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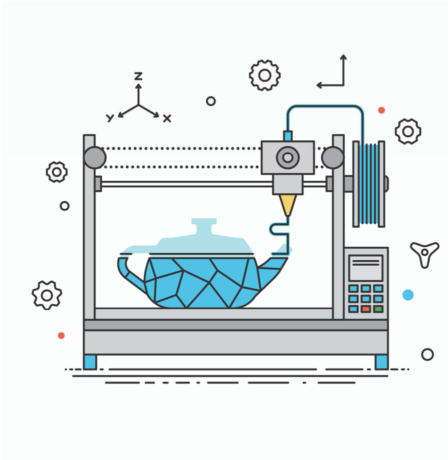
Additive manufacturing (3D Printing)



3D printing process
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Summary

- *Historically used for prototyping purposes, additive manufacturing (3D printing) is gradually being introduced into the manufacture of end products.*
- *The advantage of using 3D printing is nevertheless limited to specific cases where its control can lead to a strong competitive advantage in the industry and to considerable progress in the field of health.*
- *Research tends to improve 3D printing techniques and their fields of application. 3D printing could have a significant economic impact in the future.*

Mrs. Huguette Tiegna,
MP (National Assembly), Vice-Chairwoman

Additive manufacturing (3D printing) was presented by the Obama administration as a means of preserving manufacturing industry and jobs by relocating activities to the home country.

One concept, with several processes and technologies

Unlike conventional machining methods such as milling or cutting, which make possible the manufacture of parts by material removal, the additive manufacturing of a part is based on the addition of material, layer by layer, according to the specifications defined in a digital "3D model". Additive manufacturing is also different from thermoplastic injection moulding.

While the first machines were very slow, expensive and constraining (in terms of the size of printable parts, the diversity of usable materials, etc.), 3D printing techniques have evolved a lot since then.

To date, there are around 100 suppliers of 3D printing systems worldwide, dozens of additive manufacturing technologies (wire deposition, selective laser sintering, stereo lithography, etc.), seven principles of operation, more 200 types of materials that can be used in 3D printing (plastics, metals, ceramics, etc.). Some machines allow the use of different materials of the same nature during the same printing. Available techniques can print objects measuring from a few centimetres to a few metres.

A French invention?

The first additive manufacturing or "3D printing" technology was invented in 1984 by Alain Le Mehauté, Olivier de Witte and Jean-Claude André. However, they never obtained the patent for their invention, dubbed "stereolithography", since their then management at the General Electricity Company and CILAS did not wish to incur costs in the process of filing a patent.

The same year, the American Charles W. Hull, now considered as the father of 3D printing, filed a patent similar to their invention and obtained issue of it in 1986. He then founded 3D Systems, the first company in the world to market 3D printers.

A complementary solution to conventional machining methods

Historically, 3D printing has been used extensively for rapid prototyping of products. Not requiring tools, 3D printing can produce parts at low cost while reducing delays. The designer can easily upgrade their prototypes (by modifying the 3D model) and thus work iteratively.

While some industries continue to massively use 3D printing techniques for prototyping purposes, they are also introducing end-products because of their technical advantages over traditional approaches.

3D printing is particularly useful for producing pieces with complex geometry, sometimes inspired by forms observed in nature (a process known as biomimicry). While the complexity of such parts induces, in most cases, high costs and increased production difficulties in conventional machining, this is not the case in 3D printing. Sometimes, 3D printing can be the only technique that can be used to make such pieces. In some cases, 3D printing can also drastically reduce the number of parts needed to produce a product, and thus simplify the design. 3D printing can reduce the cost of production of one-off pieces as well as of small and medium-sized production runs.

However, additive manufacturing is not intended to replace conventional manufacturing methods. Indeed, the printing of mass-produced pieces, at this stage, is not economically viable. Moreover, additive manufacturing is sometimes unsuited to the needs of precision mechanics (1). The quality of the functional parts of 3D printed parts depends on many factors (temperature, materials, machines, manufacturing practices, etc.). As a result, compliance with the functional requirements of 3D printed parts (tolerances, surface finish, material strength, etc.) can vary. Finally, it is very often necessary to complete the 3D printing of metal or plastic parts by machining or sanding operations to improve the quality of the surfaces.

Thus, 3D printing techniques complement conventional manufacturing methods and open up new production possibilities. Selection of the process by manufacturers depends on requirements in terms of cost, time, quality or complexity of the product.

■ Main industrial sectors

Because of the advantages of prototyping and parts manufacturing by 3D printing, additive manufacturing techniques are used across industry (aerospace, the food industry, wind turbine production, luxury goods) and sometimes by craftsmen (chocolate makers, jewellers).

In the field of consumer electronics, 3D printing offers new solutions to designers. For example, semiconductor manufacturers and US laboratories (2) are developing a technology that allows for flexible electronic circuits (sensors and microcontrollers) through 3D printing (3). The applications of this technology could be numerous, as for example in the field of portable connected objects ("wearables"), a market with high potential.

Similarly, 3D printing is becoming increasingly prevalent in the aerospace industry, although the number of 3D printed parts embedded in end products remains extremely low. In this sector, 3D printing is first used to produce relatively small numbers of high value-added parts with very specific geometric characteristics. For example, the 19 LEAP engine nozzles on the Airbus A320neo are printed in 3D. These nozzles require complex geometries to ensure the proper mixing of air and fuel in the engine. Thanks to 3D printing, the nozzles are made in one piece, compared to the 20 pieces required for those made by conventional machining methods. These nozzles are 25% lighter than machined ones, and five times more temperature resistant. This technological choice leads to a reduction in operating costs equivalent to 2.4 million euros per LEAP-equipped aircraft per year (4), due in particular to fuel savings.

In addition, additive manufacturing could be a means to reduce the storage needs of aerospace manufacturers. According to consulting firm EY (5), Airbus estimates that the parts changes for its A300 and A310 aircraft models will continue to be necessary until 2050. Airbus was already stocking 3.5 million parts for this purpose in 2014. With the generalisation of the use of 3D printing, stocks could be reduced to the bare necessities: then, there would be no need to store any specific parts or tools. Indeed, printing could be done on demand, usually from easily storable metal powders.

In the automotive sector, 3D printing is mainly confined to prototyping or the production of tools. Additive manufacturing is rarely used in end products. Companies (6) have nevertheless demonstrated the feasibility of producing a car body by means of 3D printing, and in only 44 hours (7). It thus appears possible to develop micro-automobile factories generating little waste and ensuring rapid deliveries of vehicles produced directly in urban areas. The production capacity of such plants would nevertheless be much lower than those of the current major automobile groups. Again, one of the advantages of 3D printing is the ability to manufacture spare parts.

Finally, 3D printing could be a highly effective way to modernise the construction industry. As regards structural work, two laboratories in Nantes have developed a technology, BatiPrint3D (8), which allows on-site printing of housing that meets existing standards. At the end of 2017, the use of this technology made it possible to build a 95-square-meter social housing unit in Nantes in just a few days, with an energy performance that is 30% lower than the 2012 thermal regulations.

■ Economic challenges and industrial competitiveness

According to the consulting firm Wohlers Associates, the market for 3D printing (machinery, materials and consulting combined) is growing by 20% per year and could reach 18.5 billion euros by 2020. The United States has 40% of the world's machinery, with France accounting for only 3%, ranking 7th in the world and only 4th in Europe.

These examples show that properly used 3D printing can result in a strong competitive advantage.

First, the use of additive manufacturing can lead to important innovations. Producing flexible electronic components or quickly "printing" homes are major technological breakthroughs which give a competitive advantage to the industries that can master them.

3D printing of small numbers of specific and particularly complex parts can improve quality and reduce production costs, with significant added value for the customer and the manufacturer.

The shift to 3D printing greatly simplifies inventory management. Inventory management in terms of cost, warehousing and tracing is a major problem for large industrial groups like Airbus. 3D printing allows the production of parts on demand and easy storage (the raw material is most often in the form of powders).

3D printing allows companies that master these technologies to reach the market more quickly. Additive manufacturing accelerates the prototyping phases and quickly detects the corrections which need to be made to the product, which is thus more quickly developed and can be tested on the market. In addition, investment in 3D printing by SMEs and start-ups is affordable. Therefore, 3D printing can lower the entry barrier to certain markets, which promotes the rapid arrival of new players in these markets.

Finally, the use of additive manufacturing can encourage the relocation of certain activities closer to the consumer. The integrated micro-plant concept in urban areas could come into being with various benefits such as on-demand generation, reduction of distribution costs and positive environmental effects.

■ Health issues: bio-printing

Some additive manufacturing processes, known as "bio-printing", make it possible to artificially produce cell structures.

In principle, the printed cells can come from human embryonic cell cultures. However, such cells are difficult to obtain, their access being particularly restricted by law for ethical reasons. It is therefore more convenient to produce and use induced pluripotent stem cells (IPSCs), i.e. reprogrammed adult cells, for bio-printing purposes.

Ultimately, the printing of IPSCs could help to reconstitute:

- artificial organs to replace deficient organs, without causing immunological rejection (the cells used being those of the patient);

- artificial organs making it possible, in certain cases, to carry out tests on 3D models without resorting to animal experimentation;

- 3D "organoids" for research

While 3D printing of complex organs (such as kidneys or lungs) for grafting remains experimental, some therapeutic applications involving the printing of simple organs (hair, gingival mucosa and bone implants) are already very promising. For example, a large French group is working with a start-up [9] to treat baldness by restoring a hair follicle using laser bio-printing technology.

Thus, in the short term, bio-printing could profoundly modify the production of easily printable implants (hair, gum, skin, bone). In the longer term, advances in the printing of complex organs could help to overcome the shortage of organ donors as well as limit animal testing.

■ Other public health issues

3D printing is now widely used in the hearing aid sector, allowing the fabrication of prostheses adapted to the individual audiogram and to the anatomy of the patient's ear canal. Similarly, 3D printing could shake up the dental prosthetics market by improving their quality while reducing their manufacturing cost.

3D printing can find applications in the production of drugs. 3D printing techniques can be used to improve drug delivery, allowing a complex release of the active ingredient over time.

3D printing can also be used in orthopaedic surgery. An operation performed at the University Hospital of Amiens, in the autumn of 2017, helped to straighten a patient’s spine. After scanning, the patient's skeleton was identically reconstructed in 3D, making possible the modelling of a surgical procedure by a robot. Once the operation had been validated on the model, it was performed on the patient.

■ Use of 3D printing by individuals

The domestic market for 3D printing is very weak. In addition, "fab-labs" (collaborative places open to the public and equipped with machines to design and make objects) are being increasingly abandoned by individuals and oriented to professional uses. Although affordable, creating or modifying one's own parts with a personal printer often remains complex, since computer-assisted design software is difficult to master.

Nevertheless, the domestic use of 3D printing techniques raises many questions, firstly of a legal nature, but also concerning the health and safety of individuals.

For example, if illegal sharing or the "private copying" allowed in the family setting of 3D models became common, this would harm rights holders. Legal solutions should quickly be found such as end user liability, intermediation platforms and the promotion of legal offers.

In addition, parts printed by individuals are manufactured without any supervision. This poses a problem for people's physical safety, since the reliability of the printed parts and their compliance with applicable standards is not guaranteed. For example, a printed part for an automobile may not meet the necessary requirements and cause an accident. This raises the question of liability in case of an accident due to a faulty part printed in 3D. Would the person responsible for the accident be the printer manufacturer, the material manufacturer, the 3D model designer or the person who printed the object?

Finally, studies (10) have shown that, when printing, some "desktop" 3D printers emit large numbers of ultrafine particles (less than 100 nanometers) as well as dangerous volatile components. The use of these printers could therefore pose a health risk, especially in places without ventilation systems.

■ Perspectives and recommendations

3D printing seems to be in its infancy. Significant research is being conducted to improve existing techniques or expand the scope of additive manufacturing: yield enhancement, 3D nano-printing and even 4D printing – a still experimental process of 3D printing of "stimulable" materials, which change properties (such as colour or shape) over time, depending on conditions (such as temperature and humidity).

Thus, although the additive manufacturing market is, at present, very modest (a few billion euros worldwide) and the place of 3D printing in industry remains limited, the situation could evolve over the next decade. Studies in the United Kingdom (11) and the United States (12) tend to show that additive manufacturing could become a major economic lever, a factor in improving the purchasing power of citizens, a source of skilled jobs and a means of reducing the carbon footprint of the industrial sector.

This is why research and investment in 3D printing should be supported in France, including the Future Investment Program (PIA) and the Public Investment Bank (BPI) grants, as well as the calls for projects of the National Research Agency (ANR) and the European Horizon 2020 program.

It is also necessary to reinforce the structuring of the sector by supporting the action of the Future Industry Alliance (AIF) and the Carnot Cetim Institute, in particular by networking the actors involved. This effort should be distributed across the country by inviting the regions to participate around their competitiveness clusters and reference platforms.

Finally, training and information on the techniques and possibilities of 3D printing will have to be developed to ensure that this breakthrough technology is recognised and popularised.

OPECST websites:
http://www.assemblee-nationale.fr/commissions/opecst-index.asp
http://www.senat.fr/opecst/

Endnotes

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