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► To cite this version:

Francisco Cavas Martinez, Manuel Paredes, Francesco Gherardini, Carmelo Gomez Garcia. Additive manufacturing technologies for sustainable-intelligent structures: a new concept of multidimensional printing. *DYNA : Ingenieria e Industria*, 2023, 98 (1), pp.10-11. 10.6036/10778 . hal-04194685

HAL Id: hal-04194685

<https://hal.science/hal-04194685>

Submitted on 4 Sep 2023

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Additive manufacturing technologies for sustainable-intelligent structures: a new concept of multidimensional printing

TECNOLOGÍAS DE FABRICACIÓN ADITIVA PARA ESTRUCTURAS SOSTENIBLES-INTELIGENTES : UN NUEVO CONCEPTO DE IMPRESIÓN MULTIDIMENSIONAL.

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1. Introduction

In recent years, additive manufacturing has become a disruptive technology for its ability to build structures with complex geometries. In the future, additive manufacturing will combine multidimensional printing technology with the use of programmable-intelligent materials, reaching higher levels of structural freedom, sustainability, and efficiency in advanced manufacturing processes, which, ultimately, will boost the social, economic and environmental impact of this technology.

Additive manufacturing is one of the main technologies in innovation and creativity due to its ability to generate new structures with complex geometries [1], particularly when coupled with machine learning [2]. Additive manufacturing is exploited in sectors as wide as aerospace [3], medicine [4], education [5], construction [6], energy [7], automotive [8], cultural heritage [9], and induces new business models [10]. Moreover, due to the growing demand for customized products with high structural strength, the need for resistant-programmable-intelligent object printing technologies is expected to grow in the coming decades [11].

Printing technologies have evolved from the third dimension (3D) to the fourth dimension (4D), to the fifth dimension (5D), and to the more recent so-called sixth dimension (6D). These evolutions are described hereafter.

2. Evolution of additive manufacturing

3D printing was born in the 1980s and has generated a great impact at social and industrial level [12]. It is based on the repetition of the 2D structure by depositing material layer-by-layer in a plane-horizontal from a print path from bottom to top, until creating a 3D volume. It is characterized by offering some flexibility throughout the product design process, a considerable reduction in material consumption compared to a conventional manufacturing process and allows the customization of products using various shapes and geometries [12]. ASTM International classifies 3D printing processes into 7 classes [13]. 3D printing induces specific material properties [14] and can also be exploited to build metamaterials [15].

This technology has multiple applications in various sectors [16]. However, it has some limitations [11], such as restrictions on the design of certain objects due to the presence of a certain structural weakness, since this technique employs the deposition of material in flat layers-horizontal, which can cause the presence of weak points in its

structure before forces that push its layers in a direction opposite to the direction of printing. Another limitation is that once printed the product will remain with its initial geometric and mechanical properties throughout its useful life, making it a static and structurally unchanging product, which limits its use in certain scenarios that demand a change in its form.



Fig. 1. 4D additive manufacturing cases

4D printing technology was introduced in the MIT self-assembly lab project in 2012 [17]. It is an improved technology compared to 3D printing that introduces the variable time as the fourth dimension. It is based on the construction of the shape and geometry of an object through the use of intelligent materials, after its construction the object can behave as a dynamic structure since it can modify its morphology or its thermo-properties in response to external stimuli of a mechanical, electrical, thermal or chemical nature over time. At present, this technology has various applications [17].

For example, the aeronautical company Airbus is developing this technology for the development of a dynamic airframe, which modifies its geometry according to the aerodynamic conditions of the moment to reduce its air resistance. The US military is developing submarines that modify the characteristics of its hull according to the weather where they are sailing. However, this technology has some limitations [11], such as the one related to the manufacturing process itself, which requires supporting material and its subsequent elimination. Moreover, since the manufacture of the object is based on 3D printing, it lacks additional degrees of printing freedom, causing a higher programming cost to achieve a certain structural complexity, which entails a longer processing time. Other possible limitations are related to the functionality and responsiveness of the final intelligent structure, due to the lack of instructions on possible additional printings or on the precision of the structure deformation control in response to an induced stimulus.

5D printing technology is an evolution of 3D and 4D printing: the term 5D is because the printing process can be performed along 5 axes (5 degrees of freedom), allowing curved layers. This technology was introduced by Mitsubishi Electronic Research Laboratories (MERL) in 2016 [18]. It is a flexible technology capable of constructing complex curved geometries with a certain resistance level, of the order of 3 to 5 times higher than that achieved by 3D printing and with a lower material consumption of the order of 20-30% [11].

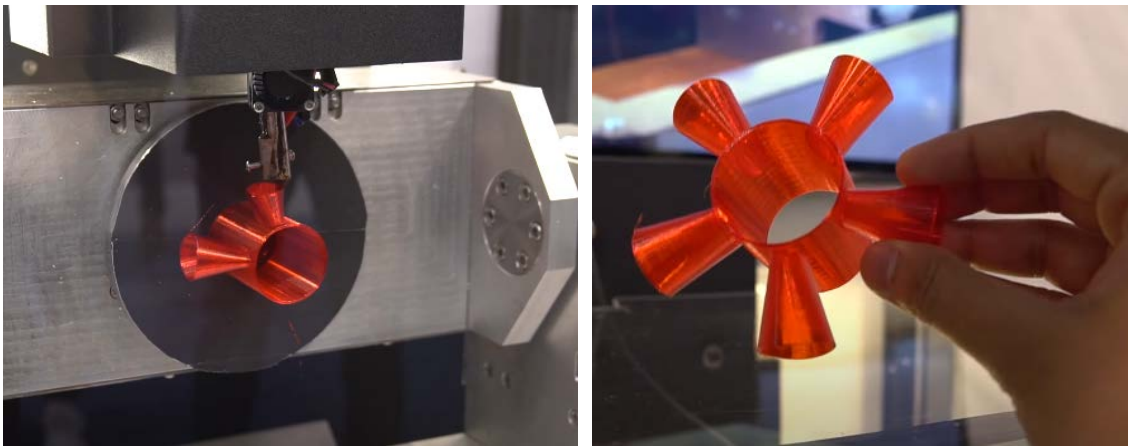


Fig. 2. 5D printing manufacturing process

This technology is based on the construction of objects by employing a new print concept. This system employ two main parts that move simultaneously during the printing process: the print head that can move through the linear axis X, Y and Z and the print bed can rotate in two additional axes with well-defined angles. These movements allow the head to reach the definition of the shape and environment of the object by depositing material layer by layer with different orientations [11-12]. Therefore, the 5D printing could be conceptually interpreted as the combination of traditional 3D printing and 5-axis CNC machining, enabling the 5D printer to print parts simultaneously along 5 axis. Currently this technology is used in different industrial sectors that demand complex structures and designs that require a lot of resistance [19,20]. However, it presents some limitation aligned with 3D printing, that is, its final products are static, invariable in time, since they do not use intelligent materials in the printing process.

In this scenario, a last evolution of additive technologies appears, it is the printing 6D. The term 6D is due to the combination of 5D technology with intelligent materials (4D). This technology was presented by a research group at the University of Athens in 2021 [11-12] making it very nascent. It is expected to provoke disruptive innovations with a strong technological impact, as it will lead to the creation of a new generation of intelligent materials or more precise and efficient manufacturing processes, in short, this technology will provide lighter and more resistant solutions with a higher degree of sensitivity to the relevant stimuli. However, there are still no technical studies to validate it, so there is some uncertainty about this new printing technique.

3. Conclusion

In conclusion, the future of additive manufacturing technologies includes multidimensional printing technologies combined with programmable-intelligent materials, which will drive the printing dimension to higher levels of structural freedom, sustainability, and print efficiency through reduced resource consumption, offering promising properties for products with different technological applications.

In the field of graphic design, it is already a reality that additive manufacturing technologies have changed the way of thinking about the role of design in engineering, that is, when the design is considered as an integral and ubiquitous component of the additive manufacturing process, the result obtained is a successful construction that can then be processed efficiently and can effectively fulfil the function for which it was designed.

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