with each other and especially with man from whom they can learn independently (BCG, 2015; Rüßmann et al., 2015).

Fig. 1: The Smart Manufacturing Technologies
Source: The BCG, 2015

These kinds of technology are already in use, such as the 3D printers, the RFID technologies and the augmented reality. The actual change makes reference to the ability to create a new production model, realizing a new relationship between customers and suppliers.
With reference to the 3D printing, it represents the most disruptive digital technology in the Industry 4.0 program. This technology is a real revolution: the production is based on a virtual 3D model and it is "printed" layer by layer. The input of additive production process is the realization of a 3D model of the object (CAD design), followed by a semi-automatic STL file conversion process, which convert the object into printable layers. Finally, after the printing process, post-production and finishing activities are required. One of the peculiar elements of 3D printing technologies is the ability to create objects in a single printing process instead of the traditional production which made several individual components and then assembled them (http://www.internet4things.it).

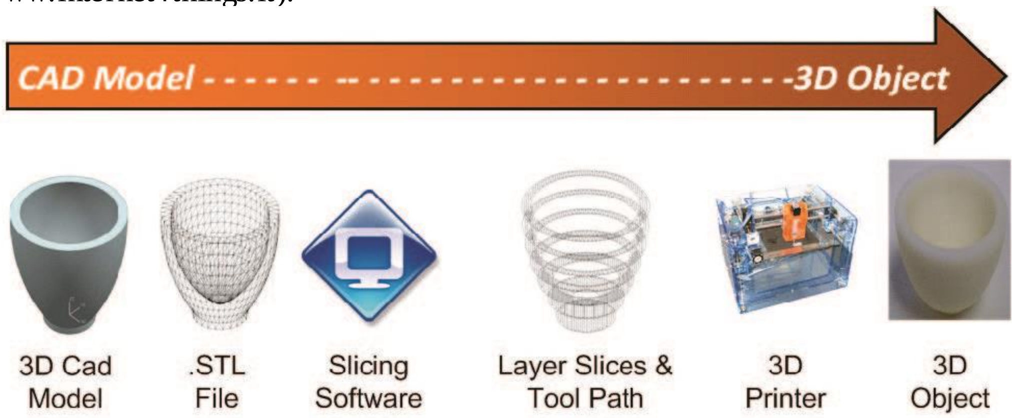

Fig. 2: The 3D printing process
Source: https://www.intechopen.com

2.1. The development of Smart factory

Nowadays it is possible to create a flexible and agile production, implementing complex technologies, combining physical objects and information systems. The phenomenon is known as Smart Manufacturing and it has created a new production era: the Industry 4.0 (Wang et al., 2015).

The adjective “smart” makes reference to the expansion of functionality resulting from the interaction between physical objects and strong technologies (Radziwon et al., 2014). Moreover, it is very difficult the application of this technology to the business in order to realize intelligent production, making the products intelligent; probably, it is due to difficulties which historically afflict the industrial sector, and which are not passed.
In fact, despite the progressive definition of promising and resolving industrial paradigms, such as lean, agile and flexible manufacturing, the questions related to cost, quality production, planning activities and processes are not solved (Wang et al., 2015).
In the nineties, computers could be considered a way to resolve these problems, thanks to the business innovation: firstly the concept of U-Factory, secondly the Factory of Things (Zuehlke, 2010), represented the connection between the IoT technologies and traditional manufacturing paradigms. This concept has been developed into the contemporary concept of Smart Factory.
To create a successful Smart Factory it is necessary not only the use of data and advanced technologies but also the rearrangement of the organizational level, aimed to guarantee flexibility and adaptability (Davis et al., 2012). Obviously, the reorganization makes reference to the activities related to horizontal and vertical dimensions: the relationship with the outside world and internal relations within the enterprise.
The study conducted by Wang (2015) puts in evidence the differences between the use of “enabling technologies”, represented by the Smart Factory and the traditional production line (Wang et al., 2015, 6).

Smart factory production system	Traditional production line
Diverse Resources. To produce multiple types of small-lot products, more resources of different types should be able to coexist in the system.	Limited and Predetermined Resources. To build a fixed line for mass production of a special product type, the needed resources are carefully calculated, tailored, and configured to minimize resource redundancy.
Dynamic Routing. When switching between different types of products, the needed resources and the route to link these resources should be reconfigured automatically and on line.	Fixed Routing. The production line is fixed unless manually reconfigured by people with system power down.
Comprehensive Connections. The machines, products, information systems, and people are connected and interact with each other through the high speed network infrastructure.	Shop Floor Control Network. The field buses may be used to connect the controller with its slave stations. But communication among machines is not necessary.
Deep Convergence. The smart factory operates in a networked environment where the IWN and the cloud integrate all the physical artifacts and information systems to form the IoT and services.	Separated Layer. The field devices are separated from the upper information systems.
Self-Organization. The control function distributes to multiple entities. These smart entities negotiate with each other to organize themselves to cope with system dynamics.	Independent Control. Every machine is preprogrammed to perform the assigned functions. Any malfunction of single device will break the full line.
Big Data. The smart artifacts can produce massive data, the high bandwidth network can transfer them, and the cloud can process the big data.	Isolated Information. The machine may record its own process information. But this information is seldom used by others.

Table 1: Technical aspects of a smart factory compared with those of a traditional factory
Source: Wang et al., 2015, p.6

It is not easy for companies, especially for smaller size one, to realize a manufacturing technology changes: the most problematic aspects are connected to the high investment (Helu et al., 2015), infrastructure difficulties (both in physical and regulatory sense), professional and technical deficiencies, security and defense issues.
The creation of a smart factory will provide a set of benefits such as the reduction of capital needs, the reduction of production time, the drop in emissions, waste, energy consumption and better returns.
In the smart factory, one of the most important factor is communication between machines and robots, which are able to make decisions independently, to self-update, to self-learning and self-adapting to internal and external changes (National Academy of Science and Engineering, 2013; Rüßmann et al., 2015). As a consequence, the production process is optimized and the production lines are automated, bringing the reduction of errors, wastes, costs, time-to-market, improving the total quality (Oesterreich et al., 2016).

2.2. The Additive Manufacturing technology
Among the different "smart" technologies, the Additive Manufacturing, also known as 3D printing, currently dominates the technology and media context, for its strong impact on business prospects (Ford & Despeisse, 2015).
The term additive manufacturing makes reference to the process of joining sheet materials by layer, starting from a virtual model: it is the opposite of traditional methods to realize goods and products. Additive manufacturing processes is a set of complex and varied techniques, which are different for the type of operation and materials used.
Additive manufacturing processes take the information from a computer-aided design (CAD) file that converts information into a stereolithography (STL) file. Additive Manufacturing uses digital design data to build up an object by depositing material layer-by-layer. To perform the printing, the 3D printer reads the digital data to form successive layers of material to build up the part (https://www.optomec.com).
From the technological point of view, this is not a recent innovation (3D printing has been used since the mid 80's), but in recent years the opportunities to use this technology have expanded considerably thanks to the ability to "print" larger objects, in a wide range of materials (plastic, metal, ceramic, wax, plaster, composite materials, etc.), with the reduction of production times. Even the cost of the machines has decreased and all these factors have allowed a very important development of this technology (Centro Studi Confindustria, 2014).
The 3D printing has gone through four evolutionary stages, starting from the technology used by Charles Hull for the "prototyping" sector (Rayna & Striukova, 2015).
In fact the first use of three dimensional technologies associated with computer aided design (CAD) makes reference to the 80', when it was created models thanks to the rapid prototyping: rapid prototyping is one of the initial additive manufacturing processes (Wong & Hernandez, 2012). The development of the rapid prototyping, allow the rapid realization of models, guaranteeing time and cost reductions (Ashley, 1991).
Over the years its application has been extended to the realization of "rapid tooling", and then to the creation of "rapid manufacturing" including various industrial sectors. This phenomenon is developed in "home fabrication": the use of 3D printers allows customers to make products directly from home. It is interesting to note that the evolution of technology has not led to abandon of areas in which this was originally applied (Rayna & Striukova, 2015).
Nowadays, these technologies are known as 3D printing and their origin makes reference to the rapid prototyping: the union between the computer aided design (CAD), computer aided manufacturing (CAM) and computer numerical control (CNC) gives the opportunity to realize three dimensional objects (Noorani, 2006; Kruth, 1991).

The 3D production has been treated by different points of view: some studies put the attention on the case study method (Mellor et al., 2013); other studies analyze the economic consequences of additive manufacturing (Weller et al., 2015); instead other authors put the attention of the future implication of this technology (Schniederjans, 2017).

The set of new features of Additive Manufacturing leads to the redefinition of products, services and business models, making the technology “disruptive” (Kietzmann et al., 2014).

The choice of using Additive Manufacturing to business has a strategic value and there is the necessity to set a detailed analysis in terms of trade-off (Mellor, 2014), considered the limits and the opportunities offered by this kind of technology. The benefits related to the adoption of 3D production are numerous: first of all it is possible to use a great number of material to realize objects (Columbus, 2015), so as a consequence, the increasing number of materials available has conducted to a major application of this technology in a great number of manufacturing industries (Bourell et al., 2009; Campbell et al., 2012; Gardan, 2015; Starr, 2015), in particular with reference to the aerospace sector, the automotive industry, the construction and healthcare industries. The consequence of 3D application differs from the traditional one: first of all in this case parts and components are produced in a short period of time, so that the time to market is really reduced, it is possible to realize the materials saving (Petrovic et al., 2011). 3D printers are fast, reliable and easy to use: with a 3D printer it is possible to create objects made up of different materials and from different physical and mechanical properties in a single process. The digital revolution, therefore, is no longer limited to computers and related devices: today production has also become digital, so that there is an industrial revolution developing a new production paradigm (http://www.3dz.it).

Connected to this type of production there are different disadvantages, such as the high production costs, considerable effort in application design and setting process parameters, a post-processing activity, discontinuous in production process, limited component in size and poor mechanical properties (http://compositesmanufacturingmagazine.com).

3. The methodology

The application of Industry 4.0 plans and the adoption of additive manufacturing technique are very widespread phenomenon. This work aims to analyze the additive manufacturing event, reporting a case study of real life, trying to investigate about the advantages, disadvantages, difficulties and future scenarios related to the adoption of this technology in a FabLab, located in the South of Italy: interviews to owners and observation method are used to collect information and analyze the phenomenon.

First of all the questionnaire has been developed putting in evidence some aspects, such as the type of machineries used, their characteristics, the strong and weakness points of the technology application, the relations with the industrial sector, the future scenarios and the principle difficulties in the development of digital factories.

3.1 The case study

The digital fabrication laboratories have been developed thanks to the diffusion of additive manufacturing techniques. The concept of Fablab (fabrication laboratory) was developed by the Professor Neil Gershenfeld, who founded the first FabLab in 2003.

According to a census in Italy, there are currently 70 Italian laboratories operating on digital manufacturing. In Italy, the first FabLab was created in 2011 in Turin.

The FabLabs are seen as centers of innovation and integration, such as physical locations where creative minds can come together and interact. The basic idea is to create a workshop that offers personalized services in digital manufacturing; moreover the networks can collaborate remotely and realize projects in digital form. The laboratory activities aim to solve problems related to technological improvement and the development of projects aligned with the needs of society and the market.

A FabLab is formed by a wide range of computer-based tools, such as the 3D printers, numerically controlled machines and laser machines. This kind of production can't compete today with mass production.

The case study analyzed makes reference to a FabLab located in Basilicata, which is important for 3D printing and digital fabrication technologies.

The FabLab is involved in several projects promoted by schools, associations and private entities, as well as being recognized and awarded for the best activities on the territory.

The aim of the association is to promote the knowledge of new technologies, facilitating the access to digital manufacturing.

The first aspect studied, makes reference to the machineries used: the FabLab works with RepRap 3D printers.

Specifically, it works with two printer models: the first is a magnetic printer, characterized by speed and precision, without making the process complex. It is a small dimension machinery used to perform a great variety of processes. In the laboratory it is tested the use of new materials which are officially unsupported, trying to make changes to improve performance. Moreover a FabLab promotes the development of "tools" that can be applied to the same printers, changing the original function.

The second type of printer allows the satisfaction of particular requirements in terms of processes especially those of larger physical size. The printer can be connected to a Wi-fi, and it supports a wide range of materials, realizing a highly precise printing.

Fig. 3: The RepRap 3D printing
Source: http:// fab.cba.mit.edu

As regards the relationships with industry and professionals, the company has made experiences with different business realities: for example it produces the oil plug for the great automotive sector, in particular for Fiat Multijet. The benefits of printing individual

components bring excellent results from the quality, functionality and cost perspectives. Other collaborations are realized with the electronic sector: the FabLab produces different components like sideburns for wireless charger in additive manufacturing, focusing on cost reduction and competitive products and prices. A great number of collaboration makes reference to the private sector: in particular the 3D supports for macro photographic, or handles for refrigerators, custom gadgets and machines to package local meats. As regards to the automotive industry it has been realized plastics components for vintage cars which have to be restored - in particular the actuators for the arrows and other controls on the steering wheel.
A great number of collaboration has been established with professionals and public sector. In particular, it has been realized collaborations with architecture experimental laboratory on the territory. Other collaborations are realized with a local design company which produces design and fashion items, which is interested in additive fabrication technique.
The company works with local dentists and dental clinicians to realize dental prosthesis: in this sector the 3D printing is applied with greater success. Also under medical realized, with the use of printer, it has been realized a prosthesis to treat the leg of a bird which is a risk of extinction. The FabLab works with health organizations and hospitals realizing a 3D reconstruction; another project makes reference to the development of a drone prototype printed in 3D using open source hardware.

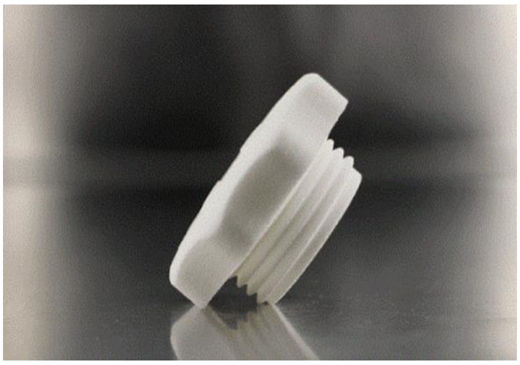

Fig. 4: Engine oil plug Fig. 5 : Dental components
Source: https:// www.3space.us Source: https://www.3dz.it

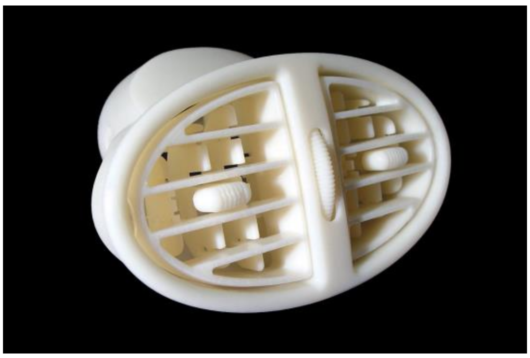

Fig. 6: Automotive components Fig. 7: Architectural models
Source: https://www.3dz.it Source: https://www.3dz.it

As regards the future projects the goal of the Smart Lab is the expansion of collaboration with the business world, trying to bypass the local limit and to individuate better opportunities.

The main obstacle to the development of digital manufacturing is the lack of a digital culture, the high costs of machineries, the slowness of processes, the scarcity of materials available.
Generally, there is a cultural nature problem: before evaluating commercial aspects regarding the distribution of equipment to the general public, the definition of innovative materials, low cost and necessary to carry out varied and complex productions, it is vital to promote and develop a digital culture.
As regards the future prospects for digital manufacturing, the actual context is characterized by a constant change, where the uncertainty is typical of a technological environment. However, in the near future the traditional printers will be replaced by 3D printers. As a consequence, the born of a new category of consumers, known as "prosumers": they are users who produce themselves goods. The use of this technology can significantly improve life, considering the ability to connect everything promoting the interaction between "things" from distance.
Fundamental is also the role of the community in the development of a Digital Lab. The community represents one of the most important factors to consider for the development of this technology, because it is necessary to study, to make experience, to keep up to date. It is necessary to take in consideration this aspect especially for small town, which suffer for the absence of young.

5. Conclusions

Industry 4.0 is a large and ever-evolving phenomenon. Additive manufacturing technology is the most representative of the new industrial paradigm and seems to be the most direct way to push towards manufacturing change. Developing this kind of technology is significant for companies: there are still a number of advantages respects to traditional production techniques. Moreover additive manufacturing can provide benefits not only for business but also for individual, which have the opportunity to produce personalized products, to create new object, to realize a self-production.
Additionally the additive manufacturing brings different kinds of advantages in a great number of sectors, as it has been experimented through the case study analyzed. First of all, additive manufacturing technologies are appreciated in the aerospace industry, for the possibility to manufacture lighter structures to reduce weight; in the automotive industry, to reproduce single small parts or components; in the healthcare sector, allowing the realization of precise model of a bone or body before a surgery; in the architectural modeling, to realize better solution and models (Wong & Hernandez, 2012). The case study demonstrates that the local entrepreneurs are investing in additive manufacturing activities, although the territorial context, especially in southern Italy, poses many difficulties in carrying out such activities.
However, there is still a lot of work before additive manufacturing processes become the standard in the manufacturing industry, reaching high levels of precision.
In conclusion, the adoption of these technologies will be successful and will bring significant benefits for corporate production and private individuals. In the second case, the development will inevitably be slower since companies have more resources than individuals.
The realization of sharing models represents an important stimulus to purchasing 3D printers because it allows the overcoming of CAD planning and design difficulties.
In general, there are some critical issues, which are technology-related, that should be perfected, but they don't represent an obstacle to 3D Printing development. So, in the next future a software exemplification is desirable to support the widespread of this kind of technology.

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