Project 2020-1-ES01-KA202-082778

INTELLECTUAL OUTPUT O1

INNOVATIVE OPEN TRAINING MATERIAL ON CIRCULAR ECONOMY AND DIGITISATION) FOR VET LEARNERS IN THE WOOD&FURNITURE SECTOR.

SECTION 2. ADDITIVE MANUFACTURING (3D PRINTING)

UNIT 1. FUNDAMENTAL OF ADDITIVE MANUFACTURING AND APPLICATIVE TECHNOLOGIES

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Content

UNIT 1. FUNDAMENTAL OF ADDITIVE MANUFACTORING AND APPLICATIVE TECHNOLOGIES.

1. FUNDAMENTAL OF ADDITIVE MANUFACTURING AND APPLICATIVE TECHNOLOGIES

1.1 Definition

The terms ADDITIVE MANUFACTURING, RAPID PROTOTYPING AND 3D PRINTING are often used indiscriminately as they are considered synonymous.

The definition of additives manufacturing (AM) provided by ASTM International is the following:

> *"A process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies*".

The term additive manufacturing therefore refers to manufacturing process of objects creations through the superimposition of layers, starting from a mathematical model of the object itself made on a CAD system (acronym for Computer Aided Design). Additive manufacturing is a process of joining materials to create objects starting from a (VIRTUAL) 3D MODEL and then printing layers of materials in succession, exactly or almost as it happens in the very common ink printers we have at home or in the office, therefore the contrary to the classic methods of subtractive production.

The term was coined to encompass the concepts of rapid prototyping, rapid tooling and rapid manufacturing, with the aim of identifying the main destinations of technology use (the process and applications will be explained in following). Regardless of the object made: a piece, a prototype or a product finished, choosing an additive manufacturing process means abandoning the well-known SUBTRACTIVE PROCESS, which involves the progressive material subtraction from a raw block until the desired shape of finished or semi-finished product is obtained according to a default design.

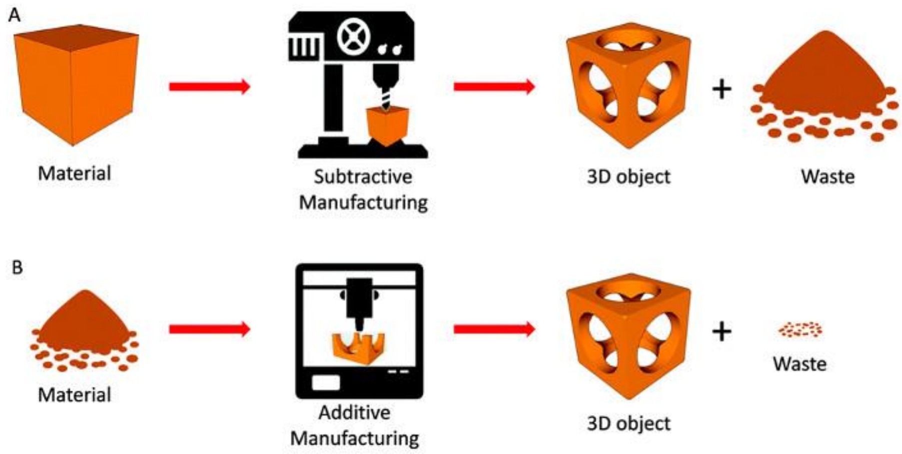


Figure 1. Subtractive and Additive Manufacturing

[* https://bitfab.io/blog/additive-manufacturing/](https://bitfab.io/blog/additive-manufacturing/)

One of the first uses of the additive method was precisely in the field of rapid prototyping, i.e. the rapid creation of even complex prototypes for evaluation purposes or the improvement of the same before the launch on the market. However, following the most recent developments in terms of usable materials, equipment costs, accuracy of pieces made the fields of application are increased and therefore the term of prototyping rapid is an understatement when compared with them.

1.2 Historical background

Although only recently we hear about 3D printing, its origins are to be traced back to the eighties. In fact, in these years that Charles Hull, founder and vice president of 3D Systems, obtains a series of patents on the subject. The first to be registered dates back at 1986 and concerns stereolithography (SLA or SL) which as Maietta explains (2014, p 19) is: "a method for creating solid objects by fixing and hardening thin layers of resins one on top of the other composed of photopolymers, materials that change their properties when subjected to ultraviolet light". Another patent obtained by Hull relates to the format of file used, called STL (STANDARD TASSELATION LANGUAGE), which allows to approximate a three-dimensional object in a series of adjacent triangles covering an entire space. A number of additive technologies have been developed around the same years, the two most important are: Selective Laser Sintering (SLS) and Fused Deposition Model (FDM), patented in 1986 and 1988 respectively.

However, in its early years 3D printing did not have a great deal of diffusion due to the very high costs of use, on the contrary the expired patents and the open source philosophy increasingly widespread has contributed to greater visibility and adoption. In 2005 the British Adrian Bowyer, professor of mechanical engineering at the University of Bath, launches the RepRap project with the aim of building a machine capable of both producing plastic objects and reproducing itself by using FDM technology, whose patent signed by Scott Crump expired in 2005. To keep costs down, the professor thought to use easily available materials and in addition to publish all information necessary for construction on a site with free access. This idea motivated many experts and start-ups with the necessary skills to propose assembly kits content for cost-effective printers (never exceeding $ 500), often finding the necessary funding on the site of American crowdfunding Kickstarter.

Another fundamental step takes place in 2007 when Bre Pettis, Adama Mayer and Zach Smith founded a hackerspace in New York with the aim of exchanging ideas and experimenting using software and other fast machines. The idea of the group is therefore to simplify and improve the RepRap predecessor maintaining at the same time its basic characteristics (opensource, rapid prototyping, low costs). The final model, presented in 2009 at the Austin fair under the name of Cupcake CNC, was so successful that the three creators founded a company, Makerbot, and started producing kits, with a first order of 3,500 units. In the following years the phenomenon continued to grow and new models were proposed to public, thanks also to the support of the community that was born around the blog, until 2013 when Stratasys bought the company for $ 400 million.

Competition has recently begun to be felt in this sector and online printing services appeared with the scope to enable people without the proper technical skills and without resources for an initial investment, to create a 3D model, have it printed and shipped; two examples are Shapeways and i.mateialise born in 2007 and 2011. Users can also create templates to share on the site by receiving then a percentage of the sale price in case some other users want to purchase them (see Cassarà, 2014).

Another recent phenomenon linked to additive manufacturing is related to FabLab (fabrication laboratories) whose history originates in America at the Centre of Bits and Atoms of the Massachusetts Institute of Technology. In 2001 Professor Neil Gershenfeld first instituted a course on desktop manufacturing and personal manufacturing and then, given the large influx of students, coordinated the first

FabLab in history. To distinguish from other shared spaces, hackerspaces and makerspaces, Cassarà (2014) recalls that each fabrication laboratory must be equipped with a minimum set of tools, including one 3D printer, and must sign and respect a list of principles (FabCharter) drawn up by the Fab Foundation, so that the same project can be carried out in any laboratory in the world. Although the sale of these projects is possible under specific conditions of copyright, the main activities must remain the open design and dissemination of culture of personal manufacturing. It therefore appears evident, given their structure and organization, that FabLab cannot completely replace mass production, at best they can be the incubators of innovations in the future.

1.3 Trends of additive manufacturing

The new additive manufacturing process was classified by Markillie (2012) as part of a THIRD INDUSTRIAL REVOLUTION. There is general agreement on the identification of the first industrial revolution, which took place in England in the 18th century with mechanization of the textile industry and the gradual replacement of machines for humans in all sectors. Even the second industrial revolution does not generate any debate, it takes place at the beginning of the 20th century and is characterized by the typically Fordist mass production. The third revolution, on the other hand, appears more questionable. The elements cited by Markillie (2012) thanks to which it is possible to classify this technology as revolutionary are: *the digitization of production methods, the change in the internal organization of factories, new materials usable, the different skills required of workers for new tasks, optimization of times and production spaces, the different structure of supply chains, the change in social attitude towards production.* In the author's opinion, the consequence of all these transformations would be just another industrial revolution, in which customized products will be made on a SMALL SCALE, MORE FLEXIBLE, WITH LESS WORK, THANKS TO NEW MATERIALS, NEW PROCESSES SUCH AS 3D PRINTING, ROBOTS AND SERVICES AVAILABLE ONLINE. Although these characteristics are indisputably present, the question remains unresolved about the possible application in different sectors; at the moment it is not clear if we deal with a new revolution, due to the absence of pervasive diffusion and the consequent changes in productive paradigm and mindset, which clearly distinguished the previous two revolutionary moments.

1.4 The additive manufacturing process in brief

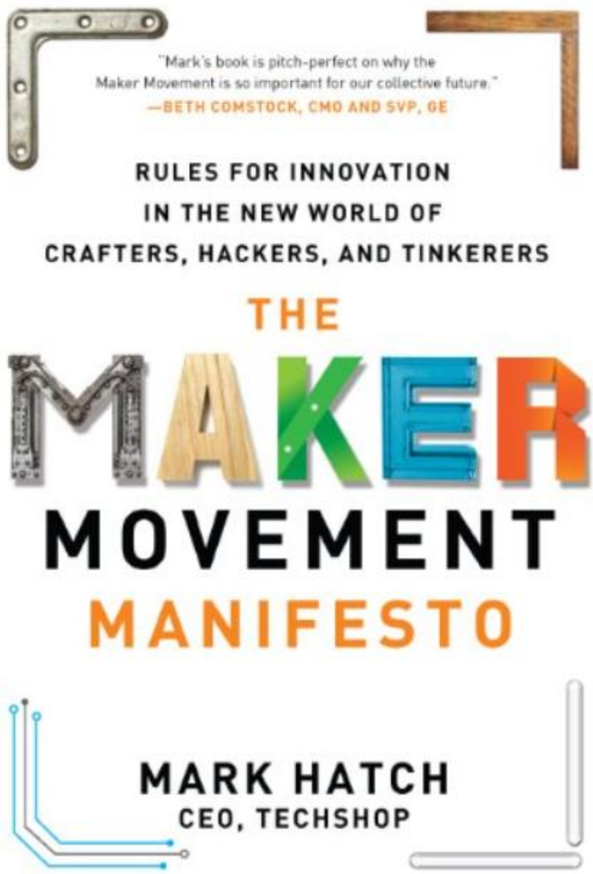
Even if the production process consists of several steps and the technologies available are many, we will summarize the fundamental stages. The first tool to be used is software thanks to which it is possible to obtain a drawing of the external geometry of the object to be printed. For this representation, any professional CAD SOFTWARE could be suitable but reverse engineering tools (LASER AND SCANNER) can also be used (see Gibson, 2015). The next step is the conversion of the CAD design into an STL FORMAT FILE (acronym for Standard Triangulation Language ToLayer), normally read by any 3D printer. The file in question, considering the surfaces represented with the CAD model, calculates the triangular sections in which the object is divided.

Once the STL file is obtained, software, called SLICERS, are used to translate the file in appropriate instructions to guide the machine in the production of the object. The functions performed are essentially two: SUPPORT GENERATION AND SLICING. It is, in fact, necessary to build of the pieces supporting the object during production, which will then be removed with different techniques in relation to the technology in use. It is also important to break down the drawing in thin layers, whose overlapping will form the desired final object. In particular, this slicing phase can be classified as UNIFORM OR ADAPTIVE. In the first case, the object has a constant thickness; the second type provides an adaptation of the thickness to the surface curvature in order to reduce as much as possible the scaling of the external surface. At this point, before the process completion, the machine must be set according to the appropriate parameters of construction (timing, thickness of the layers, material constraints). The next stage is the construction of the object. Since the process is almost automatic, the is no need to constantly supervise the machine but a superficial control is sufficient to ensure no leaking of materials or software errors. Once construction is complete, the object must be removed from the machine. Since there is an interaction of the employees with the instrumentation, it is advisable to prepare some precautions, such as safety locks for ensure the absence of moving parts or an adequately low temperature. The procedure continues in case the object may require subsequent cleaning before utilization or may have support parts to remove. In the final moment, parts made by the additive method could be assembled with other electronic or metallic components, to obtain the final object, whose surface can be also sanded or painted for the final optimization of shape and surface.

The main applications of 3D printing can be summarized in four categories: rapid prototyping, rapid tooling (INDIRECT PRODUCTION), rapid manufacturing (DIRECT PRODUCTION), spare parts. Among the user companies on a global level (Sculpteo, 2016) the main field of application is prototyping (50%); industrial production and product testing still account for a lower percentage, respectively equal to 25% and 30%. Likewise among the Italian adopters (Prometeia, 2015) prototyping counts for the highest percentage (71.2%), followed by production (10.4%). In both cases, indirect production and / or spare parts are included in the "other" category due to their low weight (about 6%).

UNIT 2. THE MAKER MOVEMENT

2. The maker Movement



MAKE, SHARE, GIVE, LEARN, TOOL UP, PLAY, PARTICIPATE, SUPPORT and CHANGE are the cornerstones of the Maker Movement Manifesto (Hatch, 2013). In this era of transformation 4.0, an ever-growing array of digital artisans are changing the economy and business models, quietly and from below. In the relationship between craftsmanship and new technologies, the point is no longer whether the craftsman must be digital, but 'how', in what form, in what ways.

The Maker Movements is about new and innovative form of production and with do-it-yourself that influence different aspects such as production, education, training activities. The Maker movement advocate the DIY attitude towards the world, especially the technological one. Makers around are developing amazing tools, materials and skills.

Mark Hatch (2013) in his book "Maker Movement Manifesto" identifies the following nine principles for the Maker Movement:

- MAKE (to do) - To do is fundamental. We need to do, create and express ourselves to feel satisfied.
- SHARE (share) - Sharing what we do and what we can do with others is the method by which we can reach a complete feeling of accomplishment.
- GIVE (to give) - There are few things that can give greater satisfaction in giving something away.
- LEARN (to learn) - It is necessary to learn how to do. It is always necessary to try to learn about what is being achieved.
- TOOL UP (equip) - We need to have access to the right tools for the project at our fingertips. Investing and developing local access to the tools are fundamental to accomplish what we are planning to do.
- PLAY (play) - We must be enthusiastic and enjoy what are doing; we will be surprised, excited and proud of what we will discover.
- PARTICIPATE (participate) - Obviously participate in the Maker Movement and reach out to those around us who are discovering the joy of doing.
- SUPPORT (support) - This is a movement and requires emotional, intellectual, financial, political and institutional support.
- CHANGE (change) - It is necessary to embrace change naturally as we go through the journey of the makers.

The Maker Movement, driven by the provision of new digital technologies and particularly of 3D printers by makerspace and **FabLab**, then takes different forms, but all characterized by the participants willingness to share knowledge, exchange ideas and experiment in the field of innovation.

2.1 Neil Gershenfeld's Fab Labs: personal fabrication

Neil Gershenfeld, director of the Center for Bits and Atoms (CBA) at MIT and professor since 1998 of the How to Make (Almost) Anything course, is a forerunner of Chris Anderson's garage companies and was the founder of the first **Fab Lab**, which defines in this way: "depending on how you want to interpret it, a manufacturing laboratory or simply a fabulous laboratory [....], a fab lab is a set of commercially available machines and components held together by procedures and software that we developed to build.

The first fab lab had a laser plotter to cut out shapes in two dimensions that can be assembled in three dimensions, a cutting plotter that uses a computer controlled blade to cut flexible electrical connections and antennas, a cutter that moves a rotating tool that cuts into three dimensions to make precise circuit boards and parts, and tools to program tiny high-speed controllers [....] the intention is to replace parts of the fab lab with parts built in the fab lab over time, until finally the laboratory itself becomes capable of self-reproduction.

From this definition it is possible to make some initial reflections:

a Fab Lab is a laboratory, usually of small dimensions, in which machines available on the market suitable for the construction of objects are gathered, i.e. laser cutting machines (or water or plasma), milling machines numerically controlled, 3D printers.

Figura 1. Fab Lab Pesaro (Italy)

These tools, once accessible only to industries due to their high costs, can now be purchased on the internet with a modest investment: after the inauguration of the first Fab Lab at MIT in 2002, the costs for the equipment of the subsequent laboratories in India, Costa Rica, Norway and Ghana amounted to around twenty thousand dollars. At the moment, the same technologies can be accessed with about half, but the trend of modern laboratories is the self-production of machines with components reused or designed ad hoc. Computers allowing the design process, use Open Source software freely downloadable from the network at no cost, eliminating any type of expense related to the purchase of licenses and updates.

The purpose with which Gershenfeld created the first laboratory, is the trust in personal technological manufacturing as an innovation of computation, in the perspective of a digital revolution that will not concern the digital world, but the physical world, in which anyone with their computer will be able to create or repair their own technological devices at home. A self-production with social ends in which people can be free to express themselves in a personal way without limitations, bringing back the individual expression in technological production, until now repressed or "adjusted" according to the products available on the market. For Gershenfeld, industrial production could finally be combined with personal expression through digital design, creating communities of creation/application of advanced technologies, communities with a common sensitivity and capable of working in the same direction in the development of a project.

A Fab Lab is generally equipped with a series of computerized tools capable of creating, in a flexible and semi-automatic way, a wide range of objects. These include technological products generally considered the exclusive prerogative of mass production.

The soul of FabLabs is **open-source**; FabLabs are spaces open to everyone in which to experiment and give life to ideas that can change everyday life. Just as often, FabLabs welcome guests who can teach aspiring makers new methods of thinking and developing projects. They often promote courses to learn how to use machinery (such as 3D printers) and software for digital design (such as Google SketchUp, Grasshopper, Rhino, Arduino, etc

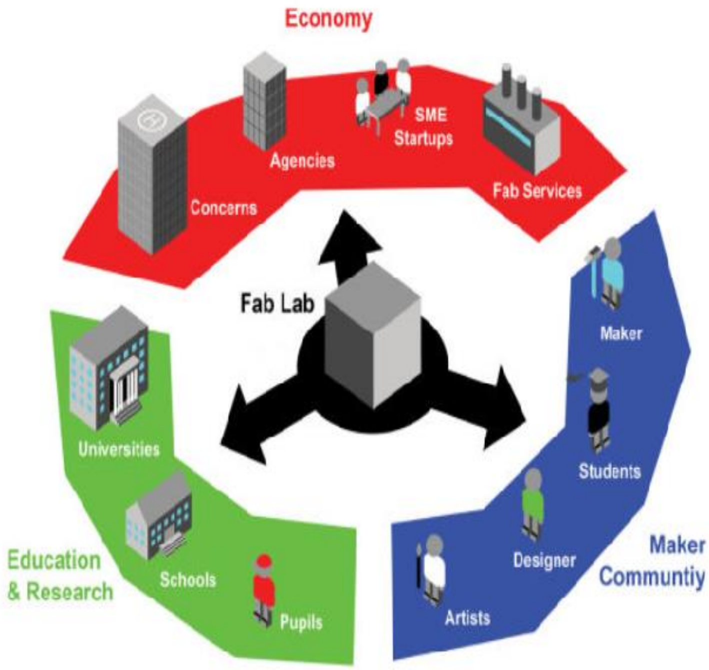
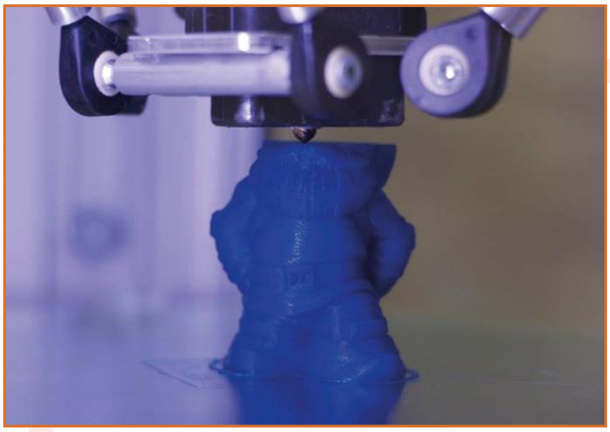


Figure 2. FabLab Network

*https://www.stampa3d-forum.it/articoli/guide/i-fablab-cosa-sono/

Flexible manufacturing equipment within a **Fab Lab** can include:



Rapid prototyper: typically a 3D printer of plastic or plaster parts

3-axis CNC machines: 3 or more axes, computer-controlled subtractive milling or turning machines

Printed circuit board milling or etching

- Cutters, for sheet material

UNIT 3. 3D PRINTED: GENERAL ASPECTS AND TECHNICAL FEATURES.

3. 3D printer: General aspects and technical features

For the Maker Movement 3D PRINTING is the most important technology that characterizes it. In chapter 1 space was given to the description of the characteristics of the enabling technologies, attributing particular importance to additive manufacturing since it has established itself as the main element that characterizes the Fab Labs. Now, however, the benefits that 3D printing can bring will be resumed.

3.1 Main applications

The main applications of 3D printing can be summarized in four categories: *rapid prototyping*, *rapid tooling* (indirect production), *rapid manufacturing* (direct production), *replacement parts*. Among the user companies on a global level (Sculpteo, 2016) the main field of application is prototyping (50%); industrial production and product testing still account for a lower percentage, respectively equal to 25% and 30%. In both cases, indirect production and/or spare parts are included in the "other" category due to their low weight (about 6%).

Rapid Prototyping

The first field of use of 3D printing has been rapid prototyping since the first additive technologies, developed in 1980, could produce at high costs only small plastic objects whose level of quality and detail were rather low. Rayna and Striukova (2016) point out that cost reduction has favored a diffusion to smaller enterprises, while the improvement of the quality has led to a massive use to develop models aesthetically identical to the finished product or prototypes to be subjected to critical tests and evaluations before a market launch.

Indirect Production

Another application began to spread in the second half of the nineties, when new 3D printers appeared on the market to solve some problems of companies in the construction of molds, equipment, tools for production. Always, in fact, companies built these tools through a slow process of subtracting from a aluminum block or other material. However, making mistakes could be very costly as it meant retracing the production stages of these parts using new materials and dedicating additional time. The transition to additive manufacturing made possible to obtain the same objects with reduced timing and with the possibility of adapting each phase, also allowing a considerable geometric freedom.

Direct Production

As Gibson (2015, p 39) writes: “Speed, quality, accuracy and material properties have developed to an extent that 3D printed parts can be made for final use". Recent developments have further lowered costs, increased quality and expanded the available materials so much so that 3D printing has begun to be used for the production of finished objects, implementing the whole additive process without using molds or other machines typically subtractive.

Replacement parts

3D printing responds in a different way to the need of companies to store in warehouses spare parts in order to immediately replace those not working anymore. Thanks to the use of additive technologies in the warehouse, the files of the parts can be kept as substitutes with the aim to be printed when needed and in the appropriate place.

In extreme analysis, a further and very recent field of use could be noted, namely home fabrication. In this case, the use of the 3D printer takes place directly at home of the consumer who has the appropriate equipment. For the moment we are speaking mainly about hobbyists or engineering students, but given the growing rate of adopters there are some experts who announce a future diffusion equal to the current one of the personal computer. At the same time, there are many skeptics who emphasize the lack of a real and constant need to have one of these printers at home (see Rayna 2015). In any case it is important that each of these applications coexist with the others and do not pay the previous obsolete.

3.2 Materials

Among the materials on the market today, plastic is the favorite one for three-dimensional printer users (Sculptero, 2016). Their arrangement favorable is due to the characteristics of the various plastics, which are not only more economic but also more resistant to shocks and allow a good level of detail. Other materials adopted are resins followed by metals. On the other hand, residual materials are ceramic and wax. The offer is not limited to the above mentioned typologies, since the list of potentially usable materials is periodically updated with new compounds, such as pastes, sand, graphene and many others. Moreover, depending on whether the method used by the 3D printer is solidification, melting o the deposit of materials, the form they assume varies from powders to filaments or liquids. Obviously, as Soppelsa (2015) reminds us, the choice of material and technology is made according to the characteristics to be obtained by the prototype, the object or the mold.

Resins

A large class of polymers depends on the category of resins obtained from different raw materials, all solidified by the laser in the production process. Several resins are available according to the technology used and the characteristics of the piece to be obtained; however, the supplier company provides all the information necessary for an accurate choice (see Chuan, Leong 2014). These machines also need a solvent for cleaning once the object is completed. Printers using resins are more expensive, but the objects are more sophisticated, precise, aesthetically attractive and therefore suitable for demonstration components or visual prototypes. In particular, in the stereolithography, one of the most used materials is Somos WaterShed XC 11122 resin while Acura 55 is often used in 3D System machines.

Plastics in grains or filaments

Calderan (2015) identifies as main materials used PLA and ABS, respectively acronym for Polylactic Acid and Acrylonitrile Butadiene-Styrene. PLA is a biodegradable plastic since it is obtained from starches such as corn or sugar cane; on the other hand, ABS is obtained from oil. This latter offers high stability since it is not very sensitive to heat, therefore at the same time it must be subjected to high temperatures to achieve fusion. The parts obtained from the PLA are stiffer than ABS, which deforms more easily during the cooling down. An object made of ABS can be sandblasted and, if polished with acetone, takes on a ceramic-like appearance. Another thermoplastic filament which can guarantee rigid, resistant and suitable for food contact objects is polyethylene tereflated (PET). Soppelsa (2015) also mentions High Impact Polystyrene (HIPS), a thermoplastic material made up of polystyrene and styrene-butadiene rubber, similar to ABS in terms of mechanical characteristics, but with a proper peculiarity: melt with the limonene at room temperature, it is suitable for building support structures also because of the easiness to remove in the post-process phase.

The powders

Nylon, endowed with flexibility, strength and versatility, is a white powder sintered from a laser and then sanded. The alumide, on the other hand, originates from the mixture of nylon and aluminum. Though it is more rigid, grainy and porous than nylon, its powder gives shine to the surface.

Other materials:

Pastes

Sugar, wax, chocolate, clay, silicone have already been used to create pastes suitable for 3D printers. However, the use of these materials is still in the experimental phase because for each one of them there are specific problems to be solved.

Laywood

It is a composite made with recycled wood (40%) and a binder polymer. The composition of this material allows to print it like any ABS or PLA filament. Calderan (2015) specifies that after printing, the object not only appears similar to wood but also assumes its odor; moreover, different shades can be obtained when the printing temperature varies.

Laybrick

The filament, a German patent, is a mixture of gypsum and binding powders; it allows to obtain objects printed with a stone effect, a useful expedient for artistic models or architecture.

Biomaterials

In the medical field, however, the fundamental components are: cells, proteins, hydrogels natural and jellies. In particular, Chua and Leong (2014) cite BioInk, a semi hydrogel synthetic enabeling the growth of different types of cells and mimics the natural material extracellular, and OsteoInk, a calcium sulfate paste, ideal for bone printing and cartilage.

3.3 The technologies used

We can group materials into three categories: powder, liquid, solid: then, we can associate some technologies according to different processes. In following paragraphs, the main technologies are summarized (expressed in abbreviation) described, and linked to the materials they use.

Selective laser sintering (SLS)

The technology was invented in 1984 by researcher Carl R Declard of the University of Texas, developed in collaboration with DTM Corporation and then acquired by 3D Systems in 2001. Today, however, the producers are more numerous because the patents are recently expired. The process consists of spreading layers of powder from various materials hit by a laser to be fused together. The powders that are not immediately sintered, act as a support for the subsequent layers until the final creation of the object. At the end of the process, the piece is removed and separated from any dust support that can also be reused (see Maietta 2014). The printers suitable for this technology are characterized by a high cost, given by the laser in use; therefore, some startups, such as Norge and Polyforge, are working on developing less expensive models.

Metal Laser Sintering (DMLS) also called Selective Laser Melting (SLM)

The history of SLM begins with a research project at Fraunhofer Institut ILT in 1995. This technology is very similar to the previous one with the difference that the laser creates the prototype melting materials into metal powder. This technique enables to make prototypes and metallic parts with a good level of detail and precision; its flaws are the rather poor surface finish and the risk of deformation.

Stereolithography (SLA)

Stereolithography uses a laser to light-cure (solidify) a liquid resin placed inside a tank of the machine. The scanning process is repeated until the construction of the three-dimensional object is completed. For each section a mirror system projects a laser which can thus scan the surface. At the end, the object is extracted from the liquid resin and placed in an ultra violet light oven in order to complete the polymerization (see Calderan 2015). Stereolithography is widespread in prototyping because in this field it is fast and cheap, it is not likewise used for the production of the final object.

Digital Light Processing (DLP)

DLP technology is newer and involves less cost and waste than SLA technology, but it is similar to this latter in the process. In fact, it uses a light source to harden a photopolymer placed inside a tank, that is lowered for the construction of subsequent sections of the object. As final result, resistant and excellent products are obtained with a good resolution.

Polyjet

The technology belongs to Stratasys and it is very similar to an ink printer. Indeed, its heads, instead of placing ink on paper, deposit and polymerize with UV rays drops of liquid photopolymers. The products thus obtained are ready for use without other processes. Its advantage is that it can print in several materials (rigid, transparent, elastic) and colors (even in a single model).

Fluid Deposition Modeling (FDM)

FDM technology was developed in the 1980s by Scott Crump (founder of Stratasys). The patents owned by this company expired in 2009; since numerous open source initiatives have developed, cheaper variants called FFF stands for Fused Filament Fabrication have been implemented. Chua (2014) explains that a print head (extruder) composes the profile of the object by depositing small drops of molten material. The printer is connected to a reel of plastic material which comes out during the process thrust into the extruder: this heats the material received until it melts and deposits on a moving floor. After cooling, the drops join together with the underlying material. Thanks to the cleanliness of the process, to the reduced dimensions of the instruments, to a relative low cost, is this the most widespread technology. It should be noted that, however, the cost is not always low: there are in fact some professional models which, because of the speediness of realization, versatility, finishing quality of the final product and print volume, are offered at higher prices.

Laminated Object Manufacturing (LOM)

Californian Helisys Inc. has developed a technology thanks to which the object is realized by depositing on a work surface sheets of paper, plastic, metal which are then superimposed, glued together by a roller heated and cut into the desired shape by a laser or a blade controlled by a computer. The disadvantage of making lower quality products than other techniques, is offset by the low cost of the material and the possibility of making large objects size. The projects and products of the design company, which closed in 2000, are brought forward from Cubic Technologies. Other companies such as the Israeli Solido 3D and the Japanese Kira are no longer present on the market but the Irish company Mcor Technologies Ltd still exists and sells 3D printers with LOM technology.

The main objective of this summary is to highlight the main benefits and the limitations of the fundamental technologies available, in order to make a choice of use aware and calibrated with respect to the object to be printed.

It is equally important to have a vision of which technique is more suitable than the specific application of 3D printing. In next paragraph, a proper description is reported in order to understand which type of printer should be used with respect to the field of application.
Almost all technologies can be used in rapid prototyping with the clarification that three types of prototypes are identified: conceptual, for validation and technical. For conceptual prototypes, stylistic and ergonomic checks are carried out, but the objects are not subjected to particular mechanical stresses. The second typology, on the other hand, is printed for assembly checks, i.e. to ensure that it has been perfectly designed. In lastly, the technical prototypes must have mechanical properties comparable with those of the final product.

3.4 Sectors of applications

CLOTHING

3D printers give the possibility to creative designers to follow their product all along the development phases, modifying their idea at low cost. In 2015 the New York designer Francis Bitoni, working in collaboration with 3D System, has created a collection of heeled shoes for the Dutch company United Nude: "Mutatio", this is the name of the work that represents the result of combination of traditional and new techniques. In fact, the heels were printed in nylon with 3D SLS technology and plated in gold while the top was made of leather.

Another example of the application of this technology to clothing industry, is the case of the first 3D printed jacket, marketed by the America start up Mistery of Supply.
The company has obtained a seamless men's garment with a different thickness of the material in certain areas to allow adequate transpiration. For his implementation they used the Electroloom printer, that use a particular process that allowed to solve the obstacle of rigidity of material. The 3D printer for fabrics produced by Electroloom uses, in fact, the process called Field Guided Fabrication (FGF). Speaking about the technology used, it suffices to say that after inserting the mold of the model to be made, a liquid solution is inserted into the printer consisting of the materials of the fabric that are wants to be obtained. Then, through an electric field, nano-fiber layers superimposed are obtained to form the materials that take the shape of the mold inserted at the beginning.

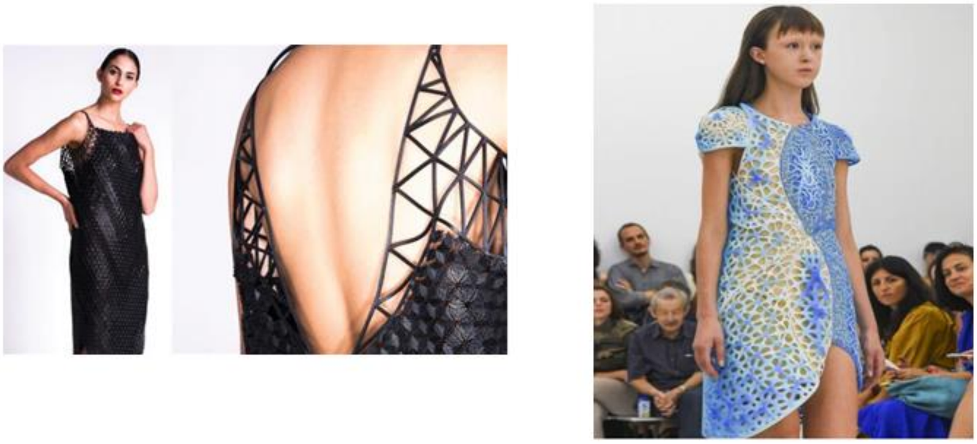


Figure 3. Examples of 3D application in clothes

*https://www.sculpteo.com/en/3d-learning-hub/applications-of-3d-printing/3d-printed-clothes/

FOOD

Even in the food sector, some cases have shown how it is possible to overcome the obstacle of the material. An example among all is the German Katjes, third producer (after Haribo and Storck) of candy in Germany, which unveiled the first candy printer marketable gummies, Candy Factory, in Berlin. Customers can first choose the shape, color of the candy and then watch the process that takes place in about five minutes. The machine therefore allows you to quickly obtain a customized product, edible and printed with natural ingredients, all at a cost ranging from five to ten euro.

At the same time there are industry giants like Barilla who work to bring the press 3D in food. And during the international food fair of Parma (Cibus, organized in 2016) the well-known Italian company presented a 3D printer prototype for pasta, as the result of his four-year work in collaboration with the Dutch research center Tno di Eindhoven. The basic ingredients are always the same, durum wheat semolina and water, but they can add other flours, legumes or vegetables to get a personalized taste, all machined in cartridge format. The consumer was then involved in the choice of the format through the international platform Thingarage, where approx. 200 models, three of which (rose, luna and vortipa) were presented at the show as demonstration.

Figure 4. Examples of 3D application in food

* https://www.3dbyflow.com/

SPORTS SHOES

Another field where 3D printing is experiencing an expansion is that of footwear sports. In 2016 NewBalance marketed the ZanteGenerate line in edition limited for the 44th anniversary of the brand's foundation. The peculiarity of the product resides in its sole, the result of the three-dimensional print, while the remaining parts of the footwear are produced following the traditional way. Collaborating with 3D System and thanks to the use of DuraForm Flex TPU elastomeric powder, NewBalance has created printed parts that adapt very well to the movement of the run. In the world panorama of shoes there is no shortage of applications in prototyping. Nike has, in fact, used 3D printing to develop the Nike ZoomSuperFly Elite model, worn by some sprinters at the Rio 2016 Olympics. Although the final product was obtained with traditional manufacturing techniques, the company has studied its implementation through 3D printed prototypes. In this way they quickly got countless variants to test performance without having to wait for the technical times of the mass industry.

Figure 5. Example of 3D printing application to shoes

*https://www.sculpteo.com/en/3d-learning-hub/applications-of-3d-printing/3d-printed-clothes/

AUTOMOTIVE

For some years, several car manufacturers have been using additive technology for production of highly customized prototypes quickly and at low costs. Such a practice it is quite common among racing cars. Chua and Leong (2014) report, in fact, the case of Lotus F1 which since 1998 uses 3D System SLA 5000 for the construction of some components of its cars since this technology allows to obtain complex elements and with an aerodynamic surface, ingredients of fundamental importance for victory in the race. Over the years, SLA technology has become an integral part of the process implemented in Lotus, and in fact the company today produces through the additive method elements such as the gearbox and suspension. The technology in question led to the company benefits in terms of cost reduction and time to market. More recent news, March 2017, reports Ford's interest in additive manufacturing. Thanks to Stratasys's new Infinite Build 3D printer, the company should be able not just to print accessories, prototypes or components in limited volumes for Ford cars Performance (racing cars), but also developing elements for 'customized' vehicles.


Figure 6. 3D printing in automotive industry

* https://all3dp.com/2/3d-printing-automotive-applications-latest-projects/
*https://www.metalworkingworldmagazine.com/europe-will-be-a-forerunner-in-automotive-3d-printing-report-says/

BIOMEDICAL

When talking about Biomedical application of 3D printing, it is natural to think about 3D printed organs, nut this is not the only one use of technology. A simpler but useful field of use is that of biomodels, which allow to abandon radiology in the pre and post-intervention study phase. In these two moments the doctor can study on a three-dimensional model the specifics of the pathology of the patient, having a clearer vision should reduce errors in the room surgery and speed up the intervention.
The printing of human organs and tissues is certainly an interesting use, so much to have triggered a separate branch called bioprinting. Even if the procedure is a bit complex there is no shortage of successful cases. For example, at the Medical Center of the University of Utrech the largest artificial skull (or plastic skull) was implanted on a girl of 22 years old with a particular pathology of thickening of the skull. Similarly, a bionic ear was prepared at Princeton University, printed from bovine cells to which layers of cartilage and an antenna have been added to reproduce sounds.
Researchers from WakeForest University, North Carolina, have prepared a printer that it should be able to produce organs, tissues and bones for insertion into the human body. This printer works with hydrogels, aqueous solutions that contain human cells, initially enriched with other biodegradable materials to improve printing accuracy. Until now the device have been used to created jaws, bones and tissues that were successfully implanted in laboratory mice while they have not yet been tested on humans.

A much more realistic use is in the field of orthodontics. Many workshops are already equipped of 3D printers with which they accurately and quickly produce crowns, bridges, porcelain dental plates as well as dental instruments.

Figure 7. Example of Biomedical 3D printing

* https://www.future-healthcare.ec/en/insights/78-biomedical-engineering-the-contribution-of-3d-printing-to-medicine.html
* https://www.medicaldevice-network.com/features/3d-printing-in-the-medical-field-applications/

AEROSPACE ENGINEERING

The application of additive manufacturing in this field allows us to respond validly to reduce the weight of the components, allowing a reduction in consumption and emissions, and the decrease in the production times of the elements themselves. A real example reported by Soppelsa (2015) is that of General Electric which in 2013 acquired the aviation division of Avio. In the Italian plant of Cameri (NO) 3D print rotor blades for some engine models such as the GEnx of the Boing 787s are printed. The realization of these components is made possible thanks to the presence at the factory of two Eosint EOS machines, operating with DMLM technology, and nine A2X systems of Arcam. Overall the weight of a turbine equipped with a 3D printed rotor has a weight reduction of 6%, a considerable advantage considering the current ones stringent legislative conditions.

Figure 8. Aereospace 3D printing applications

* https://www.hubs.com/knowledge-base/aerospace-3d-printing-applications/

*https://www.3dprintingmedia.network/aerospace-3d-printing-companies-paris-air-show/

MUSEUMS

Ultimately, museums have been taking advantage of the digital world (websites, social networks, media) to make works of art available to consumers even outside their own exhibition spaces. Always with the aim of involving interested parties, museums are discovering 3D printing to add a file to the classic two-dimensional image with which to print the digitized object on your own. An example is the Smithsonian X 3D project that made available in digital format a collection of objects that cannot be visited in person by correlating a 3D printable file. Another project belongs to the Metropolitan of New York that organized an event in which digital artists and programmers have scanned and modified different works. These collaborations gave shape to a new mix of classical works then uploaded to a platform, a site where fans make available to other people their three-dimensional models and related print files.
It is important to emphasize that the problem of fakes does not arise since the press that the consumer gets at home it is obviously different and of lower quality than the original. Museums, on the other hand, can perform a faithful replica of the work and expose it in place of the original thanks to the techniques of high quality they have. Presumably this will stimulate more collaborations and international circulation of works. In addition, Fablabs can be set up inside the museums, such as the FabLab located at the MUSE of Trento, in Italy. In these places it is possible to organize workshops at various levels, for young and adults and for different levels of expertise. The MUSE Fablab was born in 2013 and is dedicated to training, to workshops and activities for children.

Figure 9. Museum 3D printing application

* https://www.fabbaloo.com/blog/2017/8/28/3d-print-application-idea-on-demand-museum-pieces

BUILDING

There are 3D printers used in the building sectors and one of the most impressive projects is Italian. The WASP company, based in Massa Lombarda (Ravenna), built the largest 3D printer called BigDelta 12m in honor of its 12 meters high. The target declared by the company is to build zero-kilometer houses with local materials and with a low energy consumption. A recent application example is the “Eremo” project that was aimed the creation of a shelter with environmentally friendly materials such as raw earth, straw, clay, superimposed and printed. Today there is also a technology park, "Shamballa", where the company continues to conduct experiments with different materials and designs. China is another country where additive construction techniques have been used. Specifically, the WinSun company has shaped a house using quick-setting concrete and other construction waste material (patented compound by the company). After being printed, the walls were reinforced with steel and assembled on site. The company is planning other constructions on Chinese territory in the light of the advantages in terms of reduction of the costs of materials and labor as well as of the construction times.

Figure 10. 3D application in building

*https://medium.com/@o2itech/applications-of-3d-printing-in-architecture-8753fa5f9037

DEFENCE

The US Department of Defense is working on various projects to introduce printing 3D in the military sector, for example, they are studying how to insert small components obtained with additive technologies (antennas, sensors) in soldiers' armor. Others instead envisage a profitable use in war zones or in inaccessible areas, where 3D printers could be used to obtain parts of a weapon, spare parts at the appropriate time. Some year ago, a gun was made called Liberator, printable at home after downloading the CAD file of the model from the website. A few thousand copies were downloaded earlier that the US government intervened to have the file removed and thus avoid a massive one self-production.

Figure 11. 3D printing application in defence industry

*https://www.3dspectratech.com/the-increasing-demand-for-3d-printing-in-the-indian-defence-industry/

JEWELS

3D printing is revolutionizing the world of craftsmanship: this is the case of the jewelry sector.

Although it may seem that the process leads to the loss of creativity typical of the craftsman, this does not seem to have occurred. On the contrary, it remains very important the initial phase of drawing up the design, when the designer's originality and ideas are expressed.

An example in international scene is the Canadian company of Daniel Christian Tang (DCT). Founded by two architects, Heng Tang and Mario Cristian, and by engineer Luca Daniel, is one of the leading 3D printed luxury jewelry brands in Canada. The models in gold and silver are first printed on wax with a high-resolution 3D printer, then used to make a plaster mold, employing the lost wax casting process. Once the plaster molds are set, liquid metals can be poured to create the pieces of jewelry visible to the public.

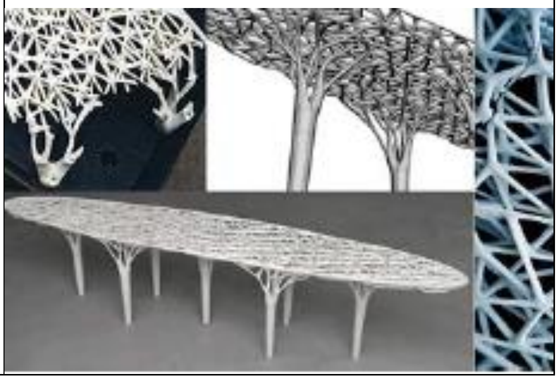
Another example of application of 3D printing in the sector is in Italy. In fact, the companies in the Arezzo gold sector introduced three-dimensional printer for prototyping and production on early 2000s. In this geographical area it located a company that has included 3D printing in its production flow, called M.E.M.O.: the company began its 3D adventure in 2007 with the purchase of a Stratasys machine, but has increased its printer fleet following the requests for an impeccable product with reduced delivery times.

Figure 12. 3D printing application in Jewelery

A focus on the Wood furniture sector

Nowadays the use of Additive Manufacturing technologies is growing also in the furniture industry, despite manufacturing real furniture is a complex process because must deal with quality, mass production capability, finishing, dimensions, mechanic proprieties (Aydin, 2015). Other factors to consider in the production of furniture are: craftsmanship, assembly stage that is an important and time consuming stage and that can be eliminated due to the production method of Additive Manufacturing (Aydin, 2015).

The next table shows some examples of Furniture products Made by Additive Manufacturing (Source: Aydin, 2015). Additive Manufacturing: is it a new Era for Furniture Production?).

Trabecula Bench: Printed from glass reinforced polyamide by SLS method. Without use of glue. They look like a delicate accessory but they are expressively strong.	

	*Furnished chair*: is manufactured in two steps: cutting small pieces of solid wood uniformly and combining these pieces to form layers by using a special binding process.
One piece sofa built using Stereolithography method and photo reactive resins were cured with UV laser source.	
	*3D printed chair:* A puzzle blocks series, simple designed and made from white and bloc color PLA, were printed out by FDM method to be assembled into a chair. With wooden legs.
Table produced with SLM method.	

	TRUSSCHAIR- 3D printed chaise longue (Source: Schwaar, 2020).
Cohda's Binary Furniture (Berman, 2020).	

	Patrick Jouin's light produced via 3D printing. The lamp opens and closes, resembling a lotus flower. (Berman, 2020).
Drik Vander Koij's Endless Pulse Chair. It is a chair realized with 3D printing technology, and it is environmentally friendly and sustainable. (Berman, 2020).	

The main advantages of the application of 3D printing in the furniture industry are (Berman, 2020):

- 3D printing streamlines, simplifies and reduces the cost of designing furniture
- Realization of lightweight furniture prototypes quickly and inexpensively
- Less production and design expenses
- Develop furniture that is beautiful and functional
- Rapidity of production and lower price
- Environmentally friendly and sustainable

3.5 3D printing and Circular Economy

The adoption of new technologies is being configured as a driver for the transition to the new model of production and circular consumption. **Regarding the relationship between new technologies and the** CIRCULAR ECONOMY**,** Ellen MacArthur Foundation (2019) argues that the development of innovations for the control and maintenance of materials, the transparent management of the supply chain together with repair activities with 3D printing, play a fundamental role in making the concepts of the circular economy tangible from the introduction of green technologies -green Technologies- which monitor resources, general waste and decrease the negative impact that human activities have on the environment.

The technologies such as the Internet of Things, Additive Manufacturing and Augmented Reality can more effectively control material flows, manage the various routes, decrease production costs for large volumes and at the same time reduce the use of fuel, decrease related CO2 emissions and reduce waste and production rejects by up to 90%.

Among the technologies that have great potential to support the transition to the circular economy there is additive manufacturing.

Despeisse et al. (2017) affirm that 3D printing can have a central value in achieving the CIRCULAR ECONOMY since the entire printing process can be designed in a circular way, "closing the circle" of the life of materials. Additive manufacturing can bring about sustainability benefits in all four stages of the product life cycle, also leading to the development of new business models aimed at extending the life of products through the repair of the same or the production of spare parts on request (Ford and Despeisse, 2016).

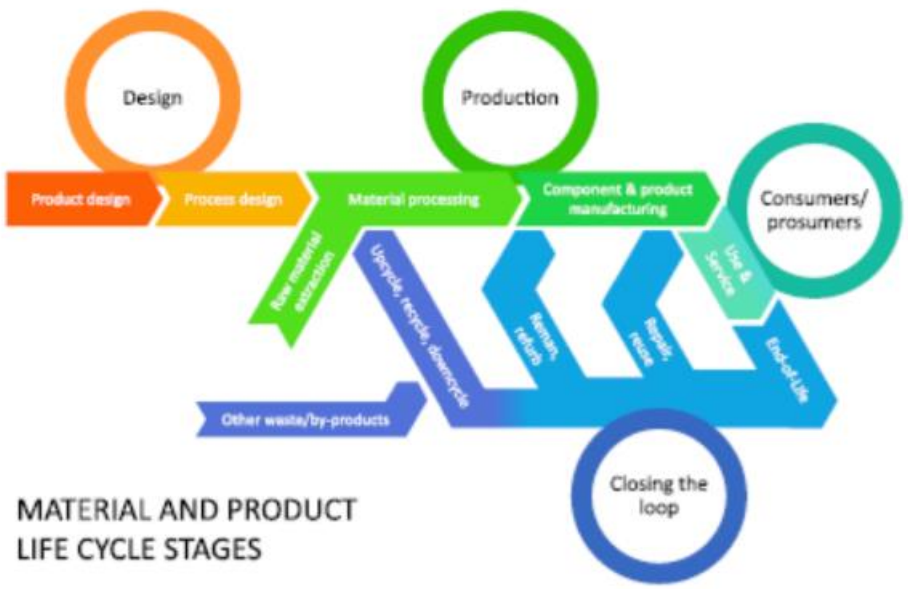


Figure 13 Product life cycle (Source: Ford e Despeisse, 2016).

As shown in Figure 11, it is possible to rethink product and process design as well as the choice of raw materials from an efficiency perspective, favoring simple designs with less use of components and the reuse of recycled raw materials or bad prints. Indeed, virgin raw materials can be replaced by recycled material through local recycling initiatives and upcycling processes.

Plastic has become an integral part of our life thanks to the combination of convenience and low price (WEF, 2016). Globally, plastics production reached 359 million tons in 2018 (PlasticsEurope, 2019) and it is estimated that 6,300 million tons of plastic waste was accumulated between 1950 and 2015, of which only 9% was recycled (Geyer et al., 2017). Single Use Plastics (SUPs) are the biggest problem in this context since only 14% is recycled, equivalent to a loss of 80-120 billion dollars per year (WEF, 2016). Despite encouraging data regarding the collection and recycling of waste (PlasticsEurope, 2019), plastics continue to pose a threat to the environment and its biodiversity, as well as to human health (WEF, 2016).

The most commonly recycled polymers are POLYETHYLENE TEREPHTHALATE (PET), high-density polyethylene (HDPE or PE-HD) - both found in household waste in the form of packaging (PlasticsEurope, 2019) -and acrylonitrile butadiene styrene (ABS). These materials are typically extruded in the form of filament, after being washed and flaked (Garmulewicz et al., 2018). The latest technologies make it possible to create filaments even from organic materials and bio-polymers such as polylactic acid (PLA).

Ford and Despeisse (2016) see the use of home-made FDM 3D printers as a solution to the local recycling of plastics such as old filaments, bad prints and other production waste. The production of recycled filament is more efficient than buying it on the market since not only the use of recycled material reduces the costs of the entire production, but the energy consumption used in the extrusion process is considered ineligible (Baechler et al , 2013). In addition, raw materials recycled from plastic waste or other available local materials can increase the cost advantage due to the use of rapid prototyping OS tools (Pearce et al., 2010). On the one hand, therefore, the lower costs contribute to increasing the convenience of the "home" creation of such printers (Pearce et al., 2010) as well as the self-production of the raw material and, on the other, the possibility of recycling unused plastic materials incentivize household waste recycling, thus reducing those associated with the use of OS 3D printers (Baechler et al., 2013).

The circular opportunities of 3D printing do not end with the creation of new raw materials and filaments, but also involve the conversion of waste and by-products into new objects of greater value through upcycling (Ford and Despeisse, 2016).

Sung (2015) defines upcycling as the process by which various materials are converted into "something" of higher quality and/or value, promoting a more sustainable production system and consumption. Waste, production scraps or old objects can be transformed into new products such as sporting goods (Figure 12) (Byard et al., 2019).

Figure 14. A skateboard and paddle for kayaks realized using 3D printing. Source: Byard et al., 2019)

There are companies that are implementing green practices and technologies: two examples are provided by 3devo b.V and The New Raw companies.

3devo b.V is a company based in Utrecht, the Netherlands. The company activity deals with proposing innovative and eco-friendly solutions for the production of filaments for high quality 3D printing. The offer of 3devo B.V. consists of three products: Filament Maker, SHR3D IT and Airid Polymer Dryer.

Filament Maker allows to transform previously shredded plastic waste into a high quality, durable and sustainable filament. The various models available, which differ according to the amount of extrudable material and price, can be used both for experimentation and prototyping -the Composer series- and for a real production activity - the Precision series. SHR3D IT is a small plastic material shredder capable of shredding any type of plastic into light flakes. This product was created to close the loop of filament production, allowing plastic waste to be converted back into industrial granulate. SHR3D IT quickly recycles more than 5 kg of plastic in an hour. Airid Polymer Dryer is a dryer capable of effectively removing any trace of moisture from plastic polymers, preventing the filaments from having bubbles or other deformities that can compromise their final quality.

These tools, when integrated, create a market-independent and eco-sustainable circular production system.

Figure 15. The sustainable printing process (Source: 3devo.com)

The New Raw is a design studio established in Rotterdam and founded in 2015 by the two architects Foteini Setaki and Panos Sakkas. The team boasts collaborations with research institutes, universities and multinational companies. The Dutch team is constantly looking for new methods that develop the concepts of the circular economy by combining technological innovations and social responsibility, focusing on the development of business models that close the life cycle of materials and strengthen local production. The projects launched by the company focus on the use of large-scale 3D technology using plastic waste as a raw material. Each initiative promoted also has a strong educational value: the New Raw wants to spread greater awareness of the problems that plastic can cause to the environment and the role that today's society can have in remedying them. Furthermore, the use of 3D technology allows a high level of customization which helps to increase the involvement of people in the process of change towards a more circular economy.

Among the main projects undertaken by the Rotterdam studio is the 'Print Your City!' Initiative, launched in 2016 in collaboration with AMS Institute (Amsterdam Institute for Advanced Metropolitan Solutions) and the support of TU Delft (Technical University of Delft) and AEB Amsterdam. The idea shared by the various teams therefore involved the creation of a closed-cycle system in which household waste was used for the construction of street furniture using FDM 3D printing. The first prototype, printed by Aectual43, was baptized 'XXX bench' and is a double-sided bench that can accommodate from 2 to 4 people with a weight of about 50 kg (Figure 14.)

Figure 16. The first "XXX bench" developed during the project "Print your city!" (Source: thenewraw.org).

4. 3D printing: economic implications

Organizations are changing the way they do business to fit a globalized scenario.
A first factor that is changing is consumer demand, which is increasingly directed towards customized products that suit the specific needs of clients. The differentiated production for a market segment is no longer sufficient and the companies should develop a one-to-one relationship that leads to the fabrication of unique products for each consumer, often involving the interested party in the process productive or conceptual. The new vision that consumers have of products is translated into the consideration of new factors of success for the company and new ways of capturing the value. Studies by Hagel (2015) and Brown (2015) state that the tangible product is always less definable as a source of value, and it is instead part of an ecosystem that it involves multiple organizations and several related products and services, necessary to for the definition of the final offer. Given these changes, it is normal to think or whether it is appropriate to think of a total or partial reconfiguration of manufacturing activities and the technologies used, such as the additive technologies.
It is difficult to estimate the actual economic impact and the organizational implications as additive manufacturing is a rapidly growing phenomenon which consequently creates generic expectations, sometimes realistic and sometimes ambitious.
In any case, it seems right to discuss certain aspects identified by many experts as radical and important. However, there is a premise to make: the way of thinking about production should move towards an additive approach. As Beltrametti (2014) points out the constraints and opportunities of manufacturing and design is changing in the additive logic and companies should think to new criteria to make the most of it. In the traditional subtractive technique, the main goal is to think about characteristics of the objects to be made that minimize subtractive operations, since the cost of the process is positively correlated to the quantity of material removed.
On the contrary, in the additive manufacturing, without prejudice to the same objective of minimizing the costs of the production, product development should be guided to employ the least amount of material given that in this way the cost is lowered proportionally.

Reduction of warehouse stocks

Beltrametti (2014) and Gasparre (2014) underline how additive manufacturing allows to obtain unique pieces or small series in the place and at the desired time, without therefore the need to prepare complex processes or dedicated artifacts such as molds and casts.

In particular, the need to hold gear parts of various equipment decreases to face with the opportunity, given by 3D printing, to print the pieces at the right time with the obvious implication on the management of the warehouse and logistics. In some cases however, the unit cost of realization could be higher than that incurred with the traditional means of production. However, as in any economic analysis, costs must be compared with the additional benefits achieved. In this case, the companies do they would find to store not the spare parts but the files with a significantly diminution of warehouse surfaces, costs of transport and fixed assets.

In addition, a rationalization of stocks and an optimization of the internal logistics is important when companies adopt Lean Production. For example, if the warehouse management is conducted with the so-called Just In Time, the activities of the production line and the processes of entry and exit from the warehouse must be highly synchronized. The delay or non-delivery by the supplier are source of risks for warehouse stock and production in general. Often the companies hold multiple stocks or relationships with multiple suppliers to find a remedy to this drawback. In alternative, they could use 3D printing, finding an economic justification overall to those unit costs that could be too high.

Redefinition of the supply chain

The starting point is traditional manufacturing, a model that can be schematized through three fundamental steps: the design, production and delivery of the product, and where the responsibilities and roles of the participants are well defined. The designer undertakes to translate the consumer desires in a feasible product while the manufacturer realize the goods in an efficient way. Finally, wholesalers and retailers are the intermediaries that are aimed at delivering the product to the consumer. The impact of additive manufacturing can be recorded from design phase. In additive logic the notion of designer assumes more nuanced outlines, so that not only professionals are not included in the category of the trade but also hobbyists or anyone with a production kit and some ideas. The customer could even indicate directly to the company, for example through a website, the product with the characteristics requested by him. Simpson (2013) and Petrick (2013) note that with this expedient the traditional manufacturing practice is completely overturned centered around the "build to stock" model and a "build to order" approach.

In first case the company production is based on an accurate estimate of market demand, while in the second case the production follow a specific order of the consumer. In this way it is possible to reduce the excessive stocks of products and it is possible to update data on customer preferences (see Hagel, Brown 2015). The relationship between producer and customer thus becomes closer and more personalized and in general is more interactive and collaborative.

However, the biggest change brought by additive technologies concerns itself the opportunity to displace production in space. The file containing the specifications of the product can be sent to any place and be printed on site. Taking this into consideration, factories no longer have a reason to concentrate in the same location, but they can freely choose where to place themselves and if they want they can get closer to consumption centers and purely urban realities.

First of all this transformation involves a reduction in transport times. Second, it leads once again to a closer relationship with the consumer. The downside of this system, highlighted by Kietzmann (2014), lies in the fact that there will be the need to increase the collaboration between several production centers, all potentially different and adapted to the market local. It is also true that each market can be explored and understood more fully and this it should lead to greater efficiency.

Bogers (2015) and Hadar (2015) underlined that the role of create value remains in the hands of the company, although the consumer is no longer a passive actor.

In addition, the new production process could reduce the incentive to relocate to emerging countries with low labor costs, thus leading to re-shoring.

Another advantage is linked to the reduction of pollution problems related to 3D printing that make foreign countries appear less attractive, even if they are supporters of looser regulations on the subject (see Breltrametti, Gasparre 2014).

Operational factors

As reported by Mellor and Hao (2014) one of the areas of operations management most changed by the additive process is that of product design. In fact, the 3D printing debases the technical constraints and allows the creativity to be exploited both in the marketing of original and creative forms and in realization of superior goods from a technical-functional point of view. An example is reported by Beltrametti (2014): when it is necessary to produce pieces and in the use phase is subjected to thermal stresses, it is also necessary to design an internal cooling. By adopting an additive process, a unique piece can be obtained and optimize its curvilinear shapes to exploit the fluid dynamic properties while the traditional manufacturing makes it through the meeting of a series of straight holes. In addition, additive manufacturing gives the object, when required, both lightness and resistance, thanks to support reticular substructures.

Mellor and Hao (2014) hypothesize many changes in quality control. To obtain an effective implementation of the methods, whatever they are, the activities must be monitored, measured and if necessary corrected. However, the methods adopted are thought in a subtractive logic that badly adapts to the opposite one and should therefore be adequate. On the one hand, 3D printing systems they do not have an internal monitoring system of the process and companies are not able to test important aspects of product characteristics such as porosity, density of the various parts, or the variability of the pieces made by a single machine that remain not adequately tested e qualified.

Petrick and Simpson (2013) estimate that this is a barrier to obtaining a quality finished product, but significant progress is being made thanks to the use of researched tomographic systems.

Forms of work organization

Whenever machines are introduced into production many herald a negative impact on labor demand. The general concern may be well founded for when it concerns the stages of production, assembly and post-production since the printers 3D are able to carry them out with little or no human intervention. Campbell (2011) explains that in the production phase the work of the operator consists in inserting the raw material into the machine which will then perform its tasks independently: the process is therefore controlled by the computer and not by man, thus involving a reduction of the experience required of employees and the interaction between them. Furthermore, the phase of assembly, where human work has always been a relevant element, can be eliminated when considering the possibility of printing finished objects. Lastly, even if in the state current technology the post-production phase requires manual processing for refining the objects is expected to improve the equipment that will allow get superior quality products right after printing.

On the contrary, the effect is positive for all those professionals involved in design, modeling of 3D systems and in the creation of ideas and business management since the demand for these professionals will increase as the expansion increases in the various sectors. Furthermore, for these figures it will be possible to design those forms of organization of the so-called flexible work.

In a nutshell, we can rethink the division of time between work and private life and achieve a balance through forms of remote work. There are actually many jobs that are not tied to a specific place but that can be done wherever the worker is since the same work result can be obtained from home, from the office or from any. Indeed, the designers would have the opportunity to settle where best they believe and send their creations to the company directly through a file. Furthermore, it will be possible to generate digital working groups made up of experts with different backgrounds and from interested people with multiple abilities, to whom it will be so permission to work on the same project without physically attending the same location, increasing creativity and the possibility of solving complex problems but decreasing human contact.

Absence of economies of scale

A factor considerably considered when deciding on the adoption of 3D printing is the almost independence of the production cost of the object from the volume of realization. In the case of the additive technology, the trend of total production costs is increasing as the quantity produced according to a substantially linear function. The absence of economies of scale is a disadvantage in some productions (large-scale ones) but a strength in production of a single piece or small series. In fact, the variations to the original model they have an almost zero cost since the revision of the construction file is free of charges monetary. The low weight of economies of scale benefits small and medium-sized companies, which can innovate and simultaneously reduce the risk of not achieving a minimum lot necessary to justify the investments. Not only the opportunity to use less specialized and therefore interchangeable machinery between different sectors and reduces the risk associated with the investment, but at the same time third-party manufacturers can be more easily used, thus lowering the cost of launching new ones and simplifying the transition from the design idea to real marketing.

Internal dynamics

In a more general, everything must be designed from an additive perspective. In the sense that at the design stage the layout should be designed for use that respects the constraints and standards of the technologies in question, presumably different from the traditional ones. Not only the phase of the project but also its implementation, the warehouse, the ways in which the materials are transported (etc.) must lead to an

optimal use of additive technologies and must be designed to ensure efficient operation.
In addition, special attention deserves the management of digital data, which is of vital importance in this type of production method. Companies should equip themselves with technologies and personnel suitable for virtual data storage and their manipulation.

The benefits

A typical application of additive manufacturing is rapid prototyping, which it allows to reduce the production times of prototypes compared to classical methods and speeds up successive phases of product production, thus allowing to reduce the total time to market. In other words, having a physical prototype available in the shortest time possible can help the designer to think about the next phase, that is the molds for the final object.
In addition, rapid prototyping, allowing to work on multiple projects simultaneously, it leads to greater freedom in thinking about the sequence of phases, even disconnecting them from the linear vision.
The reduction of time to market and the ability to adapting quickly to changes provide many strategic advantages to the company vis-à-vis its competitors. In fact, the studies on the subject of Gatto (1998) e Luciani (1998) show that companies that diversify and therefore do not depend on one or a limited number of products enjoy a certain security on the market. A second benefit achieved through the additive process lies in performance higher objects than those achievable with traditional subtractive technologies.
In fact, the possibility to put into practice otherwise unthinkable geometries, and to obtain shapes complex, it improves some mechanical characteristics, and in fields where it is required, it reduces also the weight of the product.
Furthermore, Bacchetti (2015) and Zanardini (2015) attest that the production/assembly can gain in efficiency. Using the aforementioned technologies, different pieces can be made in one printing process. In contrast, traditional techniques carry out several separately elements that must then undergo an assembly process through joints and welds, that are usually the main causes of failures and defects and therefore sources of inefficiency for the product. Then adopting a perhaps risky perspective already described in the previous chapter, the objects can be produced when the consumer requests them. Thanks to this "Manufacture on demand" there would be neither overproduction nor destruction of the products unsold and inventories would be reduced.

Another potential advantage concerns the environmental sustainability of the process. This goal, increasingly important in many fields, it is achieved as additive manufacturing should lead to a reduction in waste material, since all that is not processed it can be reused, and there is simultaneous reduction in energy consumption. It is important to note, as Campbell (2011) rightly writes, the coincidence between the specific consumer requests and the nature of additive manufacturing is often not accessible to traditional manufacture. Indeed, products made in small batches can be a lot different from each other since the cost of variation from the original model is low as a modification of the digital project is sufficient.

The costs

The costs of the additive process are difficult to estimate and therefore it is difficult to classify them as a source of advantage or a critical issue to be solved. To deepen the analysis, Douglas (2014) reports a useful classification, dividing them into "ill-structured costs" and "well-structured costs". The first, which are generally reduced, are those concerning the supply chain and have been showed in the previous paragraph. Here we would just like to summarize the major associated cost reductions:

- Warehouse cost reduction: fewer supplies are needed and consequently the cost of renting, taxes from pay, the amount of insurance and also reduce the risk of obsolescence e deterioration.
- Transport costs reduction from the place of production to that of consumption since product printing can be done anywhere using a file.
- Reduction of the number of the intermediaries: the number of steps is lower and the operators involved decrease therefore it is assumed that a minor cost is necessary for the management of the supply chain.

Well-structured costs briefly include the cost of labor, machinery and equipment materials. On the contrary, these burdens cannot be defined as a source of advantage or disadvantage since it is difficult to reach a definitive assessment of their consistency.

In general, labor and energy costs are negligible compared to the total cost of the process. As for the former, they are reduced because the process is a lot automated and can proceed under computer control, the involved employees are therefore a small number and not endowed with experience.

Even the amount of the energy used seems to be lower than traditional production and therefore in cost content. Instead, the materials most used today (plastic, metal) cost more with respect to their counterpart in the subtractive process.

Not to mention that companies must sustain enough substantial investments to equip themselves with the necessary machines. Considering these elements, these expenses appear to have a negative impact on life company, but greater adoption of the additive process could lead to a reduction of the cost of raw materials, exploiting economies of scale. And it should be noted that the price paid for the machinery varies according to the technology the machine uses. The greatest difficulty is found, however, if the company objective is to be minimize the total cost of the process. To achieve this, they consider themselves different factors and each of them, depending on how it is declined, has a different effect on the total from spend.

The criticalities

Although the advantages are evident, we must also consider the criticalities that, in fact, they have prevented a massive spread of the new method. The limitations relate primarily to mass production. Campbel (2011) estimates the time of production of 1.5 cubic meters in one hour. On the contrary, a classic molding machine can make several objects in less than a minute. Although an increase in the speed of the additive process, it will hardly come to equate the subtractive one, given the presence of bottlenecks in the process itself.

Some experts have also hypothesized a danger to human health. Indeed, one research conducted by the University of Illinois would have shown that in the absence of aspirators in the work environment the accumulation and deposit of particles of thermoplastic materials could cause harmful effects on human health (see Rota 2015). Even if it is a study that highlights only clues on the toxicity of the treated materials, the fact that various bodies, such as the European Community, are calling for a more accurate assessment of the possible risks introduced by new technologies offers ample space for debate about the alleged dangerousness. In fact, the current programs, calibrated on the design obtainable with the traditional systems are considered inadequate to exploit the creative freedom of forms which is instead granted by additive technologies. Moreover, the diffusion among nonprofessionals might be hampered by their interface, considered by many not too easy to use.

What is missing is also the knowledge of technology. Current managers fail to evaluate which technique is best suited to the production of the specific factory or what materials to use. Furthermore, specific skills are required for the efficient management of software, elements at the base of the process. The development of the aforementioned skills involves the incurring additional costs for the company or for other specific structures. In domestic use, a system of protection of the original creation should be developed that prevents the consumer-producer from replicating the work of others at will.

In addition, there is also the problem of attributing responsibility for any defects of the printed product. It has not yet been decreed which subject to respond to repairs or replacements of faulty parts, be it the supplier of the material, the manufacturer of the machine, the designer of the drawing or who else (see Mohr and Khan, 2015).

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