# Chapter 17
# The Potential of Education and Training in Additive Manufacturing

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**Abstract** The final aim of education and training in additive manufacturing is to reach competences and skills in 3D printing, but its potential in different fields and scopes of application goes beyond it. This paper presents an overview of the competencies and skills that must be developed to train students in this field at different educational levels; but also presents a set of dimensions with potential application of additive manufacturing, which allows us to understand the need for comprehensive training in this field and its role in the era of digitization and education in STEAM subjects.

**Keywords** Additive manufacturing · 3D printing · Education · Training · Applications · STEAM subjects

## 17.1 Introduction

Additive manufacturing (AM), commonly known as 3D printing, has emerged in recent years not only as a technological alternative for the manufacture of certain parts and products, but also as a field of experimentation, that allows exploring new forms of design and production, giving solutions to past, present and future challenges.

The final aim of education and training in additive manufacturing is to reach competences and skills in 3D printing [1], but its potential in different fields and scopes of application goes beyond it [2]. Thanks to its extraordinary geometric freedom, additive manufacturing has not only made it possible to find optimized solutions to existing problems, but also to propose new ones that were previously unimaginable. Its synergies with other technologies, such as 3D modeling, parametric

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design or optimization tools, are catalysts that further enhance the possibilities of additive technologies.

Moreover, these technologies have had great acceptance and interest from the society, which has been interested in their possibilities from very heterogeneous fields (productive, technological, social, cultural or educational), which is another proof of the importance of exploring all its dimensions.

It is possible to define some categories related to the development of competences in Additive Manufacturing in technical studies, namely:

- Category 1. Additive manufacturing technologies
- Category 2. Design for additive manufacturing
- Category 3. Materials for additive manufacturing
- Category 4. Data of the 3D printing process.
- Category 5. Post-processing operations
- Category 6. Regulatory and certification aspects.
- Category 7. Production management

Obviously, these competences must be adapted to the different educational levels and to the profile of the studies. This paper presents an overview of the competencies and skills that must be developed to train students in this field at different educational levels, but also presents a set of dimensions with potential application of additive manufacturing, which allows us to understand the need for comprehensive training in this field and its role in the era of digitization and education in STEAM subjects (science, technology, engineering, art and mathematics).

## 17.2 Training Programmes

### *17.2.1 Upper Level Training Cycles*

The recent publication of Royal Decree 280/2021, of April 20, establishes the Specialization Course in "Additive Manufacturing for Higher Level Professional Training" and the basic aspects of the curriculum [3]. As indicated in the aforementioned Royal Decree, the general competence of this specialization course is to develop and manage additive manufacturing projects through the use of 3D printing, supervise or execute the assembly, maintenance and start-up of these projects. As well as making implementation decisions in the development of company products, considering criteria of quality, design, safety and environmental aspects.

### *17.2.2 Bachelor and Master*

Focused on University studies, specific guidelines have not been defined yet in order to include additive manufacturing in subjects of regulated education curricula such as

Bachelor's and Master's degrees in Engineering Industrial. Thus, a propose of competences to be developed in Master studies is included in Table 17.1. Competences that are shared with undergraduate studies, are marked in bold. The Higher Technical School of Industrial Engineering (ETSI Industriales) of UNED already offers training in Additive Manufacturing through the Official Master's degree "Advanced Manufacturing Engineering" (Ingeniería Avanzada de Fabricación) with subjects such as "Additive manufacturing technologies" and "Supply chain management in Industry 4.0"; and shortly in the Master's degree "Connected Industry", with subjects "Additive Manufacturing in Connected Industry" and "Advanced Technologies of Manufacturing".

Within the offer of official studies, a promising sort of programs are the so-called Micro-degrees, being able to provide general or specific training depending on the design of the syllabus.

### *17.2.3 Longlife Training*

In addition to official studies, the longlife training has an important role to harness the potential of additive manufacturing in different fields and scopes of application. There are different programs in the national context, but the Modular Program of Additive Manufacturing (Programa Modular/Máster en Fabricación Aditiva) of UNED [5] is a singular one as it is given under agreement with the Consejo Superior de Investigaciones Científicas—CSIC, with experts belonging to the Plataforma CSIC para el desarrollo de la Fabricación Aditiva FAB3D [6].

## 17.3 Methodological Aspects

In order to explore the potential of education and training in additive manufacturing, it is necessary to define the application, challenge or problem to be solved. Some examples of different dimensions with potential using AM are the following ones: (a) Manufacturing of complex geometries; (b) Achievement of advanced functional requirements; (c) Maintenance and reparation tasks; (d) New designs and prototyping; (e) Resource in teaching and learning; (f) Alternative to social problems; (g) Applications related to Heath; (h) Advantages from a sustainable approach.

Depending on the application, one or different dimensions with potential can apply. And depending on the case, a general or specific training a needed. A sketch that summarizes all the aspects involved is presented in Fig. 17.1. Hereafter some examples of applications where AM show its potential are presented. These are practical examples of opportunities of the 3D printing as disruptive technologies in the era of digitalization.

**Table 17.1** Main professional competences and skills in education and training in Additive Manufacturing for Master programs[1]

| Category | Description |
|---|---|
| 1. Additive manufacturing technologies | • **Describe and differentiate the AM technologies, analyzing the general vision of process categories and raw materials according to the UNE-EN ISO 17296–2 standard** [4] |
| 2. Design for additive manufacturing | • **Recognize dimensional precision in 3D printing technologies**<br>• Build and apply the concept of topological optimization<br>• Manage and transform a design for additive manufacturing (DfAM)<br>• Employ reverse engineering concepts for additive manufacturing<br>• **Skill in the use of soluble support filaments** |
| 3. Materials for additive manufacturing | • Select and differentiate advanced 3D printing materials (polymers, metals, composites, loaded, special)<br>• Handle special materials management applications in 3D printing |
| 4. Data of the 3D printing process | • **Programming capacity of the process variables**<br>• **Validate and control the use of any STL repair and lamination software**<br>• Manage and transform the mesh of the piece according to needs<br>• **Ability to calculate and program mounting tolerances between printed assemblies**<br>• **Ability to recognize the glossary and terminology of 3D printing**<br>• Ability to apply 3D printer calibration routines<br>• Determine the cost estimate for a 3D printed part |
| 5. Post-processing operations | • **Ability to remove supports in printed parts**<br>• **Ability to clean printed parts**<br>• **Ability to use electrical cutting, cleaning parts**<br>• Control the use of paint coating technique<br>• Control the use of welding technique<br>• Control the use of the paste technique<br>• Other post-processing |
| 6. Regulatory and certification aspects | • **Being able to handle the reference regulations in additive manufacturing**<br>• Acquire knowledge about the main inspection techniques of components obtained through additive manufacturing |

(continued)

[1] Those competencies that are shared with undergraduate studies, are marked in bold.

**Table 17.1** (continued)

| Category | Description |
|---|---|
| 7. Production management | • **Ability to compare additive manufacturing processes with other manufacturing methods in terms of production time, quality, cost and flexibility**<br>• **Ability to take advantage of the potential of additive manufacturing for a more sustainable production**<br>• Ability to integrate additive manufacturing into production systems, meeting the requirements of Industry X.0 |

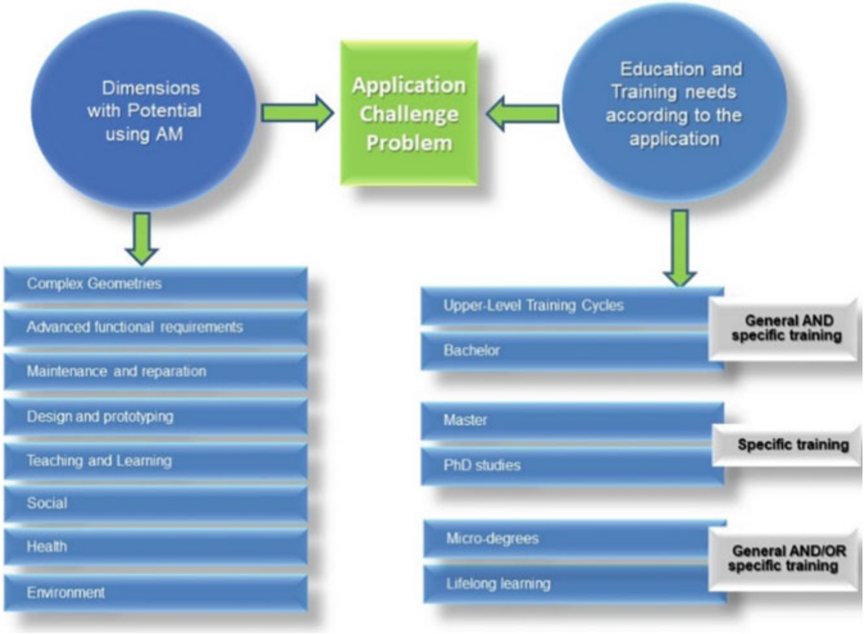


**Fig. 17.1** Summary of the dimensions with potential using AM and different training programs depending on the application, challenge or problem to be approached

## 17.4 Examples of Application in Industrial Engineering

### *17.4.1 Manufacturing of Components as an Alternative to Non-additive Processes*

Thanks to the important scientific-technical development of AM technologies in the last decade it is already possible to fabricate fully functional parts, and therefore,

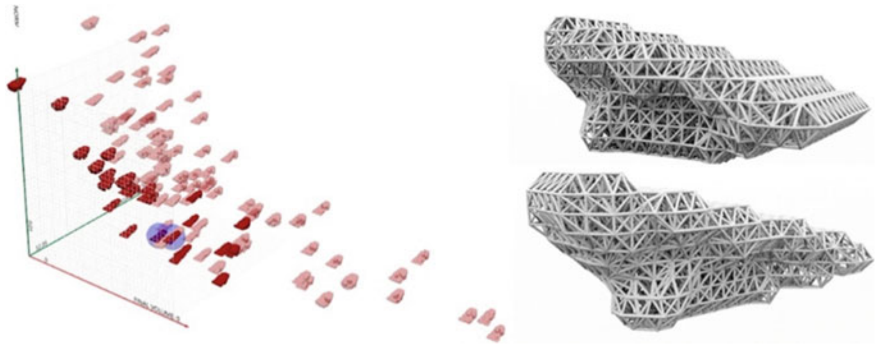

**Fig. 17.2** Multi-objective optimization algorithm result for a shoe last design to be produced with additive technologies [11]

AM can be considered an alternative to conventional processes in cases where the high customization of the component prevents its mass production, among other examples. Depending on the technology to be used, the training should be general or specific.

### 17.4.2 *Manufacturing of Components with Complex Geometries*

Additive manufacturing is not constrained by the restrictions of conventional technologies and allows the manufacture of complex geometries that are very expensive to manufacture with other technologies. This represents a paradigm shift in the design of parts to be manufactured with additive technologies. Due to the complexity of design problems and the resulting geometries, it is essential to have specific software and algorithms (Fig. 17.2) to help the designer [7–9]. Therefore, specialized training is essential, both in the knowledge of additive manufacturing technologies for the formulation of design problems and of the computational tools for solving them [10].

### 17.4.3 *Manufacturing of Lightweight Structures*

One of the greatest potentials of additive technologies is the manufacture of lightweight parts, since it is possible to obtain geometrically complex parts with internal cavities. Lightened designs allow, on the one hand, to practically eliminate material waste in the manufacturing process, and on the other hand, to reduce energy consumption due to the use of these lightened components in use, for example, in the aeronautical sector [12].

### *17.4.4 Reparation of Parts of Widespread Use*

The presence of additive manufacturing equipment in home environments, in small businesses and even in our children's schools, shows how close this technology is to society. This knowledge and interest in these technologies, combined with a significant increase in the possibilities of accessing low-cost equipment, pose scenarios that were previously difficult to imagine, in which a growing number of end users of certain products can act as designers and manufacturers of parts to replace damaged ones.

### *17.4.5 Maintenance Through Reverse Engineering*

In some industries such as electricity generation or in sectors such as petrochemicals, in recent years difficulties have been encountered in replacing certain critical components that, with a complex geometry, together with discontinuous production over time, have given rise to an obsolescence problem. AM has turned out to be a solution to this problem, as these parts and their designs are very difficult to obtain due to the lack of design information, such as manufacturing drawings or bills of materials. In other cases, the manufacturer does not provide manufacturing data [13]. In these cases, a solution is the application of a reverse engineering process to establish design and manufacturing requirements.

### *17.4.6 Maintenance Tasks Through DED Techniques*

Another field with potential of AM technologies, especially in the field of metal components, is its use in the repair of mechanical parts with high initial cost. These processes improve on the existing techniques of repair by material addition through welding and subsequent machining. Thus, the AM techniques allow a more precise control of the repair process, increasing the quality of the final part in terms of surface finish, dimensional accuracy and structural integrity [14]. Given the greater rigidity of use of the other additive manufacturing technologies, direct energy deposition (DED) processes stand out in their application in maintenance tasks.

### *17.4.7 Resource for Teaching and Learning*

3D printing is a very powerful tool in teaching and learning as resource for teaching and learning theoretical concepts that are difficult to visualize, and specially in distance learning education of technical subjects. Some examples are the design of machines, equipment, and tools in manufacturing processes, such as stamping or extrusion dies, or the Bravais crystal lattices in Materials Science and Technology [15]. This is confirmed by the increase in teaching innovation projects where additive manufacturing plays a fundamental role.

### *17.4.8 Design and Manufacturing of Prototypes*

Product and component prototypes are necessary in order to validate designs from different points of view. The marketing department, for example, uses prototypes to test different aspects of the products to the consumer before launching them on the market. On the other hand, designers also use prototypes to validate designs for new products or improvements to them. For this purpose, the use of AM for rapid prototyping is already stablished in most sectors, since it is not necessary to make a large investment to produce a few prototypes and it is also possible to quickly manufacture multiple design variants to evaluate the design [16, 17].

### *17.4.9 Potential Against Depopulation*

Additive technologies have the potential not only to revolutionize the manufacturing of products, but also to create new environments for innovation and promote the entrepreneurial spirit of entrepreneurs in areas far from the currently established industrial poles. Thus, according to this point of view, the impact of AM on depopulation could be measured around some aspects, where AM can have an active role: (a) Relocation of production, (b) Access to in-situ diagnostic tests and (c) Creation of new job positions. In this line, there are several initiatives, among which it is worth highlighting at the national level (in Spain) the project [18].

## 17.5 Conclusions

This paper presents a set of dimensions with potential application of additive manufacturing, which allows us to understand the need for comprehensive training in this field and its role in the era of digitization and education in STEAM subjects (science, technology, engineering, art and mathematics). To this aim, both general and specialized training are necessary according to the profile and needs, as described in this paper.

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