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INTERACTIVE TRAINING MATERIAL ABOUT ADDITIVE MANUFACTURING TECHNOLOGIES

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ABSTRACT

The Engineering education is living a change driven by the new opportunities and technologies that appear in the Industry 4.0 context. One of them are the Additive Manufacturing Technologies. Nowadays, these technologies are mainly applied in the preliminary design and prototyping phases, around 80% of the usage cases belong to this stage of the product development process. However, utilization is increasing because companies are becoming more aware of Additive Manufacturing potential. In fact, research shows 72% of industrial companies will invest or educate for specialized use of additive technologies. On the one hand, professionals have created communities to learn about these technologies, practice and share their knowledge. Further, it is necessary to include this knowledge in engineering degrees. Due to this, the educational innovation group Ingeniería de Fabricación of University of Las Palmas de Gran Canaria has developed an interactive learning material about Additive Manufacturing technologies. This material has been developed especially for students of Manufacturing Process, but it can be used to coordinate other subjects of the engineering degrees, given the fact that it is a transversal knowledge for all engineering profiles. Moreover, it has focus on helping the teacher labour and students self-learning (Flipped Classroom).

KEYWORDS

Additive manufacturing, interactive training materials, flipped classroom, competitive engineering education

1. INTRODUCTION

This paper describes an Interactive Training Material (ITM) about Additive Manufacturing technologies which is included in the educational innovation project, methodological renewal and creation of didactic resources for Design and Manufacturing carried out by the educational innovation group *Ingeniería de Fabricación* (GIEIF) of University of Las Palmas de Gran Canaria (ULPGC).

Additive Manufacturing (AM) has been developed for more than 30 years and it is characterized by its capability of generating forms through the addition of material layer upon layer. These technologies are in continuous development and they are mature technologies which already have a common usage in the business sector, as well as, at final consumer level. To decide on the usage of these technologies in product development processes, it is important to consider the advantages and disadvantages of AM in comparison with conventional processes and be aware of the point where our product development process is. Moreover, there are a variety of processes or categories with their capabilities and limitations which professionals and users should know to choose the most appropriate technique.

Due to this, the ITM developed for this project, includes an introduction on the most relevant characteristics of AM in general and a description of the categories where the different AM technologies are classified according to international standards. It also shows the design considerations for taking better advantage of their extraordinary possibilities, as well as criteria for selecting the most appropriate technology for the developed application. Despite the importance of AM in the current industrial context, its application in education is only 7% [1], so it is very important to encourage the knowledge of these technologies among students and professionals who require it.

2. ADDITIVE MANUFACTURING (AM)

The term which has been used to denominate this group of technologies has been evolving over the years. First, when they emerged, their objective was the elaboration of prototypes and, due to that reason, they were denominated ‘Rapid Prototyping processes’. When these technologies were developed, and offered greater performances, they began to manufacture fully functional parts, products and tools. Then they were called 'Rapid Manufacturing processes'. Other names have also emerged due to their use of digital files, such as E-manufacturing or 3D printing colloquially.

However, the ASTM F42 American standardization scientific committee was formed to standardize AM designation in 2009. According to the ASTM definition, which was seconded by ISO then [2], AM is called the ‘process of joining materials to make objects from 3D model data, usually layer upon layer’.

The AM development, which has led to evolution in its name, has been carried out since the 1980s until now. The following section discusses the characteristics of the context of AM.

2.1. Context

The AM development began in the 1980s and it continues to evolve. Making a review of the most important facts of AM [3]–[5], two stages can be distinguish.

A first stage from the 80s, when the beginning of the AM development started, until the first decade of the 21st century. During this time, the creation and development of different AM technologies have occurred and the companies which generated the patents have been founded. In this stage, the AM was characterized by being very expensive and limited. Therefore, its usage was oriented to prototyping and design of personalized pieces.

At the beginning of this century, many of these patents have expired, as it is shown in the Figure 1 [6], so the growth and development of AF is being further promoted.

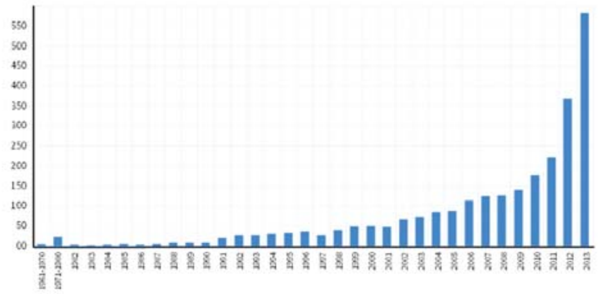

Figure 1. Patent publication around 3D printing [6].

This fact supported the second stage, where we currently are, as accessibility to the AM is increasing. In addition, the industrial capacities are increasing, opening new application fields for AM as biomedicine or micromanufacturing.

Due to this AM evolution, the standardization and the creation of norms which would regulate its use and guarantee the quality of the products manufactured by them is important.

To this end, several American and European standardization committees have been created (ISO TC261, ASTM F42 y CEN/TC 438) which have the same aim, to develop a shared normative. The effort to standardize globally indicates the worldwide interest in AM. For the development of these standardization activities, the European Union has promoted projects such as SASAM (Support Action for Standardisation in Additive Manufacturing) to develop a roadmap of the carried out activities for the standardization of the AM [7].

A consensus has been reached on the structure within the standards, which is based on 3 main levels [7]: (1) general standards on general concepts and requirements; (2) standards related to processes or categories of materials and (3) specialized standards on specific requirements for specific materials, processes or applications. Between these levels there is a parent-child relationship to make easier development and avoid the risk of duplication of work.

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In general, the achievement of this standardization will promote the quality of products, processes and services; will improve the quality of life, safety and health and the protection of the environment. It will also promote the adequate and efficient use of resources; clear communication between stakeholders within a legal framework and the promotion of international free trade and industrial efficiency. In conclusion, standardization will encourage the industrial implementation of AM technologies.

2.2. Advantages and disadvantages

These technologies, although relatively new, will continue to coexist with conventional manufacturing processes, and knowing the advantages and disadvantages which they present against traditional processes is very important. According to the specialized website Additively [6], the general advantages which stand out are: freedom of design and the possibility of producing, complex parts without cost overrun and customized parts; material optimization; capacity of innovation; reduction in time to market; the profitability of manufacturing in short series; its operation as accelerator of the Industry 4.0 and its role of democratization of manufacturing.

On the other hand, AM presents several generic disadvantages such as low production capacity and production ratios, post processing is required, constraints regarding size of manufacturing, materials and formats, immaturity and lack of development of some technologies, and lack of a broad standardization that provides guarantees of use.

However, apart from these common features among AM technologies, each of them has specific characteristics, and a more specific comparison would require a detailed analysis of the processes involved.

2.3. Classification

The operating principle of all AM technologies is very similar, i.e. the addition of material layer upon layer, therefore, the large variety of existing processes are usually grouped, mainly based on these two parameters: how the material is deposited on to the building platform or format of feedstock as it is shown in the Figure 2. Following these parameters, the ISO/ASTM 52900:2015 standard [2] has proposed a classification into 7 main groups:

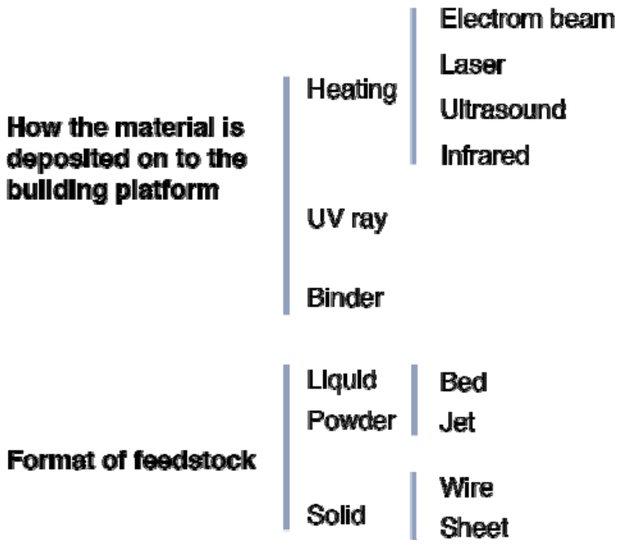

Figure 2. Parameters to classify AM techniques or categories.

- VAT Photopolymerisation (Figure 3), integrated by Stereolithography (SLA) and Digital Light Processing (DLP) variants of this technique. The material is a light-cured resin polymer which hardens under the action of light.

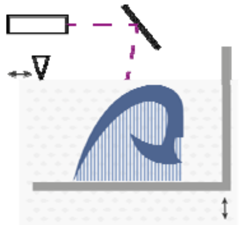

Figure 3. VAT Photopolymerisation

- Material Jetting (Figure 4), integrated by commercial techniques as Drop on Demand and Inkjet Printing. The material is injected by a head selectively. Basically, as inkjet printer.

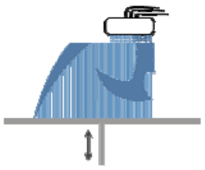

Figure 4. Material Jetting

- Material Extrusion (Figure 5), integrated by commercial techniques as Fused Deposition Modelling (FDM), Fused Filament Fabrication (FFF) and Plastic Jet Printing (PJP). The material is a thermoplastic which is heated until fused and extruded by a head on the platform.

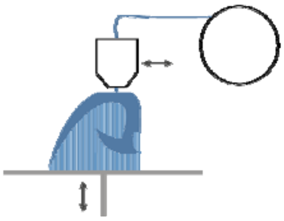

Figure 5. Material Extrusion

- Powder Bed Fusion (Figure 6). There are techniques for polymeric materials, as Selective Laser Sintering (SLS), Selective Mask Sintering (SMS) and Selective Heat Sintering (SHS); and for metals as Direct Metal Laser Sintering (DMALS), Selective Laser Melting (SLM) and Electron Beam Melting (EBM). These materials are in powder form and they are melted by the thermal energy of a laser.

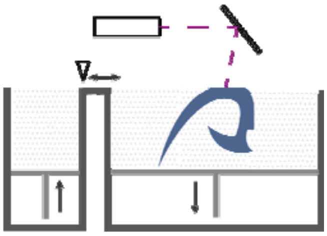

Figure 6. Powder Bed Fusion.

- Binder Jetting (Figure 7). The material is in powder form and the layers' adhesion is carried out by binder.

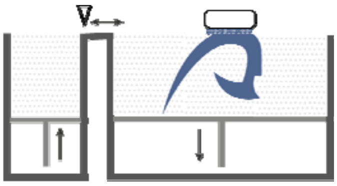

Figure 7. Binder Jetting

- Sheet Lamination (Figure 8), integrated by Laminated Object Manufacturing (LOM) for paper and polymers and Ultrasonic Additive Manufacturing (UAM) for metals. The sheets are joint together by binder (LOM) or ultrasound (UAM).

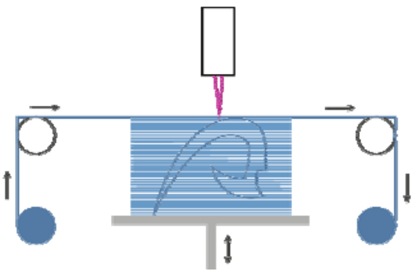

Figure 8. Sheet Lamination.

- Directed Energy Deposition (Figure 9). The used materials are metals where thermal energy is focused to melt the material.

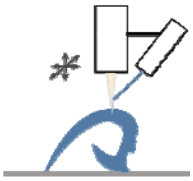

Figure 9. Directed Energy Deposition

The ITM description section (section 5.2) shows the structure of the explanatory chapters of each of these technologies. These include the graphic descriptions of their operation presented at the top (Figure 4-Figure 8) but they are completed with text.

3. IMPACT, CURRENT STATE AND FUTURE OF AM

Currently, the AM is becoming more important and this trend is going to continue in the next few years. Its current impact can be analysed from the perspective of the final consumers, the industrial sector and the professionals of different sectors.

The breakthrough in the market of the low-cost equipment, especially the FFF technology, is causing changes in consumers increasingly looking for customized products, and they are divided into two groups: (1) those who design and manufacture objects by themselves and they have a more specialized profile and (2) users who buy files to print their products.

The information and conclusions offered in the following sections have been taken from the analysis of the studies carried out by the companies Sculpteo [1], [8] and Stratasys [9].

3.1. Industry

Currently, the main applications of AM, around 80%, are related to the product development stage rather than the final products manufacturing.

In relation to the sectors where they are applied, where AM technologies have a greater impact are those of consumer products, in general it has gone from 26% in 2015 to 17% in 2017. It also highlights the high impact in the medical industry (15%), aerospace (11%), automotive (8%) and energy (6%) [9].

In addition, the distribution of income streams of companies engaged in the commercialization of AM systems [10]: they obtain more income from the sale of machinery and raw materials, however, they point out that the design consultancy services, together with maintenance and software services, are at a much lower level. This indicates the companies of other sectors demand professionals or companies specialized in Design and Product Development in these new technologies.

AM presents several advantages that make its application attractive: its ability to accelerate product development, the ability to achieve complex designs, to be able to offer customized products, the decrease in the investment in tools and equipment and the enhancement of after-sales service influencing the impact of the product in the environment. Moreover, they favour the trends included in the concept of Industry 4.0 as it implements flexibility in production and allows to decentralize production using Cloud computing tools.

However, the AM technologies also present several complications which limit their implementation: the costs of equipment, maintenance, production and materials are high; there are important limitations in the choice of materials, as much for their properties, as for the format and typology; the productive capacity is limited, and they are discontinuous production processes, which makes it difficult to apply economies of scale. There is also a lack of clear legal framework and, as has already been mentioned, it is necessary to train experts in the use of these new processes.

These aspects should be improved so that in the future AM will expand its field of applications and be more easily integrated into the value chains of many industrial sectors. As already mentioned, standardization bodies have created committees to work within the legal framework and standardization of AM. The future trend of AM, especially in technologies for metallic components, is production capacities will experience high growth and machine prices will stabilize or even decrease, depending on the specific technology. The cost and limitations of the materials will be reduced as well as the labor cost while increasing the volume of the machines workspace [9], [10].

An increase of 70% of companies investing in AM is expected in 2018 and remaining around 50% for this year. In terms of recruitment of staff, an estimated 40% increase in companies are expected to hire more professionals, of which around 20% will hire candidates related to their AM activities [1].

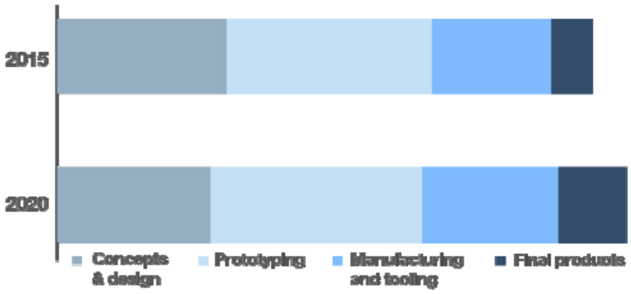

Figure 10. Variation of the utilization of the AM in the next 5 years, based on [8].

Not only a change in the attitude of the companies to the AM is foreseen but also in the orientation on its use. It will move from being a technique for product development (conceptualization, design and prototyping) to be destined to produce finish goods, and tools for other manufacturing processes (Figure 10).

3.2. Professionals

All the aspects mentioned in the previous section will make necessary the hiring of professionals specialized in these technologies, and engineers should have many opportunities in the next years. In addition, the design and manufacturing departments are in second and third place in the list of clients of companies included in the AM sector [1]. For this reason more than 70% of companies plan to hire engineers and designers, in the same proportion, rather than operators or project managers [1]. The profile of the Industrial Design Engineer and Product Development combines skills of both professionals, so it is expected to become a highly-demanded profile.

Engineers and other independent professionals are potential consumers of AM, especially with the bursting of low-cost equipment. Because of this, the 'Maker', 'DIY' movements are growing strongly and a global community which shares knowledge and projects is being created. Among these communities are the Fab Labs platforms (Digital Fabrication Laboratory) where the entrepreneurship is stimulated through the global networking between different profiles that pursue innovation, online communities that share designs and develop collaborative projects that become part of the Technological World Heritage protected by licenses Creative Commons. Other communities (e.g. 3dHubs or MyMiniFactory) and large companies (e.g. 3DSystems, Protolabs or Stratasys) have also emerged, which offer on-demand manufacturing services or infrastructure for

AM use. The crowdfunding platforms also contribute to the development of projects faster and at a lower cost.

However, one of the difficulties which these professionals have during the product development by AM are the software tools. To develop parts with these technologies, traditional CAD-CAE applications need to be complemented by specialized AM modules. These specialized applications are dedicated to the optimization of the parameters, the creation of the lattice structures in hollow pieces, the adequate generation and repairing of the files with the geometric information and from the specific manufacturing processes. The generation of support structures, layered fragmentation (slicer) and operational control of AM equipment should also be improved. Some software companies have already acquired various tools to offer an integrated solution for the development of parts by AM [11].

4. SELECTION OF THE ADEQUATE AM TECHNOLOGY

In order to select the appropriate AM technology and take full advantage of their respective capabilities, a number of design considerations, materials, and so on, must be taken into account and a selection process must be carried out to address the need to be. In this way it will be detected if there is potential for AM application and what technology is the most suitable. The information presented below has been extracted from various documents of companies specialized in the use of these technologies and application of international standards [2], [12]–[16].

4.1. Considerations to use AM

Design considerations must be known from the early stages of the development process to avoid problems and time wastage in later stages. People tends to think AM has no limitations, although it is capable of achieving certain results impossible to achieve by other manufacturing techniques, they also present some specific limitations of each technology and

Figure 11. Kinds of considerations to use AM as they are showed in the ITM.

products must be designed with these in mind. Geometric, material, sustainability and economic considerations can be distinguished (Figure 11).

The geometric considerations vary taking into account the intrinsic specifications of each AM technology, especially in cases where precision, tolerances and surface finish are required. In general, overhangs trapped volumes should be avoided and the layer thickness and how it can affect to the surface finish and functionality should be considered (Figure 12, left). In addition, the orientation of the part and cleaning in the process (Figure 12, right) affect the final result.

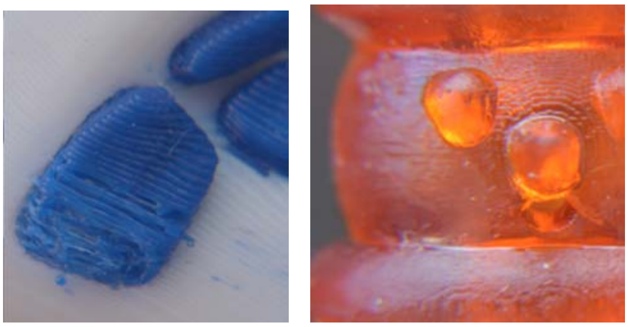

Figure 12. Poor surface finish because of layers, left, VAT Photopolymerisation part which needs postprocessing (cleaning), right.

The designer should take into account a number of material considerations. To select it is essential to know the properties offered depending on their type and technology with which are going to be used. However, in general terms, AM processes produce parts with anisotropic properties greater than those obtained in most traditional processes and that is because the parts are constructed by layers upon layers and the mechanical properties depend on the orientation of the part (the mechanical properties are different in each object showed in the Figure 13).

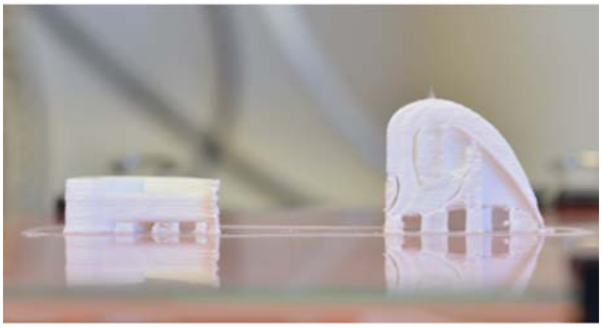

Figure 13. ULPGC logo in two layers' orientations.

Regarding sustainability considerations, the AM produced objects must comply with the current regulation to maintain control over the environmental

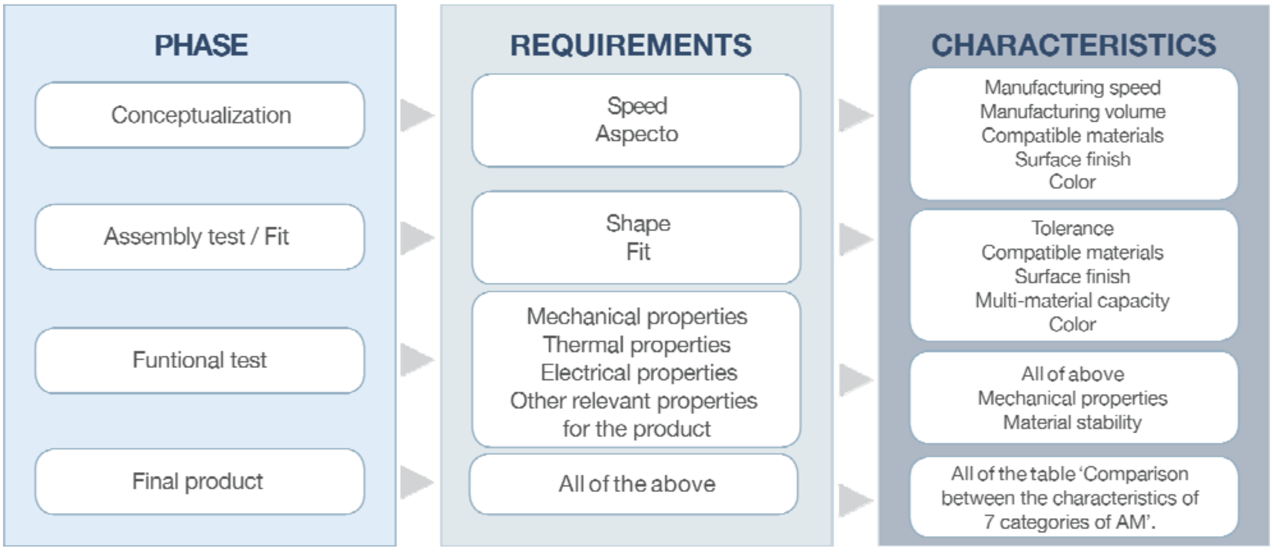

Figure 14. First stage of the AM selection process. Designing based on [16].

impact. Initially, there is a reduction in the resources necessary along the whole productive chain and can make it a more efficient and sustainable alternative, although, in concrete cases, there can be a negative evaluation of AM due to these technologies requiring more energy than a conventional process. In addition, AM allows to carry out services of maintenance and aftersales that can extend the useful life of certain products. They greatly accelerate the development of products that increasingly have shorter life cycles, better adjusting to demand, significantly improving social and economic sustainability.

The contribution of AM to a company should be also considered to decide whether producing with these technologies is the most cost-effective option. Aspects should be assessed as adding value and attractiveness in respect to traditional products, if the additional costs and risks, production capacity and other more specific economic aspects of the particular application can be born.

4.2. Selection Process

This section will describe the recommended process

Table 1. Comparison between the characteristics of 7 categories of AM. Designing based on [16].

COMPARISON BETWEEN THE CHARACTERISTICS OF 7 CATEGORIES OF AM							
	VAT Photopolymerisation	Material Jetting	Material Extrusion	Powder Bed Fusion	Binder Jetting	Sheet Lamination	Directed Energy Deposition
Compatible material	Pte RC Ce	Pte RC	Ptp	Me Ptp RC Ce	Pte Ce	Me Ma Pte	Me
Tolerance and precision	●●●	●●●	●●◐	●●○	●●◐	●●◐	●●◐
Surface finish	●●●	●●●	●●○	●●○	●●○	●●○	●●○
Manufacturing volume	●●○	●●○	●●◐	●●○	●●◐	●●○	●●●
Manufacturing speed	●●○	●●○	●◐○	●●◐	●●●	●●◐	●●◐
Need of support material	●●○	●●●	●●●	—	—	—	●●○
Time/Difficulty of postprocessed	●●●	●○○	●●○	●●◐	●●●	●●○	●●○
Material stability	◐○○	●○○	●●◐	●●○	●○○	●●●	●●◐
Mechanical properties	●○○	●◐○	●●◐	●●◐	●○○	●●◐	●●◐
Multi-material capacity simultaneously	◐○○	●●●	●○○	◐○○	◐○○	◐○○	●○○
Color variety	●○○	●●●	●●○	●○○	●●●	●●●	—

Pte Thermosetting polymers; Ptp Thermoplastic polymers; Me Metal; M Wood; RC Resin Composites; Ce Ceramics; ●○○ Low; ●●○ Medium; ●●● High to select between AM or conventional processes. If the AM is considered suitable concrete recommendations are given to use specific technologies taking into account aspects of the stage of development where the project is located.

The first step is identifying the potential to manufacture the product by AM versus other traditional processes. One way to assess potentiality is in terms of the advantages and disadvantages that AM generates. Only if this potential is medium-high should the use of AM be considered.

After deciding to use AM, the specific technology to be utilized must be determined by: (1) identifying the key part requirements according to the development phase following Figure 14, (2) comparing the 7 fundamental categories of AM processes synthesized in Table 1.

Once the technology is chosen, the flowchart of Figure 15 is followed. A complete production by AM could be economically unviable, and a more specific application might have great interest. AM will not replace traditional methods but will complement and integrate them into productive processes making them more efficient.

5. INTEGRATION IN AN INTERACTIVE TRAINING MATERIAL (ITM)

AM is a computer assisted manufacturing method and shares certain similarities with other technologies such as computer numerical control (CNC), and they become a starting point to facilitate the learning of these new manufacturing processes.

In the first place, the users to whom this ITM is addressed will be indicated. They will be mainly students in the field of Engineering where subjects in the area of Manufacturing Processes Engineering, or similar are taught. It may also have great interest for professionals in the field of product development, or even amateurs motivated in knowing the technological development and its applications.

In response to these different needs of these users, the ITM has been designed to facilitate the reading for any of them, allowing the more expert users delve into more specialized content on AM. Interactivity in layers allows the query of information to be structured hierarchically.

In the ITM contents, the information in previous section are summarized and expounded graphically to facilitate compression. They are structured into 16 chapters: (1) a 'Preface' where interactivity and other aspects of the ITM use are exposed, (2) historical 'Background' of the AM, (3) the evolution of the term of 'Additive Manufacturing' and standardization, (4) the generic description of 'AM Process' (Figure 16), (5) exposing the 'Advantages and disadvantages of the AM' (6) 'Classification AM processes'. In the following chapters (7-13) a description of the main characteristics of the seven categories of AM is performed, (14) the 'Impact, state and Future AM', (15) the proposed process 'Selection the right technology in the design process' and (16) ends with the 'Bibliography and references' that collect the information sources where the contents presented are based. Within each of these chapters, the main themes are divided into different sections.

This structure allows the user to have the necessary information about the AM to make a justified selection of the specific technology. With interactive elements and links between contents of the document (as shown in Figure 17) users can easily access the contents related to each stage of the selection process.

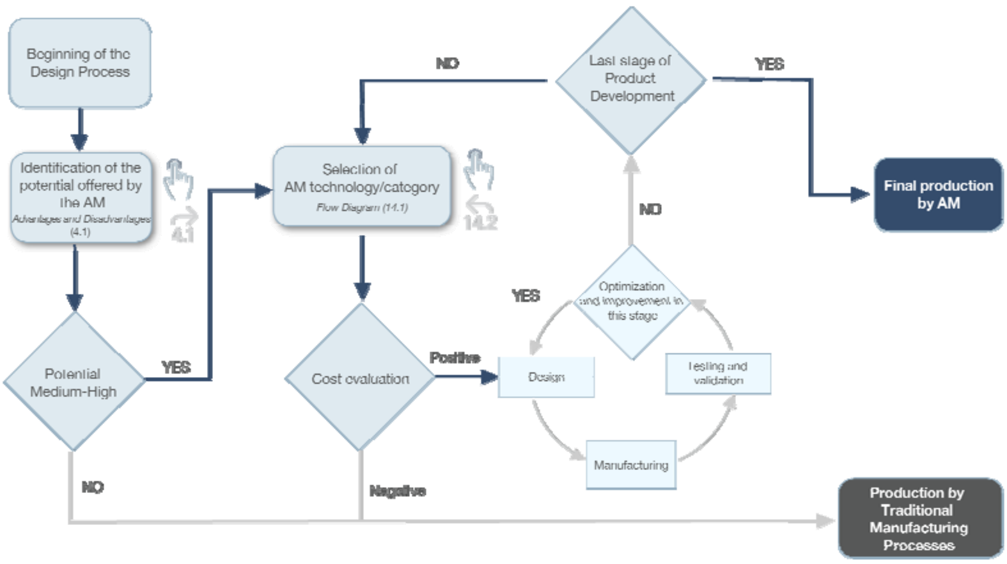

Figure 15. Flow diagram to use AM. Designing based on [15]**TM description**

Figure 16 AM process linked to each stage of its process. ITM in Spanish.

In many pages of the document, there is additional information in the form of pop-ups windows (Figure 18). This way you can select the information you want to consult more deeply and always the most relevant information visible. As an example, in the timeline, complementary information of each of the milestones referenced in it, can be consulted.

In addition, from any chapter or section you can access a list of all chapters to facilitate your query (Figure 19). You can also get back to the front page of this chapter to access another section thereof. This

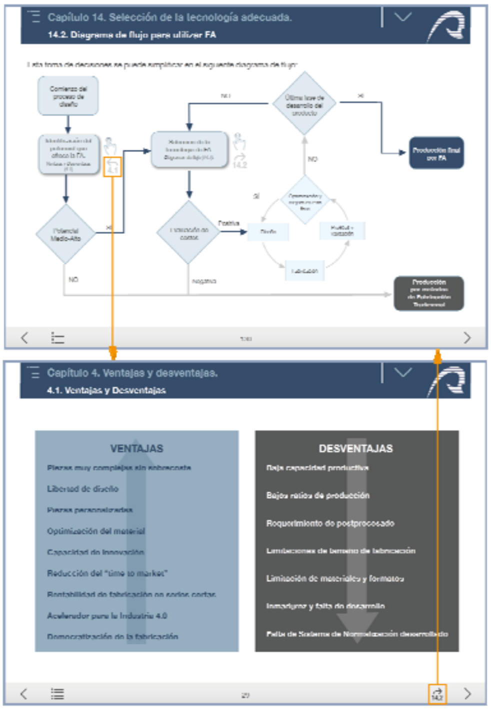

Figure 17. Example of how we can go to a page with related content and return to the principal page.

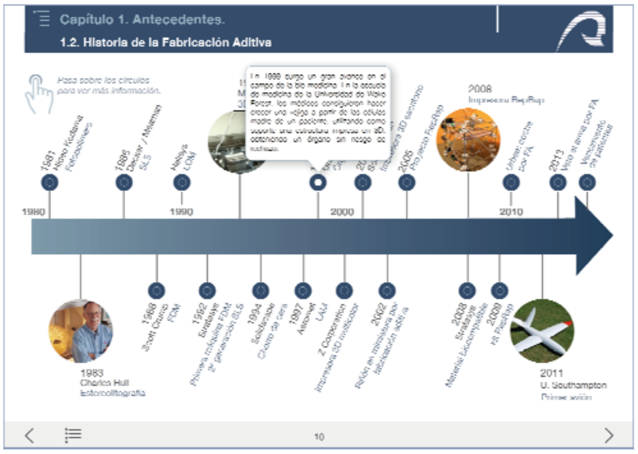

Figure 18. Example of pop-up window. ITM in Spanish.

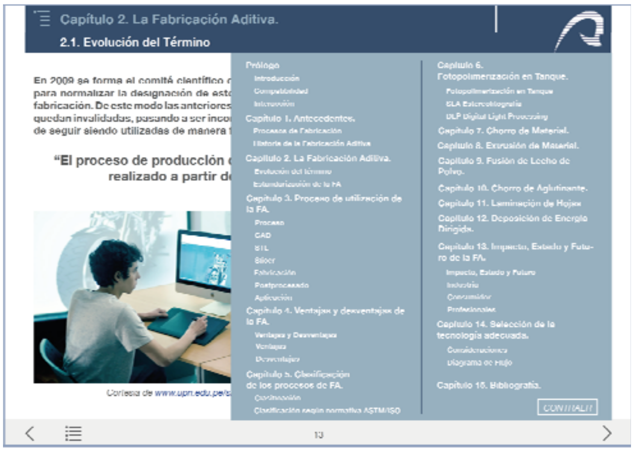

Figure 19. Drop-down index of chapters. ITM in Spanish.

way you can access any content, even if it is not directly related to those that are exposed in the page being consulted.

Many of the multimedia resources appeared in the ITM can be expanded to full screen (Figure 21),

Figure 20. Example of own videos: slicer and manufacturing of ULPGC logo.

including operation schemes of each group of technologies or data sheets. Image galleries allow you to include several illustrative examples of the contents of a page without taking up more space. Videos of real examples of processes and software simulations of AM have been included, as those of Figure 20, some of them expressly created for this ITM. These interactive elements are identified in the document by specific icons presented to the user at the beginning of ITM (Figure 22).

This common structure for all AM categories enables them to be easily compared to each other and it follows the recommendations and proposals made by other organizations [17]. This structure consists of an initial page that briefly describes the definition process, the compatible materials, links to variants within that process technologies and their advantages and disadvantages are shown. With this first page the user acquires a basic notion about the process and its capabilities. In the following pages users enter into more detail in technology: another page with a more extended description, the operation scheme and an explanatory video; another page about the post-processing and obtaining the final piece; other about process limitations and design conditions; continues with images of compatible machines and materials; and ends with a page with applications and sectors of application where graphical examples are offered. These pages help easy identification of contents.

Figure 23 shows the pages of one of the technologies (VAT Photopolymerisation) that serves as an example of the structure discussed. The format of these pages, helps easy identification of contents.

This ITM has been used experimentally in the subject Product Development Technologies of the fourth

Figure 22. Key of interactive elements. ITM in Spanish.

year of the Degree in Engineering in Industrial Design and Product Development in the ULPGC during the academic year 2016/2017. The professor used as support material for seminars (Flipped Classroom) and part of the material was provided to students to carry out a partial delivery of course project on the product development using advanced manufacturing technologies.

In this academic year 2017/18 will use this ITM within Flip Teaching methodology in order to better exploit the face to face sessions and get more active and participative attitude of students in these sessions.

6. CONCLUSION

AM is constantly evolving, but has mature technologies that show great potential and significant growth will be expected in the coming years. In the current state of these technologies, and even more with the new developments, the need to exploit its capabilities taking into account their limitations and

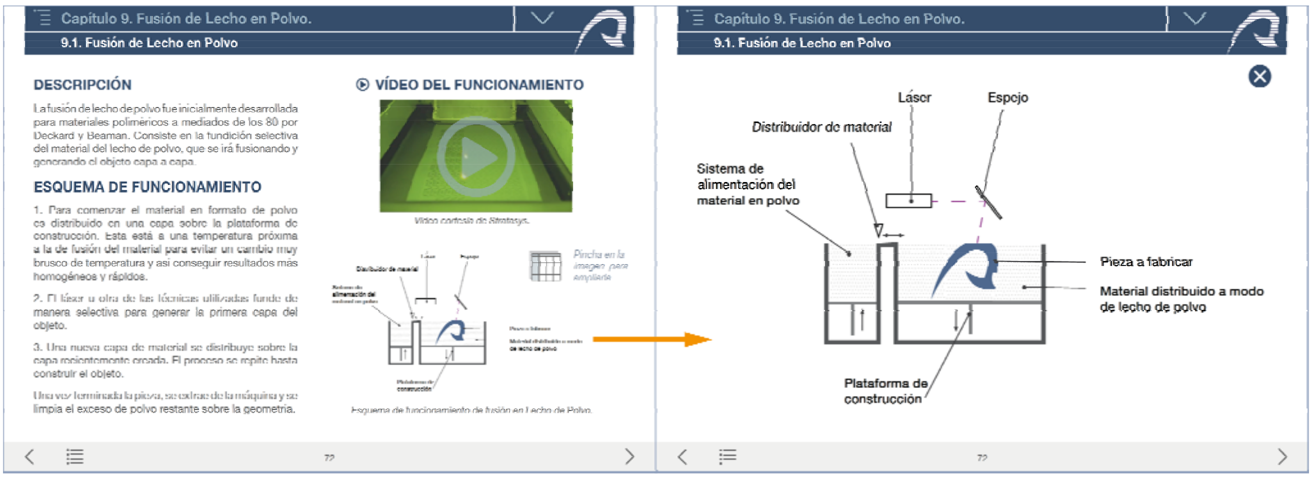

Figure 21. Photo enlargement to full screen.

Figure 23. Example of structure of a AM specific category. ITM in Spanish.

specific characteristics are manifested. It has opened a wide gap of applications with great interest for many professionals and especially for Engineers in Industrial Design and Product Development, who can count on the AM both for the stages of new products development, as the direct manufacture of fully functional, optimized, customized and final parts for many industrial sectors.

This ITM intends to highlight the importance of the use of interactive didactic resources for the teaching-learning process of students, especially in these new technologies in continuous evolution. It is also interesting to facilitate the lifelong learning process of many professionals who need to update their knowledge and skills in order to take better advantage of the growing potential of AM.

The contents expounded in this ITM demonstrate AM should not be considered as a substitute for all conventional manufacturing processes. They are alternative processes will become more important and integrating with greater intensity in the productive chains to develop products in the most efficient way possible.

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