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Brief History of Additive Manufacture and the Effect of Patents

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Abstract

In the present article, the author presents a study of the history of patents, as well as the effect of this on the progress of additive manufacturing. This brief history of additive manufacturing, aims to be a mandatory reading for all that researcher, scientist or company manager, who wants to be able to situate the current moment of additive manufacturing, and be able to judge the effect that patents have had on the development of this technology. Therefore, it should be noted that the expiration of the patents that protected some Additive Manufacturing technologies, thus allowing the entry into the market of universities and small companies manufacturing and marketing personal printers economically very affordable.

Keywords: patents; additive manufacturing; printing 3D; History.

1. Introduction

The last three decades have seen, mainly, a transition towards the digital in different areas of life, both professional and personal. There are many examples that describe this radical change:

- In the field of communications, there has been a change from the sending of postal mail to the fax and then e-mail;
- Within the field of technical offices, there has been a change from hand-drawn paper planes to parametric files, first in two dimensions (2D CAD Assisted Drawing Systems) and then in three dimensions (3D CAD Assisted Drawing Systems);

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- Within the sanitary field, from X-rays radiography to magnetic resonance, CAT (Computerized Axial Tomography), or 3D Doppler Ultrasound.

- Within the leisure field, from two-channel black and white television to the infinite offer of DTT, or the exchange of the deck of cards for the augmented reality video game;

Therefore, and as is logical, factories are not alien to this phenomenon. Computer Aided Drawing Systems (CAD), which affect product conception in technical offices, have already been commented on, but Computer Aided Manufacturing (CAM) or Computer-aided engineering (CAE) software, the use of automatons and robots in the plant, artificial vision inspection, control of production progress in real time (MES or Manufacturing Execution System), or virtual modelling and recreation of processes and entire factories with simulation software (CAPE or Computer-Aided Protection Engineering) are also well known [1,11,15].

Advances in cybernetics allow huge amounts of data to be processed at high speed and mechanical systems to be operated, exceeding the known limits of reliability and precision. Advances in software and computational techniques are what enable substantial advances in additive manufacturing technologies [14,16].

However, the parts manufacturing processes, although assisted by more advanced controls, remain basically the same: shaving removal, cold or hot forming, injection or melting [1,3].

All of them face limitations, not only control but also physical, such as the impossibility of making curved drills, collisions of tools with the complex geometry part, restrictions of moulding angles, etc.... These limitations block creativity and constitute a barrier, sometimes difficult to overcome, to the development of new products of high added value or with new functionalities [2,4].

It is fundamental that nowadays, the managers and general directors of the industrial companies, have knowledge of all these technological changes, in order to be able to take strategic decisions about the company, which will undoubtedly mark their future and their competitiveness in the market [7,12].

2. Fabrication, Chronology and Patents

2.1. Fabrication of Objects by Adding Material Layers

The last quarter of the 20th century saw the emergence of additive manufacturing technologies, which take advantage of all this knowledge developed in the digital age, and which can overcome the limitations described above. Essentially, they represent a Copernican revolution with respect to the construction processes of parts used up to that moment, since they are now manufactured by controlled deposition of material, layer by layer, contributing exclusively where necessary, until achieving the final geometry pursued, instead of removing material (machining, die-cutting...), or forming with the aid of tools and moulds (casting, injection, bending...) [5,6,7].

Therefore, the manufacturing processes of parts can be classified in the following way:

- **Conformity technologies:** they use preforms to obtain the required geometry. The material is introduced into a mould with the cavity of the part to be obtained, it is adapted and processed with the shape of this mould and finally, the part is extracted from it. Some examples are the following:

  - o Injection moulding: the cast material is injected into the cavity of the mould (which is the negative of the part) and solidifies with the shape of the part.

  - o Forging, embossing: the material is plastically deformed so that it adapts to the cavity of the mould.

  - o Thermo-shaped: a sheet or a thermoplastic semi-finished sheet is heated in such a way that when softened it can be adapted to the shape of a mould thanks to the vacuum pressure or by means of a counter-mould.

  - o Conventional powder metallurgy (sintering, MIM, CIM, etc...): the cavity of the mould is filled with material in powder format, after a compacting and sintering process the part is extracted.

- **Subtractive technologies:** they obtain the required geometry by subtracting material from a larger geometry since the starting point is a block of material with larger dimensions than the final geometry to be obtained. By means of successive material removal operations, the material is selectively removed, creating the desired part. Some examples are the following:

  - o Machining: manufacturing process comprising a set of operations for forming parts by removing material, either by removing chips or by abrasion.

  - o Electrical discharge machining: it consists of generating an electric arc between a part and an electrode in a dielectric medium in order to remove particles from the part until achieving to reproduce the forms of the electrode. Both the part and the electrode must be conductive so that the electric arc that causes the material to start can be established.

  - o Cutting by water, laser, saw, etc.

- **Additive Manufacturing (AM):** the part is directly obtained from a 3D digital CAD file by adding the

material in layers without the use of preforms (conformity) and without subtracting material (subtractive) (Hopkinson N., 2006), as indicated in Figure 1:

Figure 1: comparison between Conventional manufacturing and Additive manufacturing

Rapid prototyping techniques have been evolving towards more sophisticated technologies that are being consolidated as Additive Manufacturing technologies, with their own identity, and differentiated from rapid prototyping (Gibson, 2010).

Additive manufacturing application techniques (such as Stereolithography or Selective Sintering) that allow parts to be obtained directly from a 3D CAD file, "printing" them in a totally controlled way on a surface are very diverse.

Today they have not yet been widely implemented in the industry, partly because some limitations of the process itself must be resolved, as well as some peripheral elements, but also because it is quite unknown by potential users, who are not aware of the enormous advantages it can bring over other processes in many market niches.

2.2. Chronology

1976 - Invention of ink printing

3D printing dates back to 1976 when the inkjet printer was invented. 3D printers work like inkjet printers and, instead of ink, they deposit the desired material in a series of successive layers to create an object from a digital format.

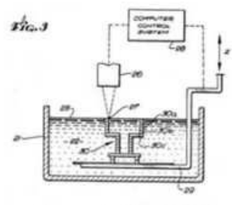
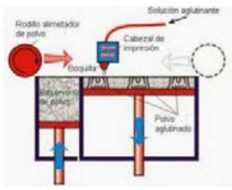


Figura de US4575330

1984 – Invention of the SLA

Chuck Hull patented his system in the United States, under the name stereolitography. This machine worked using an ultraviolet laser to solidify a thin layer of acrylic resin and, with the repetition of the process adding resin on top and solidifying it again; it created, layer by layer, the object in three dimensions.



1988 – 3D Systems

Hull sets up 3D Systems

1988-1990 – SLS and FDM

New printing methods are developed:

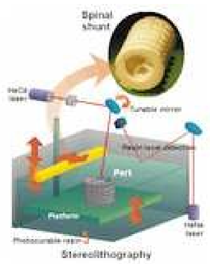
- Fused Deposition Modelling (FDM).

- Selective Laser Sintering (SLS).

1990 – Stratasys

Scott Crum, who had conceived the FDM printing method, sets up the company

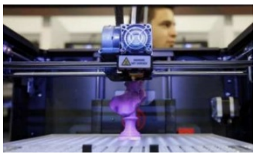
Stratasys in order to market his invention. Over time, this method allowed a greater diffusion of 3D printing lowering costs and allowing small users and non-industrial workshops have access to this technology for their own purposes.



1992 – Layer by layer prototype manufacturing

The first SLA (stereolithographic) 3D printing machine on the market was developed by the 3D Systems company. The basic operation of this machine is that a UV laser solidifies a photopolymer, a liquid with viscosity and colour similar to honey; it produces three-dimensional parts layer by layer. Despite the imperfection, it is amply demonstrated that highly complex parts could be manufactured at night.

1995 3D-printed injection



MIT students Jim Bredt and Tim Anderson develop 3D-printed injection: they modify an inkjet printer to extrude a binding solution onto a bed of dust instead of ink onto the paper. The resulting patent led to the creation of the modern 3D printing technology of the Z Corporation companies (set up by Bredt and Anderson, and now owned by 3D Systems) and ExOne.

1999 – Organ printing

The first laboratory-bred organ to be implemented in humans was an augmentation of the urinary bladder using a synthetic coating with its own cells.

The technology used by scientists at the Wake Forest Institute of Regenerative Medicine, opened the doors to the development of other strategies for the organs of engineering (print them). Because they are manufactured with the patient's own cells, the risk of rejection is practically zero.

2002 – Functional 3D Kidney

Scientists design a fully functional miniature kidney with the ability to filter blood and produce diluted urine in an animal.

The development led to research at the Wake Forest Institute of Regenerative Medicine aimed at printing organs and tissues with printing technology.

2005 – RepRap: Open-Source entry

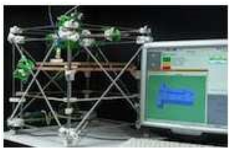
Dr Adrian Bowyer sets up RepRap at the University of Bath, an open source initiative to build a 3D printer that can print most of its own components. The vision of this project is to democratize the manufacture of low-cost RepRap distribution units to people around the world, allowing them to create products on a daily basis on their own.

2006 – SLS and personalisation in mass production

This year the first machine of the SLS type (Selective Laser Synthesis) is built.

Basically, this type of machine uses a laser to melt materials in the 3D printing process. This discovery opens the doors to mass customization and the demand for manufacturing industrial parts, and later, prostheses.

That same year, Object, a supplier of materials and 3D printers, creates a machine with the ability to print on multiple materials, including polymers and elastomers. The machine allows a part to be manufactured with a wide variety of densities and material properties.



2008 Darwin, the first printer with auto-replica capability

After its launch offer in 2005, the RepRap project brings Darwin to light, the first 3D printer with the ability to print most of its own components, allowing users who already have one to make more printers for friends or even repair components of their own.

2008 – Co-creation services

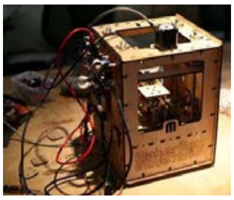
Shapeways launches a private beta website to offer a new co-creation service to the community allowing artists, architects and designers to present their designs in 3D as cheap physical objects.

2008 – Prosthesis

The first person to walk on a 3D printed prosthesis leg, with all parts (knee, foot, etc.), printed on the same complex structure without any kind of assembly. This type of advancement allows prosthesis manufacturers to make custom developments in the prosthetics industry.

2009 – 3D printer kits

MakerBot Industries, an open source hardware company for 3D printers, begins selling assembly kits that allow buyers to manufacture their own 3D printers and products.



2009 – From Cells to Blood Vessels

Bio-printing arrives, with the technology of Dr Gabor Forgacs, who uses a 3D bio-printer to print the first blood vessel.

2011 – First aircraft printed in 3D

Engineers at the University of Southampton designed and planned the first plane printed in 3D. This unmanned aircraft is built in seven days, with a budget of 7000 €. 3D printing allows its wings to have an elliptical shape, a feature normally expensive that helps to improve aerodynamic efficiency and minimizes the induced resistance.

2011– Urbee, the first car printed in 3D

Kor Ecologic presents Urbee, a prototype car that tries to be as efficient as possible with the environment, being all its body designed and printed in 3D. It tries to be an efficient car in terms of gasoline consumption and production cost. Its price will range between 12000 € and 60000 € as long as it is commercially profitable.

2011 – 3D printing in gold and silver

Materialise was the first company to offer a 14 Karat gold and sterling silver 3D printing service. This option will allow opening a new market to jewellers with more economical designs using this material.

2012 – First 3D Printed Jaw Prosthesis Implant

Dutch doctors and engineers work with a 3D printer specially designed by LayerWise, which allows custom jaw prostheses to be printed. This group was able to implant a jaw for an 83-year-old woman suffering from a chronic bone infection. This technology is being further studied in order to promote the growth of new bone tissue.

From here, the development has been very fast, thanks also to the expiration of different patents: if between 1984 and 2011 were sold in the world 45000 3D printers, in 2012 the same number of printers was sold in a single year. The reason for this rapid spread can be explained by the following causes:

- The availability of new materials with greater functionality and performance.

- The expiration of the patents that protected some Additive Manufacturing technologies, thus allowing the entry into the market of universities and small companies manufacturing and marketing personal printers economically very affordable.

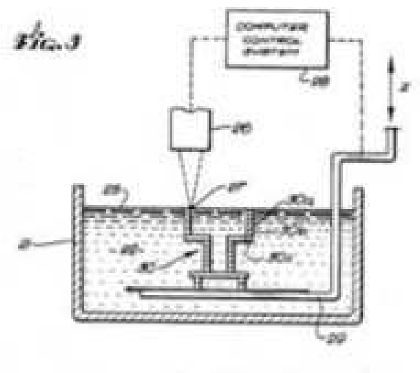
- The marketing task being carried out by the leading companies at a global level.

- The unsuspected applications that have enabled these manufacturing technologies and the diffusion that has enabled the Internet.

2.3. D Printing and Patents

3D printing has been appearing frequently in the media for several years, announcing a revolution in the manufacture of all types of products, which is gradually reaching all areas of production [8,9,13].

It seems that the credit for the invention of this type of technology lies with the American Chuck Hull, who actually invented one of the modalities of 3D printing, the so-called "stereolithography". He invented the technology when he worked printing coatings on top of boards using ultraviolet rays. In those years, one problem facing the manufacturing industry was that the production of small plastic parts for prototypes could take months, and that was the problem he was trying to solve with his invention: obtaining plastic prototypes more quickly. The essence of this technology, as well as its name, can be found in the US patent US4575330, "Device for the production of three-dimensional objects by stereolithography", filed on 8th August 1984. Broadly speaking, it consists of a ray of ultraviolet light "drawing" layers on the surface of a "photopolymer", as seen in Figure 2, in collaboration with an elevator [10,15,16].



1. A system for producing a three-dimensional object from a fluid medium capable of solidification when subjected to prescribed synergistic stimulation, said system comprising:
means for drawing upon and forming successive cross-sectional laminae of said object at a two-dimensional interface; and
means for moving said cross-sections as they are formed and building up said object in step wise fashion, whereby a three-dimensional object is extracted from a substantially two-dimensional surface.

Figure 2: figure of patent US4575330 and its first recognition

Hull is listed as an inventor in about 60 patents, but apart from the first, the most relevant are **US4929402** and **US4999143**. In 2014 he won the "European inventor" prize awarded by the European Patent Office in the "non-European inventors" section. He now has his own company "3D-Systems", in California, which works essentially for the entertainment world. Chuck Hull emphasizes that the most exciting thing for him is to see the advantages that this technology brings to the world of medicine. As early as the 1990s, this technology began to be used for the manufacture of prostheses; it is also still used for the procurement of tissues and organs. However, its first industrial use was in the world of the automobile, for prototyping. Today, it is widely incorporated in the manufacture of cars, from racing engines in Formula 1 to gear levers and buttons in cars. Patents are often referred to as a form of industrial property that fosters innovation by rewarding the inventor for technological advances, but throughout the history of patents, there have been examples of situations where the existence of existing patents has prevented the popularization of a particular technology. Some scholars claim that the existence of very broad patents on the different 3D printing technologies has caused that, although the essential technology has been invented for around 30 years, it is not until recently that there has been a real explosion in its use. Many companies were unwilling to invest in R&D in 3D printing for fear of being sued for infringement. Only a few years ago, the technology is spreading, when most of those patents are expiring and printer prices are falling. Among the "relevant" patents that have expired in recent years, the following ones can be highlighted:

- **US5174931**, referring to a perfected method and device for "stereolithography".
- **US5569349** also on stereolithography, which gave answers to safety problems arising with the original technique and where the material is supplied through a nozzle.

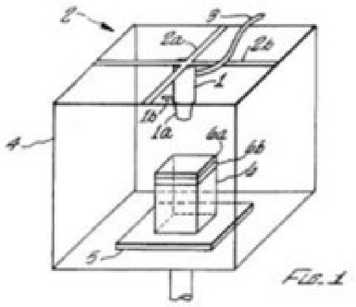


Figure 3: figure of patent US5569349

- **US5637169:** it refers to a procedure in which printing is done on overlapping sheets of material and uses electromagnetic radiation instead of ultraviolet radiation.
- **US5639070:** on a selective sintering 3D printing method. It consists of depositing powdered material at certain points and then melting it with a laser.

These patents are just a selection of the many that have expired in recent years, as can be seen in the following histogram:

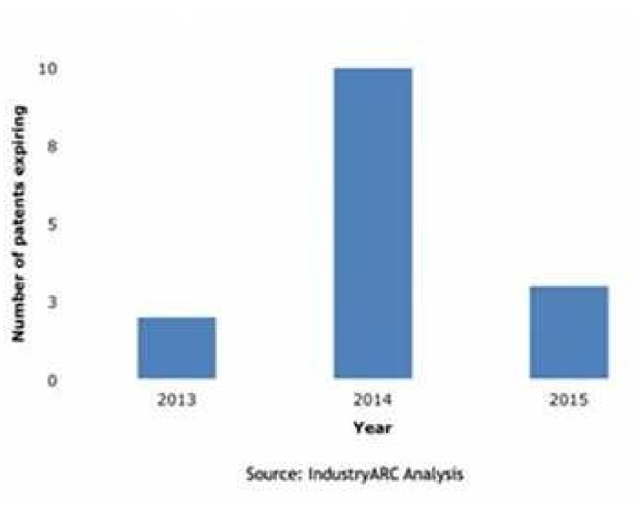


Figure 4: patents expired between 2013 and 2015

3. Discussion and Conclusion

Although "essential" patents are expiring and printer prices are declining, it must be borne in mind that the materials used are quite expensive, especially for titanium additives, and that it is necessary to have knowledge of CAD and advanced software. However, it is undeniable that the industry has been undergoing a revolution for a few years.

As can be seen from a report by the UK Intellectual Property Office on the emergence of 3D printing, many patent applications are being filed, in which all that is provided is the manufacture of objects or devices already known through 3D printing. As always, it will be necessary to analyse each case, but if the only thing claimed is the manufacture by printing rather than any other means of obtaining, at least initially this will not involve an inventive step, unless a technical problem is solved.

Once again, the UK Intellectual Property Office has published another very interesting report entitled "The current Status and Impact of 3D Printing Within the Industrial Sector: An Analysis of Six Case Studies". It concludes that 3D printing technology is unlikely to pose major problems to the world of intellectual property in the next ten years. There will undoubtedly be infringement problems, especially cases of unauthorised manufacture and distribution of spare parts, for example for cars, but there is legislation in place to combat such potential conflicts. As far as spare parts are concerned, "domestic" technology does not yet allow for the production of parts of sufficient quality and where technology exists to provide quality comparable to industrial quality, the cost of manufacturing is even higher than in traditional industry. The report, however, acknowledges that after a few years, the situation could change due to the fall in prices and the increase in the quality of the products obtained.

Although the British Intellectual Property Office does not seem too concerned about the problems that 3D printing could pose to the world of patents in the short term, other experts are more concerned and believe that 3D printing threatens the patent system and could spread a piracy similar to that currently existing in the world of music and film. Just as sound or image files are over the Internet, so could CAD files where the necessary information is found to "print" all kinds of objects using 3D printers, increasingly cheaper and of higher quality. This practice will undoubtedly lead to patent infringement.

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