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MBDA MISSILE SYSTEMS

ADDITIVE MANUFACTURING FEASIBILITY STUDY & TECHNOLOGY DEMONSTRATION

EDA AM State of the Art & Strategic Report

Cover: Photograph of the 3D-printed military transport aircraft, inspired in the A400M, designed and produced by Fundación Prodintec for the Distinguish Visitor Day associated to the official opening of the European Tactical Airlift Centre (ETAC) in Zaragoza, © EDA

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Executive Summary

Additive manufacturing (AM) technologies have been identified as one of the key enabling technologies to improve European industrial competitiveness. They are considered to empower the transition from mass production to mass customization in several leading sectors including, among others, automotive, medical, aeronautics, energy and consumer goods. **The defence sector, however, is not yet exploiting the full potential offered by AM technologies**. It is expected that AM technologies could enhance defence capabilities in mobility, sustainability, effect and protection. By implementing repair and maintenance operations in the field it is possible to reduce logistic costs and execution times significantly. Repair parts can be produced on demand when and where required, such as in extreme environments, on a ship or on the frontline. This has an especially high impact in military assets where a large volume of inventory is constantly maintained to ensure operational readiness. It could also lead to improved sustainability and a reduction of both delivery times and logistical footprint, crucial for the smooth operation of warfighting and peacekeeping missions. However, there are still technical challenges that need to be identified to fully achieve AM capabilities, such as the qualification of parts produced in this manner to ensure they will not fail in service.

The potential of AM has been understood by EDA and has been identified as a technology gap to address in the Strategic Research Agenda of the CapTech Materials & Structures 2014. There is a clear need to raise awareness of the capabilities that AM can offer in defence and to demonstrate these in a simulated operational situation that can be used as a showroom for future applications of the technology in real scenarios.

To this end, this report summarizes current AM technologies and their potential applications, identifying limitations and proposing actions to overcome existing barriers. The report does not aim to be an academic exercise, but a practical review. It includes bibliographic review, value chain definition and analysis, stakeholder consultation, a roadmapping exercise and final conclusions.

The objectives and structure of the report are set out in chapters 2 and 3, followed by an explanation of the methodology and process in chapter 4. The remainder of the report comprises two parts: State of the Art Study and Strategic Study.

The State of the Art Study provides an introduction to additive manufacturing (section 5). It describes the basic concept and process and highlights common applications such as product development and parts manufacturing. It also compiles seven of the main additive manufacturing technologies (section 4.3). For each of the technologies, the report provides a description of the basic concept, the main raw materials used, applications, pros and cons, and a summary of the capacity of a representative machine. This information is summarized in section 4.4, providing the basic set of data needed to understand the potential of the different AM technologies. The compilation of this information is aimed at non-technical potential users of AM, enabling them to learn the basics of the different technologies and understand that AM is a new manufacturing concept that can be exploited through different technical means, depending on the required applications and raw materials.

Following the description of AM technologies, the study continues with a summary of the current applications of AM for security and defence applications, grouping them around three main areas and illustrating them with real case studies within the defence sector. Design and development (section 5.1) highlights the potential for new products and designs; processes and design optimization prototyping; and small series manufacturing and manufacturing of serialized products. Field operations support (section 5.2) explains how AM can support strategic and tactical planning, troop field support, the provision of humanitarian aid and catastrophe assistance, and support isolated operations (e.g. submarines, ships). Finally, in-house operations (section 5.3) considers maintenance and repair, medical support and training.

The State of the Art Study concludes with an overview of current capabilities of AM, highlighting a few significant projects and considering R&D funding for AM activities at the EU level (chapter 7). Chapter 8 reviews existing AM patents, providing an indication of the strength of AM in the defence industry and showing that AM is a technology that is currently being implemented and explored at all levels, and that is set to become a key technology for future developments in the defence sector. Finally, chapter 9 summarizes recent experiences of AM in the field at European and US level. The State of the Art section concludes with an overview of current capabilities on AM and summarizes different experiences at European and US level on AM in the field (Sections 6, 7 and 8). Here, the relevant projects, summarizing R&D funding for activities based on Additive Manufacturing at EU level will be presented. This overview is completed with a review of existing patents, which provides an indication of the strength of AM among the defence industry. In this manner, this final part of the State of the Art aims at showing that AM is currently a technology that is being implemented and explored at all kind of levels, called to become a key technology for present and future developments in the defence sector as well.

The Strategic Study aims to analyse the strategic interest of Additive Manufacturing technologies in defence. Chapter 8 introduces the concept of the value chain and defines three main value chains to enable the study of the impact of AM on the security and defence sectors: product development, logistics and field applications. A “step by step” analysis of each of these includes a description of every stage involved in each chain, an analysis of the potential implication of AM on the stage and a summary of the pros and cons of AM in each stage. The analysis of the value chains concludes with a summary of the main pros and cons for each of them (section 9.5), highlighting its main advantages (product development enhancement, logistics optimization and AM field applications) and disadvantages (relating primarily to non-technical aspects such as training requirements, the need for a decision making system review, quality and certification aspects, etc.). This part of the Study provides the starting point for the analysis of the current limitations for AM implementation (section 11).

The analysis of the limitations of AM technologies has been addressed from two different perspectives. One considers the technology limitations, mainly due to machine capabilities, raw materials requirements, cost, scalability, quality and deployment. The other looks at current non-technological limitations preventing defence from benefiting fully from the potential of AM. Such factors include: training; standardization; qualification and certification; Intellectual Property Rights (IPRs); regulatory frameworks; and environment, health and safety (EHS). This analysis has been complemented with a stakeholder survey of potential defence users and AM experts (chapter 10).

To achieve the objective of this study, which is to identify main areas where further work could be promoted in cooperation, a SWOT analysis has been performed in order to categorize the advantages and limitations associated with AM technologies (chapter 13). Chapter 14 studies potential actions to be taken in order to overcome the existing barriers that were described in chapter 11 and follows the same structure. The Strategic Study concludes with a proposal for a process for implementing AM in defence from the point of view of different stakeholders; product developers and producers, on-site users and logistic centres (chapter 15).

The conclusions of the report are summarized in a final, separate section.

1. Objectives of the Report

The **specific objectives of this study** are as follows:

- To assess the areas where additive manufacturing can make a greater contribution to defence capabilities. This work summarises the state of the art of relevant additive manufacturing technologies and compares this with existing capabilities in Europe. The main outcome of this comparison is the identification of opportunities for and weaknesses of AM in the European defence sector and the analysis of technological and non-technological factors delaying or preventing European defence forces from benefiting from the technology. It also gives an indication of what defence capability and economic benefits may be expected in the short-term, mid-term and long-term.

- To raise awareness in the defence community and to identify possible areas for cooperation. This study aims to promote a better understanding of the potential of these technologies, thereby stimulating their implementation in defence-specific areas. To this end, the strategic part of the report highlights the main areas where cooperation in defence at European level could benefit the implementation of these technologies to support defence capabilities.

The main objective of this study is to increase awareness and disseminate the potential of AM in different defence contexts. In the mid-term, the study and its outputs are expected to support the synergies with other organizations such as ESA, or EC, in order to better exploit the dual-use potential of additive manufacturing.

This report is complemented with the report on AM Facility Deployment.

2. Structure of the Document

For clarity, this study is presented as two main parts:

- State of the Art Study. A review of additive manufacturing (AM) technologies and their potential applications in the context of Security and Defence (S&D). This part of the study is divided as follows:
    - Introduction to AM: basic aspects to understand additive manufacturing as a concept for manufacturing parts and products, its general applications, and a review of the different types of technologies that nowadays are classifiable as additive manufacturing technologies.
    - AM applications for Security and Defence: several examples of current applications of additive manufacturing technologies in the field of defence.
    - Current AM capabilities: a look at the current stakeholder structure related to additive manufacturing, significant recent projects focused on AM technologies and a study of funding of R&D into AM.
    - A brief study of AM patents.
    - A review of significant AM field experiences in Europe and the United States.
- Strategic Study. A review of the potential of AM technologies to transform value chains, current limitations and strategies for surpassing them, a survey of the perceptions of AM held by various S&D stakeholders and a brief overview of the main issues to take into account when considering AM implementation. This part of the study is divided as follows:
    - Transformation potential on main value chains: analysis of the impact of additive manufacturing in the field of defence, from the perspective of the main identifiable value chains (product development, logistics and field applications), identifying its capabilities and pros and cons on each value chain stage.
    - Current limitations of AM: technological and non-technological aspects that demand further development in order to achieve additive manufacturing's greatest potential.
    - Asking stakeholders about AM: a survey conducted of more than 70 S&D European stakeholders in order to measure their current and future AM perception.
    - SWOT analysis: analysis of Strengths, Weaknesses, Opportunities and Threats regarding AM implementation in the S&D sector.

- **Overcoming existing barriers**: a look on the future of AM technologies through a roadmap based on the possible scenarios of evolution over current limitations.
- **Brief process for implementing AM**: a brief review of main questions and issues to address when considering AM implementation from an organizational point of view.

The following diagram presents this structure in a graphical way:

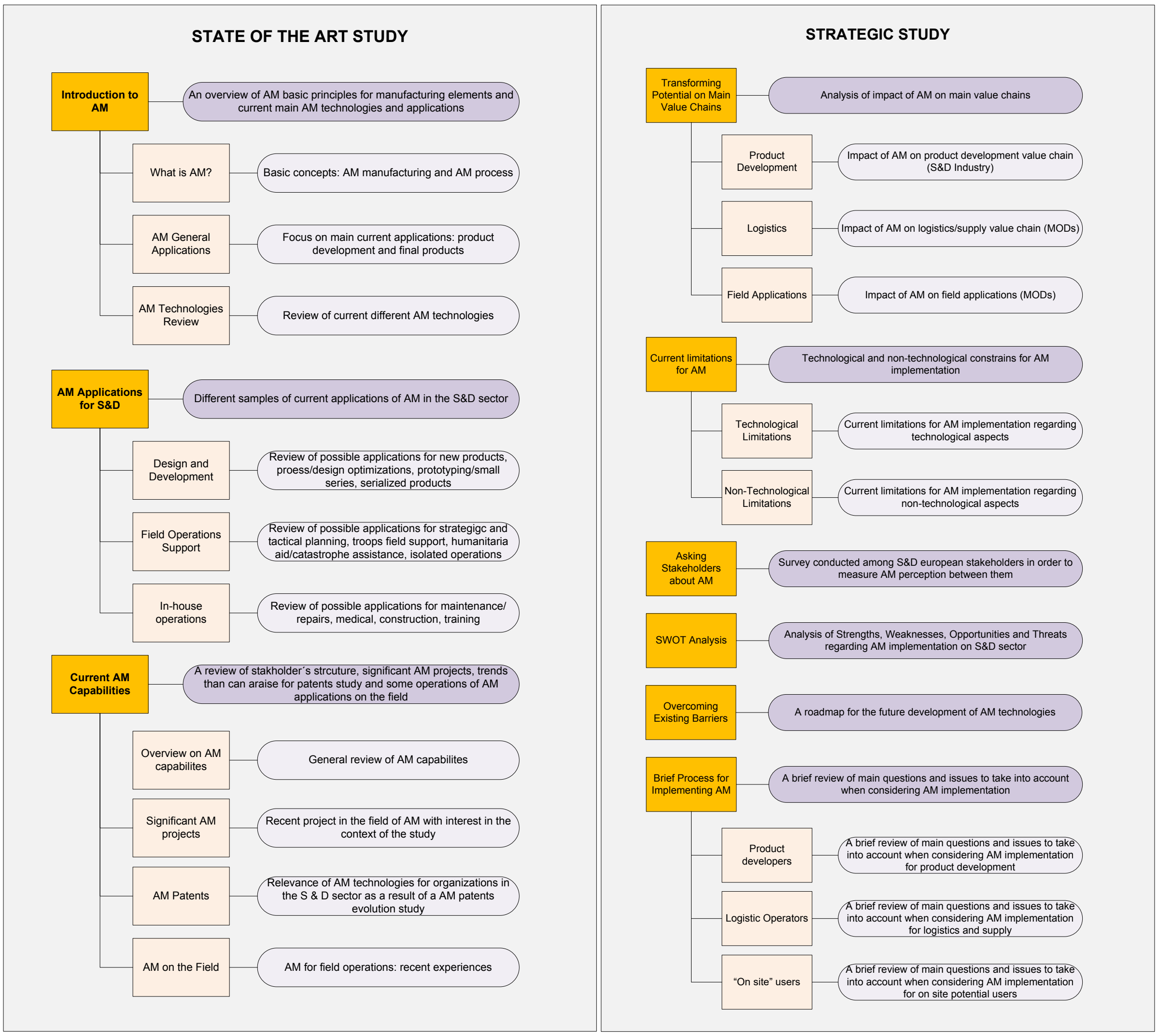

Figure 1: Basic structure of this Desktop Study (own creation)

3. Methodology

The methodology applied to develop this document is based on the following pillars:

- Extensive bibliographic review for the preparation of the State of the Art Study: initial collection, analysis and processing of sources of information focused on additive manufacturing technologies. This work is especially important when it comes to creating content that can reliably reflect the current state of the art of additive manufacturing technologies. In this way, through the review of various sources of information (Internet sources, publications, strategic agendas, databases, etc.), it has been possible to identify and characterize the various additive manufacturing technologies, exemplify their applications within the scope of defence, establish current capabilities and summarise experiences in the field. Additionally, it establishes a solid basis for those parts of the document related to the analysis of value chains, current limitations of technology, SWOT analysis and roadmapping for overcoming current limitations.

- Identification and analysis of value chains for the application of the AM in the field of defence. Starting from the fact that MODs are the main "engine of activity" in the field of defence, three value chains are identified and described as a basis for analysing the relevance of AM technologies in that sector. Two obvious value chains are "product development" and "logistics" - fundamental pillars of activity in the sector. A further value chain "field applications" was identified, closely related to the capacity of AM technologies to provide manufacturing means in the field. The three value chains are described by means of flow diagrams through which the different value chain steps are used as a basis for the review of the potential implication of AM and the pros and cons of the implementation of AM in the defence sector.

- Survey on additive manufacturing technologies. A survey was carried out to assess the perception of additive manufacturing held by organizations within the field of defence. It was designed to identify the degree of knowledge, experience, main applications, problems, and the future prospects experiences by a variety of organizations in relation to additive manufacturing. More than 70 organizations (public, private, suppliers, etc.) were surveyed, giving rise to results that represent an important source of information for this document, especially in regard to verifying the current limitations of AM technologies and the need for development around them.

- SWOT analysis and roadmapping. Based on the results of the previously described methodologies, it was possible to organize and summarize the main conclusions within a framework of the most important strengths, weaknesses, opportunities and threats (SWOT) of these technologies. Roadmaps were established to outline the main routes towards the implementation of AM for different groups of stakeholders (product developers, logistic operators and on-site users) and towards solving the limitations that can delay AM technologies reaching their maximum potential.

The study ends with the presentation of a series of conclusions to support the full implementation of AM technologies in the defence sector.

State of the Art Study

The following diagram presents the structure of the State of the Art Study set out in chapters 5 to 9.

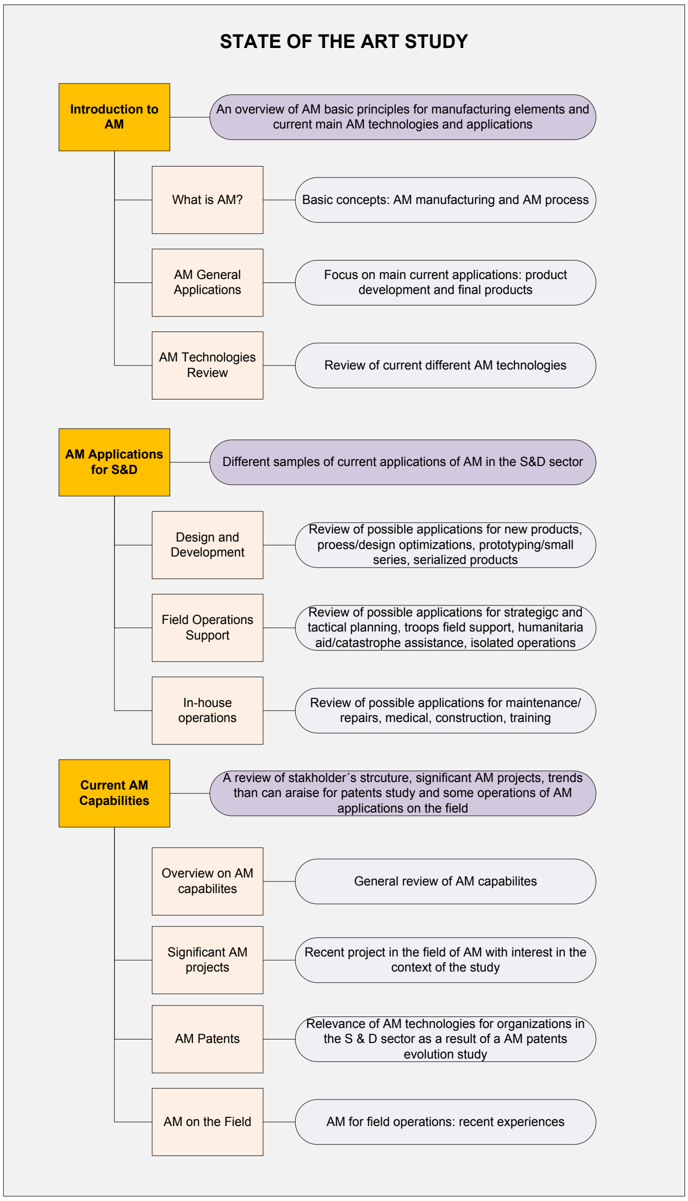

Figure 2: Basic structure of the State of the Art Study (own creation)

4. An Introduction to Additive Manufacturing

4.1. What is Additive Manufacturing? (Basic concept and process)

Additive Manufacturing (AM), also known as 3D printing, is currently one of the most popular technologies and is undoubtedly the most disruptive of recent years. It is defining and will continue to define the development of all types of industry during at least the first decades of the 21st century.

The principle of AM is the "layer by layer" manufacture, a way of producing elements that, starting from a 3D file/model and dividing it into "slices", is able to shape an entire element from the progressive manufacture of each one of the layers that form its geometry, using the precise amount of material necessary to make each one.

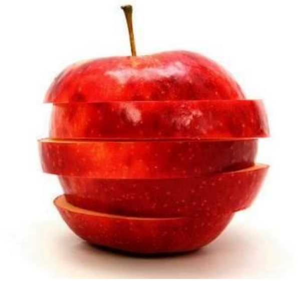

Figure 3: Layer by layer manufacturing concept[1]

These are the generic steps of the manufacture of a part via an AM process:

- **The process starts with a 3D file** that could come from any 3D CAD application, which then must be **converted into a "standard" 3D format,** such as .STL format[2] (although STL is the most common format these days for 3D printing applications, in the last years others such as .AMF[3] or 3MF[4] have also arisen).

- The **part could include some inaccuracies or characteristics preventing it from being AM manufactured** (e.g. geometries with high risk of drooping when 3D printed, non-closed vertexes, mistakes arising from the STL conversion process, etc.) and necessitating a reparation process in order to assure a good subsequent manufacturing result. Some designs

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[1] *Image by Richie Girardin under Creative Commons CCBY-SA 2.0. licence*

[2] *3D Systems. (n.d.). STL File Format description.* https://es.3dsystems.com/quickparts/learning-center/what-is-stl-file

[3] *ASTM. (n.d.). SO/ASTM 52900:2015 (ASTM F2792) Additive manufacturing – General principles – Terminology.* https://www.iso.org/standard/69669.html.

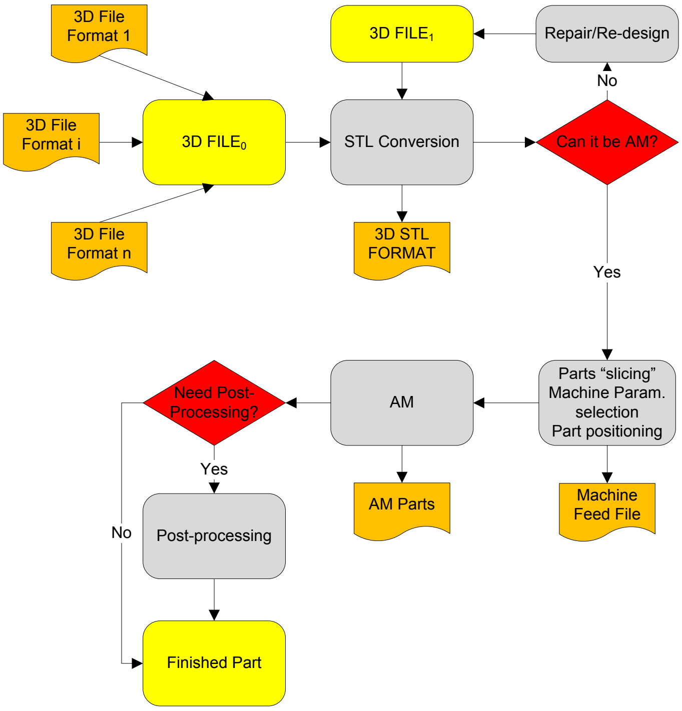
[4] *3MF Consortium. (n.d.).* http://www.3mf.io/what-is-3mf/

may require the presence of support structures during the printing process. If some specific problems preventing manufacturing are found, **the process may require a partial re-design of the part** to correct them and to ensure a 100% successful manufacturing process.

- Once it has been ensured that the part is manufacturable, **a slicing process is applied to the 3D file.** This process is perhaps the most crucial stage of the additive manufacturing process since it is this division of the 3D model that enables it to be manufactured layer by layer.

- **The resulting file is then ready to be sent to the AM machine.** Depending on the required specifications, various machine parameters may be selected (layer width for example) and once these are fixed, the manufacturing itself can begin. Production time will depend on the AM technology, the number of parts produced concurrently, part complexity and layer width.

- **Once the part is manufactured, it may be necessary to carry out a post-processing phase.** Each technology can require different methods. For example, Stratasys POLYJET[5] technology requires the removal of the structure supports with a water jet while others, such as FDM[6] (Fused Deposition Modelling) or metallic powder-based technologies, require their removal with mechanical tools. It should be considered that in most cases, once the additive manufacturing process is over, the parts will need further treatments depending on the AM technology used (e.g. fine machining, heat treatments, polishing, etc.).



[5,6] *POLYJET and FDM are trademarks of Stratasys Ltd.*

Figure 4: Basic additive manufacturing process (own creation)

4.2. Common Applications of Additive Manufacturing Technologies: product development and parts manufacture

There are currently two generic applications for which additive manufacturing is widely known: product development and manufacture of final parts. Each will be considered in more detail.

4.2.1. Additive Manufacturing Technologies for Product Development

Additive manufacturing technologies bring previously unknown capabilities to the development of a new product. For the first time, there is a technology capable of supporting the design and engineering process with the manufacture of individual elements or parts, demonstrators and prototypes that is not constrained by the technical limitations of traditional technologies, producing them quickly and at reduced cost. From this perspective, **additive manufacturing technologies have an application in each and every one of the steps that make up a product development process**:

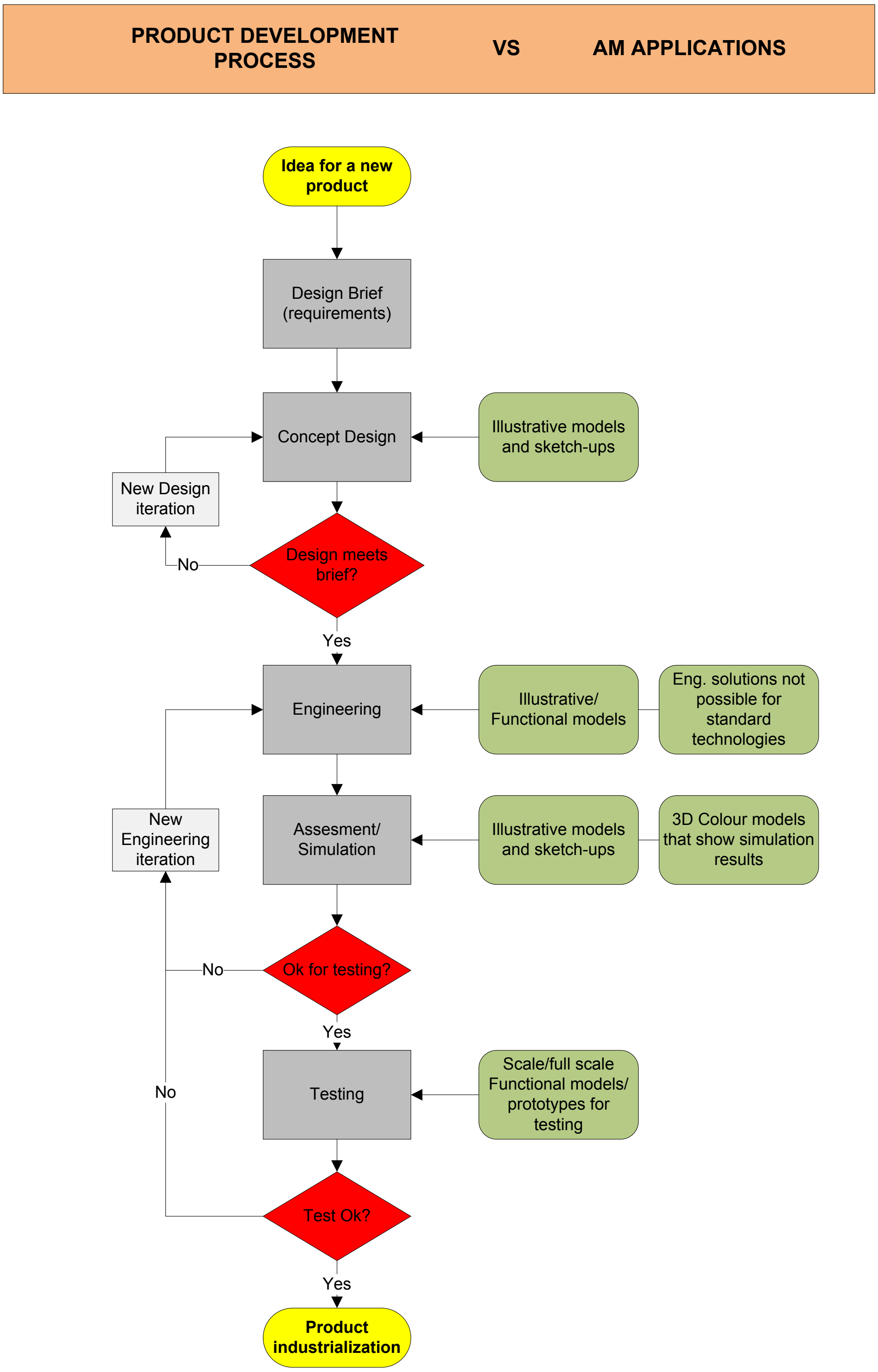


Figure 5: General AM applications on the different stages of a product development process (own creation)

- Concept Stage. Once the initial developmental work has given rise to the first sketches and design concepts, additive manufacturing allows the development of non-functional prototypes (or with a very limited functionality), primarily aesthetic, with the purpose of making such concepts corporeal and to be able to make initial assessments and appreciations of them.

  At this stage, additive manufacturing has a tremendously important advantage over any other traditional manufacturing technology, since only these technologies are capable of manufacturing simple but realistic design concepts, at a low cost and in a short time. This is especially the case when paired with popular and affordable technologies such as desktop fused deposition modelling machines which are particularly well-suited for mock-ups.

- Design and engineering. Once various concepts have been evaluated and one or several design concepts have been selected, AM technologies can be used to produce demonstrators and prototypes for engineering testing.

  The distinguishing feature of additive manufacturing at this stage of product development[7] is that, given the freedom of design it provides and the speed and ease with which the technology can be applied, it reduces the technical, time and cost restraints associated with traditional technologies. This allows an increase in the number of design and engineering iterations and a more rational distribution of the cost of demonstrator and prototype manufacture.

- Prototyping and testing. Once the design and engineering have resulted in a complete and developed product concept, AM technologies allow the realization and testing of functional prototypes (scaled or actual size, depending on the application). The advantage at this stage is again the elimination of the limitations of other technologies, allowing a shorter manufacture time, a rationalization of the cost and a lower cost of design changes.

To summarise, the potential impact of additive manufacturing technologies on the product development process is more than estimable, given its benefits during all stages and this is **why, in this area, additive manufacturing is here to stay and will be a basic tool for designers and engineers in any field of technical development.**

4.2.2. Additive Manufacturing Technologies for Parts Manufacturing

In the previous section, it was shown how AM is undoubtedly a very important tool for product generation and development, being able to produce fully functional prototypes with which to give validity and solidity to a design concept. Logically, therefore, the next question arises: “**is it also possible to manufacture parts and/or final products with additive manufacturing technologies?”**

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[7] *An extended look into AM opportunities for product design can be seen at Deloitte University Press. (n.d.).* https://dupress.deloitte.com/dup-us-en/focus/3d-opportunity/3d-printing-product-design-and-development.html

The concept of additive manufacture houses a range of different technologies, all sharing the concept of "layer by layer" manufacturing, but each having different characteristics in terms of materials, technical capabilities, constraints, etc. As it will be seen throughout this report, not all additive manufacturing technologies will be suitable for use beyond the manufacture of aesthetic or functional prototypes, and in general the possibility of implementing additive manufacture for the production of final parts/products depends, as with any other technology, on demonstrating that the manufacturing process is adequate (technically speaking) for the intended application. This means that for a given material, a given technology/machine and a reference or set of manufacturing references, the process must guarantee a reproducible result and the expected quality. Therefore, **there is not a unique answer to the previous question, and the suitability of additive manufacturing for producing final parts depends on the desired application and the available technological options.**

The demonstration of the technical capacity of an additive manufacturing technology for a given product/application is the same as that for any other more traditional technology/process, in order to certify/approve its capacity to produce a product with replicable quality.

It should be borne in mind that **traditional precision manufacturing technologies such as CNC machining are generally at least one order of magnitude superior to additive manufacturing technologies**[8]. Even the most well-known and developed of the current AM technologies are not suitable for applications requiring very precise and fixed tolerances (see section 4.3, where details of accuracy for each AM technology are provided), although AM can be combined with other technologies to achieve required precision.

However, technical capacity, although of critical importance, is only one aspect to take into account when considering additive manufacturing technology as a means to industrialise a part/product, since the economic aspect is undoubtedly the deciding factor. In any activity, the **cost always tips the balance in the selection of different options**. In this respect and given its variability, it is not possible to carry out an overall assessment of all additive manufacturing technologies to produce final parts/products, since important elements such as material cost, energy consumption, processing time, or post-processing activities vary enormously, and it only makes sense to analyse specific cases. Despite this, **the concept of additive manufacturing and its global characteristics do make it possible to make a series of general statements.** [9,10,11,12]

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[8] *3D Hubs. (n.d.).* https://www.3dhubs.com/knowledge-base/3d-printing-vs-cnc-machining#conclusions

[9] *3D Printing Engineering. (n.d.).* https://3d-printing-engineering.com/easyblog/entry/additive-manufacturing-technologies

[10] *University of Nottingham, University of Oxford, SAID Business School. (n.d.). The economics of 3D printing: A total cost perspective.* https://www.sbs.ox.ac.uk/sites/default/files/research-projects/3DP-RDM_report.pdf

[11] *Thomas, D. (2016). Costs, Benefits, and Adoption of Additive manufacturing: A Supply Chain Perspective. Int J Adv Manuf Technol, 1857-1876.*

[12] *National Institute of Standards and Technology NIST. (2014). Costs and Cost Effectiveness of Addtive Manufacturing. A Literature Review and Discussion. USA Deparment of Commerce.*

- Compared with traditional manufacturing technologies, which require high initial investments (moulds, manufacturing tools, etc.), additive manufacturing can produce the first series of parts/products without the need for any additional investments beyond the additive manufacturing technology itself, so the initial costs may be significantly lower. The option to subcontract professional additive manufacturing services should also be taken into account, which may reduce the initial costs even further.

- For the same reasons, when the volume of product is small or moderate, the costs can be reduced by the implementation of additive manufacturing.

- Similarly, additive manufacturing may be economically more advantageous when the product is to be highly personalized, when the product life cycles are short or in any situation that results in reduced and/or not very prolonged production volumes over time.

- On the other hand, the cost of the raw material required for an additive manufacturing technology can be considerably higher than the raw material used in a traditional manufacturing process, so for high production volumes additive manufacturing tends to be less competitive.

  In other words, **additive manufacturing technologies are more economical until the moment/volume of units is reached that allows the amortization of the investment required by traditional technologies.** From that point, the optimization associated with these traditional technologies usually offers a lower unitary cost.

- Sometimes the characteristics of a developed part/product make it impossible to manufacture by conventional technologies. In this case, the dilemma will be between launching the product as developed and absorbing the corresponding unit cost in the final price, or to go through a redesign process in order to give rise to a product that can be manufactured by conventional technologies, with ostensible reduction in price.

- Based on the above, any development process must take into account that the industrialization of a product developed with the support of additive manufacturing technologies must undergo a structured and conscientious analysis, considering all aspects necessary to carry out a thorough technical and economic evaluation.

Bearing the previous statements in mind, the most important features of additive manufacturing are summarised in the following “pros and cons” table:

PROS	CONS
Part complexity Being a layer-by-layer fabrication process, this technology is capable of rendering geometries of great complexity, with cavities and forms not possible to obtain with traditional technologies.	**Detail/Precision** Traditional technologies such as subtractive manufacturing have significantly more accuracy than additive manufacturing technologies. In general, it is ± 0.X00 mm (AM) vs 0.XX0 mm (Subtractive).
Lead time (First part/short series) The ability to generate a part simply from a 3D file makes these technologies unbeatable when manufacturing a first part, since it eliminates the need for other technologies, such as tools or moulds.	**Long batches** Although aspects such as speed and raw material costs are being continuously improved, when aiming to produce large amounts of parts/products, these technologies tend to be slower and more expensive than traditional ones.
Customization Since no additional tooling is required, the manufacture of a modified part is as straightforward as the manufacture of the original design.	**Range of available materials** Although the range of available materials is continuously improving (especially in the area of plastics and metals and, more recently, ceramics), it is still limited compared with the materials available for other technologies.
Lower fixed costs for product development and first product series As no additional investments are required (tooling, moulds, etc.), it is possible to considerably lower the initial cost of producing prototypes and first series of products.	**Quality and certification** As a relatively new technology, there are still some uncertainties and a lack of standards for assuring the long-term quality of the manufactured parts.

Table 1: General Pros and Cons of Additive Manufacturing Technologies (own creation)

4.3. A Review of Additive Manufacturing Technologies

Layer by layer manufacturing is a very basic concept that can be implemented with different capacities and results thanks to different technological approaches; this is why, when we speak of "additive manufacturing", we are not referring to a single technology, but to a group of significantly different technologies. Thus, **it is helpful to make a classification and description** that serves as a first orientation when it comes to understanding the different manufacturing technologies covered by the concept of additive manufacturing. **The following classification divides the technologies according to the most basic manufacturing concept**[13] (beyond the “layer by layer” principle):

Name	Basic Description	Usual Materials
Fused Deposition Modelling	Layers are conformed by fusing and extruding a thermoplastic through a nozzle.	Thermo-plastics **Usual Applications** Illustrative models and sketch-ups/functional models (technology and application dependant)
Powder Bed Fusion	A fine layer of particled material is deposited and sintered/melted by the action of a selective heating source.	**Usual Materials** Plastics/metals **Usual Applications** Functional models/final parts
Direct Energy Deposition	Very similar to a welding process, a nozzle mounted on a multi-axis arm deposits material and provides a heating source to make up each layer.	**Usual Materials** Metals **Usual Applications** Functional models/final parts
VAT Photopolymerization	Uses photopolymer resins that can be selectively cured by the action of a UV light.	**Usual Materials** Resins **Usual Applications** Illustrative models and sketch-ups/functional models (technology and application dependant)
Material Jetting	With great similarities to a traditional printing process, inkjet printing heads are used to deposit the material that makes up each layer.	**Usual Materials** Resins/metals/wax **Usual Applications** Illustrative models and sketch-ups/functional models (technology and application dependant)
Sheet Lamination	A material stored on a roll is applied and bound over a plain surface (first layer) or the previous layer, and then cut to the desired shape.	**Usual Materials** Paper, composites **Usual Applications** Illustrative models and sketch-ups (paper). Functional models/final parts (composites).
Binder Jetting	A fine powder material layer is deposited, and selectively bound by the action of a print head.	**Usual Materials** Sandstone **Usual Applications** Illustrative models and sketch-ups

Table 2: Main groups of additive manufacturing technologies (own creation)

The **main technologies depicted in Table 2 can be further divided into 15 specific technologies**[14] as shown in Figure 6:

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[13] *This classification is based on the different AM processes defined by ISO/ASTM 52900:2015 (ASTM F2792) Additive manufacturing – General principles – Terminology.* https://www.iso.org/standard/69669.html

[14] *There are several sub classifications of AM technologies, but one of the most graphic (and the basis for the one presented in this document) is by 3D Hubs. (n.d.). Additive manufacturing Technologies: An Overview.* https://www.3dhubs.com/knowledge-base/additive-manufacturing-technologies-overview

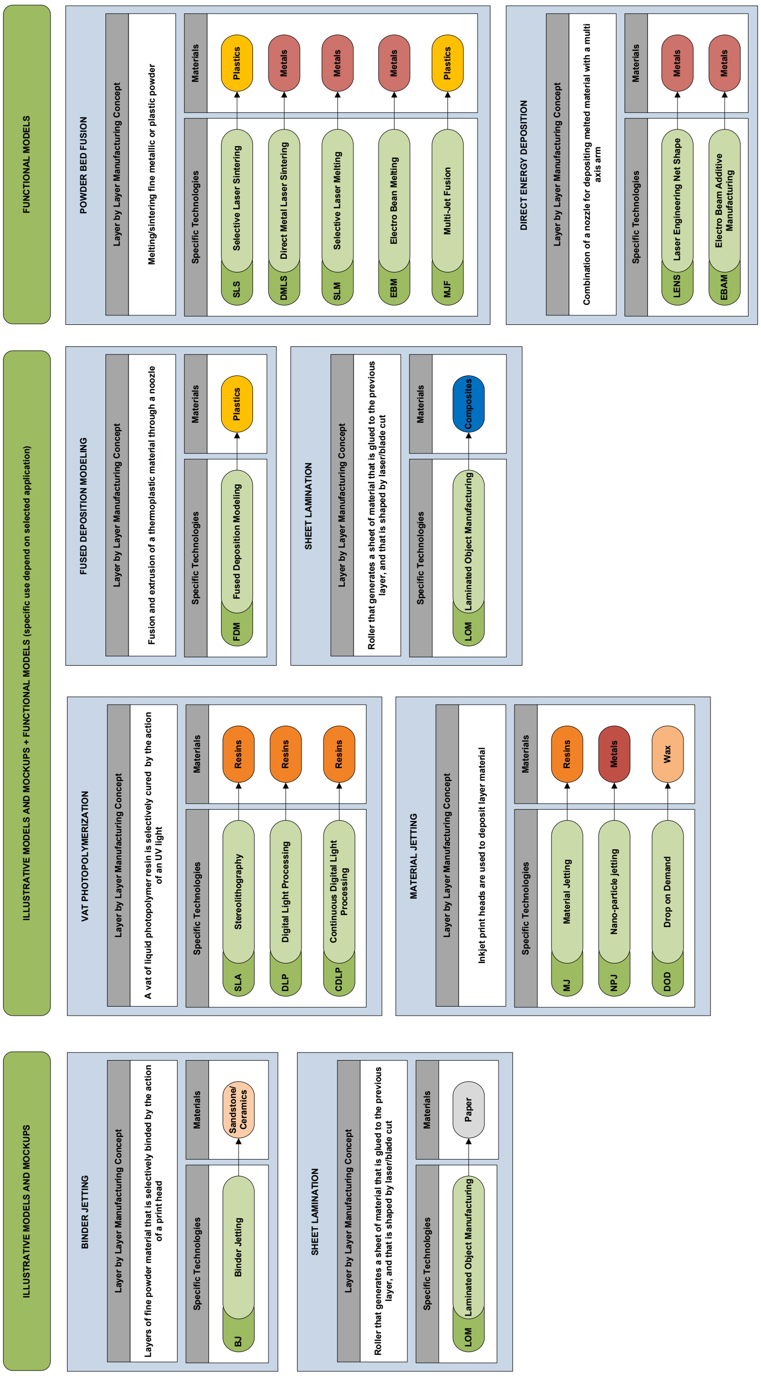

Figure 6: Main uses for Additive Manufacturing[15] vs Specific Technologies (own creation)

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[15] *SLA is a trademark of 3D Systems, INC.; DMLS is a trademark of EOS GmbH Electro Optical Systems; SLM is a trademark of SLM Solutions Group AG; EBM is a trademark of ARCAM AB; EBAM is a trademark of Sciaky Inc; DLP is a trademark of Texas Instruments Inc; LENS is a trademark of Sandia National Labs.*

4.3.1. Powder Bed Fusion

4.3.1.1. Selective Laser Sintering (SLS)16

Description

This technique sinters the particles of the top layer of a powder bed using a laser that follows the digital 3D design pattern. The bed then descends, and a roller spreads a thin new layer of powdered material on top of the previous one. The powder supply is stored in another chamber which slightly ascends, layer by layer, enabling the roller to drag the particles to form the new layer. The process continues the same way until the part is completed. Once finished, the object is allowed to cool, the bed is raised, and the parts are broken out. Finally, the product is bead blasted to remove any remaining material. A high percentage of unused powder can be reused, and this technology conserves a lot of waste material compared to traditional ones.

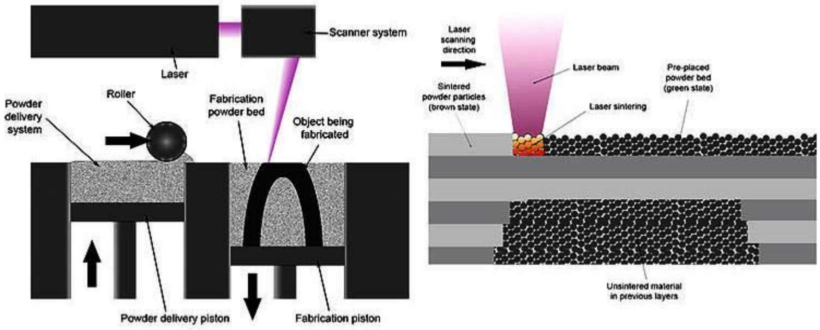

Figure 7: SLS Technology Operating Principle (Image by Materialgeeza under Creative Commons CC BY-SA 3.0 licence, via Wikimedia Commons)

Materials and main uses/applications

The SLS technique is able to use several materials, mainly plastics such as polyamides (nylon), polystyrenes and thermoplastic elastomers. Using nylon, a strong and slightly flexible object may be manufactured. Additionally, the non-melted powder can act as a scaffold, supporting the structure and allowing complex shapes to be created. However, hollow cavities may require the addition of escape holes to allow unsintered powder to be eliminated and the resultant grainy surface may have to be polished.

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[16] *A more extensive description of this technology can be found at:*

- *3D Systems.* https://es.3dsystems.com/resources/information-guides/selective-laser-sintering/sls
- *Formlabs.* https://formlabs.com/blog/what-is-selective-laser-sintering/
- *Materialise.* http://www.materialise.com/en/manufacturing/3d-printing-technology/laser-sintering

Figure 8: example of a part produced with SLS technology (Image courtesy of Ineo Prototipos S.L.)

There are many existing uses for this AM technology, principally rapid design model prototypes, functional prototypes or wind-tunnel test models, series of small functional components with low volume production (e.g. tools and moulds), customized products, etc. Another popular use is in the manufacture of customized products; this is especially relevant in the medical field for the manufacture of objects such as hearing aids, dental retainers and prosthetics. Additionally, lightweight objects using complex lattice structures can be designed for specific uses.

Pros and cons:

- Pros: suitable for functional and highly detailed, strong and moderately large plastics parts. Does not require support structures to prevent layers from drooping. High production rate, moderate unused material recycling rate (≈ 50%).

- Cons: rugged surface finish, curvature of parts with large surface layers (caused by plastic contraction when one layer requires a significant amount of sintering).

Capabilities of a representative SLS machine:

Min. Layer Thickness	Building Volume	Standard Accuracy
0.06 mm	700 x 380 x 580 mm	± 0.2 mm

Table 3: Selected SLS machine specifications

4.3.1.2. Direct Metal Laser Sintering (DMLS)[17]

Description

This technology is based on the same principles as Selective Laser Sintering but uses a bed of powdered metal. A high-powered laser sinters the particles without melting them. A new layer of powder metal is then applied and sintered, and gradually the object is created. The material being sintered in the building platform is provided by a dispensing platform with a recoating blade. Once this process is complete, the product is left to cool and excess powder is recovered and recycled for later use. Support structures may be necessary to anchor the object and any overhanging structures to the build platform in order to reduce stresses during the process.

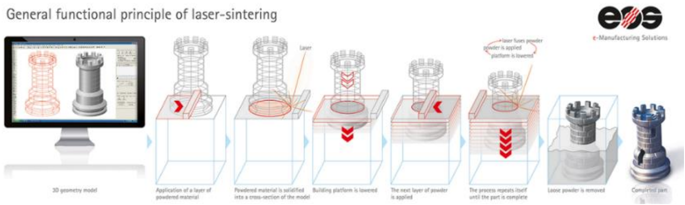

Figure 9: DMLS technology Operating Principle (image courtesy of EOS GmbH Electro Optical Systems)

Materials and main uses/applications

This technology can use a variety of materials such as Inconel (nickel-chromium-based alloys), aluminium, stainless steel, titanium, etc. The resultant products are durable, strong and heat-resistant, and may be subsequently heat treated to maximize mechanical properties. The final surface may need to be polished to achieve a smooth finish.

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[17] *A more extensive description of this technology can be found at:*

- *Canadian Metalworking. http://www.canadianmetalworking.com/article/management/understanding-direct-metal-laser-sintering*
- *i.Materialise. (n.d.). https://i.materialise.com/blog/direct-metal-laser-sintering-dmls/*
- *Proto Labs. (n.d.). https://www.protolabs.co.uk/services/3d-printing/direct-metal-laser-sintering/*
- *3T. https://www.3trpd.co.uk/dmls.htm*

Figure 10: Speedboat engine exhaust flanges manufactured by DMLS (Direct Metal Laser Sintering). The flange on the left is CNC machined using Ti-6Al4V - Courtesy of CRP Technology SRL.

Multi-part assemblies and highly complex geometries can be manufactured using DMLS and this technique is used to manufacture direct parts for industries including aerospace, medical and dental. It is widely used in medicine for the production of prostheses and implants that precisely match the patient’s individual anatomy. In aerospace, the complex shapes save weight and the material properties enable the parts to be used for high heat applications. Other uses include functional test prototypes, tooling and the manufacture of cooling channels that, due to their complexity, cannot be created any other way.

Pros and cons:

- Pros: suitable for functional and highly detailed, strong and relatively large metal parts. High unused material recycling rate (≥ 90%). Rugged surface finish can be improved by blasting or other surface finishing processes.

- Cons: selective metal particles sintering leads to considerable thermal stress on the parts, requiring a strong metallic building plate and support structures to avoid deformations and layer drooping. A post-thermal process may be required to relieve these tensions, in addition to a mechanical process for separating the parts from the building platform and for removing support structures.

Capabilities of a representative DMLS machine:

Min. Layer Thickness	Building Volume	Standard Accuracy
0.02 mm	800 x 400 x 500 mm	± 0.2 mm

Table 4: Selected DMLS machine specifications

4.3.1.3. Selective Laser Melting (SLM)[18]

Description

This technique is similar to Direct Metal Laser Sintering except that the patterns of each layer are fully melted by high powered laser rather than just sintered. Since each layer must be heated above the metal's melting point, a very high temperature is required. This process takes place within a controlled atmosphere of inert gas in a low oxygen environment (less than 500 parts per million). The process continues in the same way, lowering the bottom of the build platform and spreading thin layers of particles to be melted until the object is completed. The final product must be cleaned of any excess of powder and some post processing is always needed to separate the product from the build platform, to eliminate any support structures and to enhance final material properties.

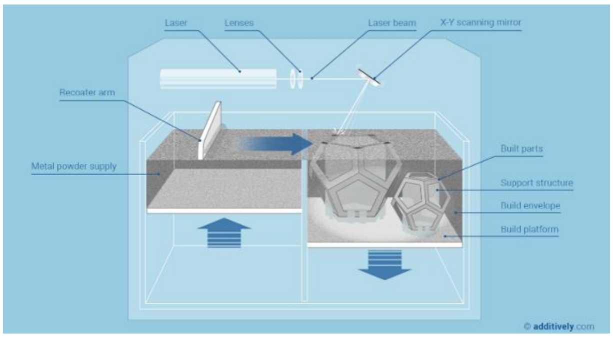

Figure 11: SLM Technology Operating Principle (image courtesy of www.additively.com)

Materials and main uses/applications

This technology can currently use stainless steel, tool steel, titanium, cobalt chrome, aluminium and nickel-base alloys. Products produced using these materials are extremely dense and strong, and the chemical composition, mechanical properties, and microstructure are similar to traditionally manufactured items.

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[18] *A more extensive description of this technology can be found at:*

- *3D Printing Engineering.* https://3d-printing-engineering.com/easyblog/entry/additive-manufacturing-technologies
- *REALIZER.* http://www.realizer.com/en/?page_id=56
- *Sculpteo.* https://www.sculpteo.com/en/glossary/selective-laser-melting-definition/
- *Article Yap, C. Y. (2015). Review of selective laser melting: Materials and applications.* Applied Physics Review.

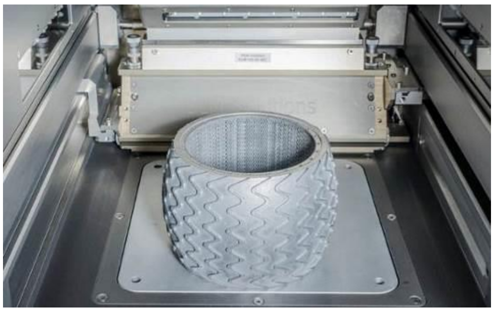

Figure 12: Part produced by SLM technology in the build chamber of a SLM Solutions SLM 280 machine (image courtesy of SLM Solutions Group AG)

Applications of this technology include the creation of complex geometries with thin walls or hidden voids and channels that minimize the weight and the quantity of components. In aerospace, SLM is very effective at creating resistant lightweight parts due to its extreme freedom of design. In medicine, where individual and customized products can be created, implants and prostheses with lattice type geometries can help the object to integrate easier. Other uses include prototyping, mould manufacture, automobile and aircraft industry parts, turbines and many more.

Pros and cons:

- Pros: suitable for functional, highly detailed, strong and relatively large metal parts. Rugged surface finish can be improved by blasting or other surface finishing processes. As all the material is pre-heated to below melting point, this process can lead to lower thermal tensions on the parts compared with DMLS so although a building platform and support structures will still be required, less pre- and post-processing is required.

- Cons: although this process lowers the thermal stress on the parts, a strong metallic building plate and support structures for avoiding deformations and layer drooping are still required. Post-thermal processing for relieving stress tensions and mechanical process for separating the parts from the building platform and for removing support structures are required. Since the process takes all the material to a pre-melting stage, its unused material recycling rate can be significantly lower than with DMLS.

Capabilities of a representative SLM machine:

Min. Layer Thickness	Building Volume	Standard Accuracy
0.02 mm	500 x 280 x 365 mm	± 0.2 mm

Table 5: Selected SLM machine specifications

4.3.1.4. Electron Bean Melting (EBM)[19]

As with Selective Laser Melting technology this process also fully melts the powder metal particles of each layer, but uses an electron beam. A high-speed stream of electrons bombards the powder and the resultant heat melts the particles. After the first layer is created, the build platform descends and a new layer is coated on top. This process is repeated until the object acquires its form. Support structures are used to anchor overhanging structures and other parts to the build platform in order to reduce thermal stresses and to prevent drooping. The process takes place in a vacuum to avoid collision of the electrons with air molecules. Some kind of post-processing is always required.

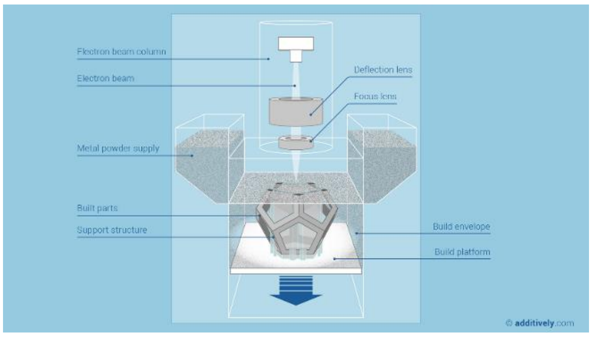

Figure 13: EBM Technology Operating Principle (image courtesy of www.additively.com)

Materials and main uses/applications

Currently, this technique is only able to work with a limited number of metals. Titanium alloys are often used and due to the vacuum environment they work in, there is no problem with their high affinity for oxygen. Cobalt chrome and nickel-based alloys can also be used. EBM creates fully dense metal parts with good mechanical properties.

Figure 14: Example of a part produced with EBM technology (image courtesy of ARCAM AB)

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[19] *A more extensive description of this technology can found at:*

- *ARCAM.* http://www.arcam.com/technology/electron-beam-melting/
- *www.additively.com.* https://www.additively.com/en/learn-about/electron-beam-melting#read-more
- *3Dnatives.* https://www.3dnatives.com/en/electron-beam-melting100420174/

As with other powder bed fusion techniques used for manufacturing metal parts, Electron Beam Melting is primarily used for prototyping parts for use in functional testing. The high resistance of the products makes the process ideal for the manufacture of customized medical implants that fit perfectly into the patients. Additionally, small series parts and support parts like jigs or fixtures can be manufactured.

Pros and cons:

- **Pros**: suitable for functional and strong metal parts. The process has lower power consumption. Preheating results in lower thermal stresses compared to other powder bed fusion technologies and thus fewer support structures are required. The technology is not based on mechanical systems to direct the electron beam, so the applied effective heat does not vary in the X-Y axis.

- **Cons**: a strong metallic building plate and support structures for avoiding deformations and layer drooping are still required, requiring a post-thermal process for relieving these tensions and mechanical process for separating the parts from the building platform and for removing support structures. Due to its nature, this process has a lower scalability and production rate compared to other powder bed fusion technologies.

Capabilities of a representative EBM machine:

Min. Layer Thickness	Building Volume	Standard Accuracy
0.05 mm	200 x 200 x 380 mm	± 0.2 mm

Table 6: Selected EBM machine specifications

4.3.1.5. Multi-Jet Fusion (MJF)[20]

Description

In this powder bed process, an arm applies layers of powder material coating over a platform. Another arm then precisely deposits a fusing and detailing agent onto the powder layer and the entire layer is fused by heat energy from infrared radiation lamps. The detailing agent protects individual grains from the sintering process. Multi-jet fusion is faster than technologies such as selective laser sintering because the entire layer is fused at once rather than sintering the individual particles. After the first layer is formed a new layer is built following the same process. When the product is complete it passes into a cooling station. Vacuum tubes remove most of the unfused powder and an operator finishes the work. The unfused powder can be reused.

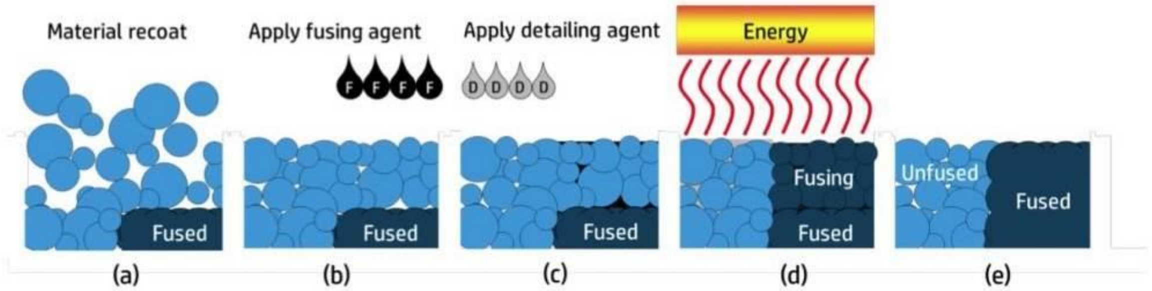

Figure 15: MJF Technology Operating Principle (image courtesy of HP Inc. via 3DPrint.com)

Materials and main uses/applications

This technique is very recent and currently only prints in black using a nylon material. Nevertheless, new materials and colours are in development. This technology achieves good strength and surface finish in its products.

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[20] *A more extensive description of this technology can be found at:*

- *3D Print.* https://3dprint.com/172448/hp-remaking-the-landscape/
- *Materialise.* http://www.materialise.com/en/manufacturing/3d-printing-technology/hp-multi-jet-fusion
- *Sculpteo.* https://www.sculpteo.com/blog/2017/08/22/plastic-3d-printing-technologies-hp-multi-jet-fusion-vs-sls/

Figure 16: Example of a part produced with MJF technology (image courtesy of Sculpteo)

Multi-jet fusion has many uses such as rapid prototyping and the production of some functional components, resulting in cost and weight reduction in many industries. Additionally, it can be used in short-run production and has a potential application for embedded electronics.

Pros and cons:

- Pros: suitable for functional and strong plastic parts.
- Cons: it is currently an emerging technology, so technical data is scarce. Some characteristics such as the building volume are inferior to those of selective layer sintering processes.

Capabilities of a representative MJF machine:

Min. Layer Thickness	Building Volume	Standard Accuracy
0.07 mm	380 x 284 x 350 mm	± 0.2 mm

Table 7: Selected MJF machine specifications

4.3.2. Fused Deposition Modelling (FDM)[21]

Description

In this technique, a plastic filament is melted and extruded through a nozzle and then laid down onto a build platform, instantly cooling and solidifying. The plastic filament is unwound from a coil and directed to a heated nozzle that melts the plastic material. Existing layers act as a foundation for additional extruded material and the machine creates the object bottom up, layer by layer. In some machines the nozzle can follow the 3D design in both horizontal and vertical directions; in others the nozzle only moves in the X-Y (horizontal) plane and the building platform descends in the vertical axis to maintain the current layer at a constant height. A second nozzle may be necessary to create a support structure in a different material printed with filament from another coil. The melted plastic is pushed through the nozzle at a controlled rate using mechanisms such as a worm-drive. Any necessary support material is afterwards eliminated.

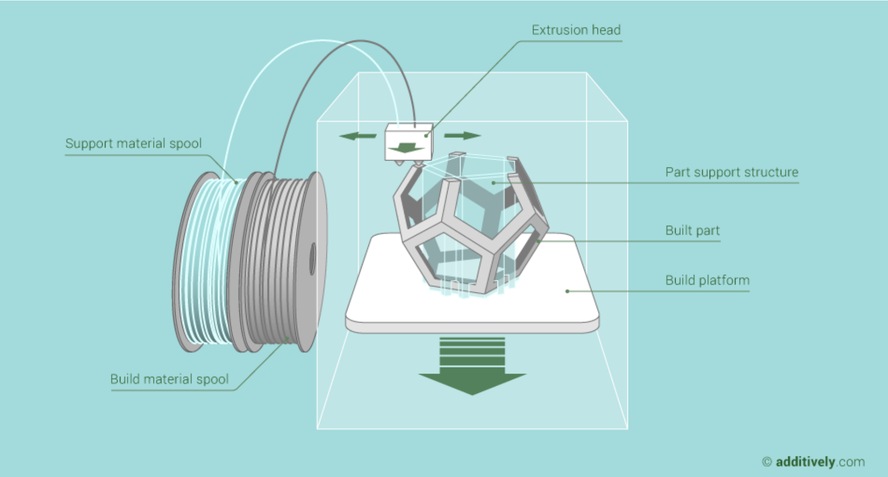

Figure 17: FDM Technology Operating Principle (image courtesy of www.additively.com)

It is important to highlight that although this technology has been fundamentally based on the use of plastic materials, its principle of operation makes it a valid technology for the deposit of other types of material with the capacity to be fluidly injected and subsequently solidified. Hence this technology is also being incorporated in the 3D printing of materials such as concrete, food and bioabsorbable polymers (bio-printing).

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[21] *A more extensive description of this technology can be found at:*

- *LiveScience.* https://www.livescience.com/39810-fused-deposition-modeling.html
- *www.additively.com.* https://www.additively.com/en/learn-about/fused-deposition-modeling#read-advantages
- *THRE3D.* https://web.archive.org/web/20140221050642/https://thre3d.com/how-it-works/material-extrusion/fused-deposition-modeling-fdm

Materials and main uses/applications

This technology's current main applications use several plastic-based materials including acrylonitrile butadiene styrene (ABS), polycarbonate (PC), polystyrene (PS), polyamide (PA) and polylactic acid (PLA). These materials provide products with resistance to heat, chemicals and mechanical stresses and a wide range of colours is available.

Figure 18: Example of a part produced with FDM technology (Image by C Mitchelle under Creative Commons CCBY-SA 4.0. licence, via Wikimedia Commons)

One of the main applications of FDM is rapid and low-cost prototyping for testing parts for fit and form. In addition, rapid manufacturing can be worthwhile but only for very short runs. Fused deposition modelling is also useful in prototyping scaffolds for medical tissue engineering applications. Some small and affordable FDM machines have been developed for enthusiasts, inventors or small business owners, making this without doubt the most affordable and accessible AM technology currently available.

Pros and cons:

- Pros: currently the most simple, affordable and accessible AM technology (with plenty of options for professional and non-professional users). Lower cost raw materials, availability of a wide range of thermoplastics (and even polyamides and fibre-reinforced polyamides). Suitable for all levels of modelling needs and for some functional parts (especially for elements such as covers or cases that are not going to suffer mechanical stresses).

- Cons: due to a lower cohesion between layers, the produced parts are liable to anisotropy in the Z axis, with poor resistance to pulling tensions perpendicular to the layer's direction. Layer thickness results in poor surface finish and tolerances. Support structures may be required to prevent newly deposited layers from drooping during the cooling process.

Capabilities of a representative FDM machine:

Min. Layer Thickness	Building Volume	Standard Accuracy
0.178 mm	914 x 610 x 914 mm	± 0.15 mm

Table 8: Selected FDM machine specifications

4.3.3. Direct Energy Deposition (DED)

4.3.3.1. Laser Engineered Net Shape (LENS)[22]

Description

This technique fabricates metal parts by the direct deposit of melted metal powder. The metal powder is delivered via a deposition head (either by gravity or by means of pressurised gas) and is then melted by a high-power laser. Typically, the laser beam is focussed through the centre of the supply head, coaxially to the direction of the powder supply. The table onto which the object is printed moves horizontally to create the desired pattern of the layer and when complete, the deposition head moves vertically to generate the next layer. The process takes place in a controlled atmosphere of inert gas (argon) and no oxygen in order to improve layer adhesion and to control the product properties. In contrast to Selective Laser Melting technology, the metal powder is only applied where required.

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[22] *A more extensive description of this technology can be found at:*

- *Sandia National Laboratories (Lockheed Martin):* http://www.sandia.gov/mst/pdf/LENS.pdf
- *EFESTO LLC. "Additive Manufacturing and 3D Printing LENS ® Technology".* http://www.lortek.es/files/fab-aditiva/efesto-ik4-lortek-27th-november-2013.pdf
- *OPTOMEC.* https://www.optomec.com/3d-printed-metals/lens-technology/

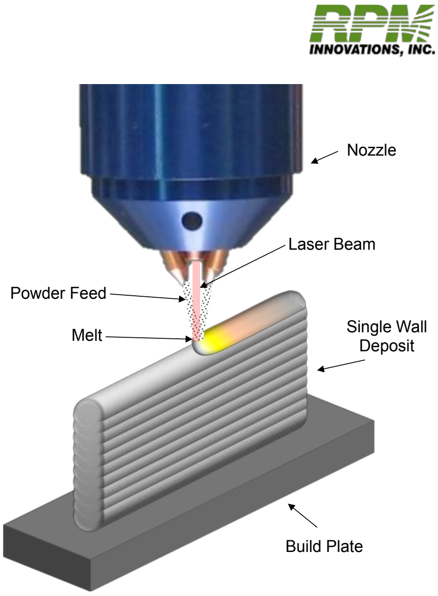

Figure 19: LENS Technology Operating Principle (image courtesy of RPM Innovations Inc.)

Materials and main uses/applications

This process is able to print a wide range of alloys such as stainless steel, tool steels, nickel, cobalt and titanium. However, aluminium and copper alloys are difficult to deposit due to their reflective properties. The final product is dense and displays good mechanical properties, high strength and high ductility.

Figure 20: Part being manufactured using LENS AM technology (image courtesy of OPTOMEC)

Principal applications include component repair, rapid prototyping for testing and some limited-run manufacturing in sectors such as aerospace and defence. This technology can also be used to develop customized medical implants and prostheses.

Pros and cons:

- Pros: one of the best suited technologies for repair and customization of large size existing parts (AM or not AM manufactured).
- Cons: poor surface finish and tolerances due to layer thickness. This technology allows limited design complexity compared with powder bed processes.

Capabilities of a representative DED machine:

Min. Layer Thickness	Building Volume	Standard Accuracy
0.025 mm	900 x 1500 x 900 mm	± 0.25 mm

Table 9: Selected LENS machine specifications

4.3.3.2. Electron Beam Additive Manufacturing (EBAM)[23]

Description

This technology is similar to Laser Engineering Net Shape but with slight differences. In this case, an electron beam gun is used to create a molten metal puddle and additional metal material is fed into that pool. The substrate plate moves the product so that the machine adds material just where it is needed, and the deposit solidifies immediately once away from the heat source of the electron beam. This sequence is repeated layer by layer until the desired 3D object is created. The process takes place within a vacuum environment without the need for inert gases. Using a dual wire feed system, two different metal alloys can be combined into a single melt pool.

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[23] *A more extensive description of this technology can be found at:*

- *Sciaky.* http://www.sciaky.com/additive-manufacturing/electron-beam-additive-manufacturing-technology
- *www.additivemanufacturing.com.* http://additivemanufacturing.com/2015/10/14/electron-beam-additive-manufacturing-ebam-advantages-of-wire-am-vs-powder-am/

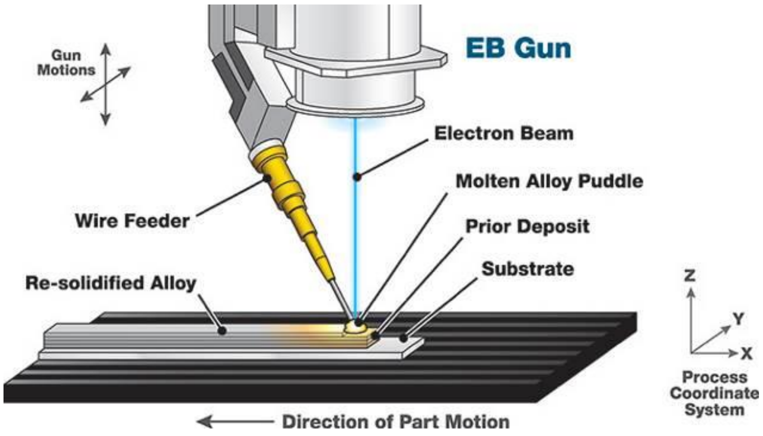

Figure 21: EBAM technology Operating Principle (image courtesy of Sciaky, Inc.)

Materials and main uses/applications

Materials used include stainless steel, copper-nickel alloys, titanium, tantalum and nickel-based alloys. As mentioned above, "custom alloys" can be created by combining two different materials with a dual wire feed process.

Figure 22: Example of a part produced with EBAM technology (image courtesy of Sciaky, Inc.)

Electron Beam Additive Manufacturing is faster than other powder bed metal processes and therefore can be used for creating rapid prototypes. Since material is only deposited where needed, it is also suitable for repairs. Other uses include titanium alloy medical implants and some parts manufacturing.

Pros and cons:

- Pros: one of the best suited technologies for repair and customization of large size existing parts (AM or not AM manufactured).
- Cons: poor surface finish and tolerances due to layer thickness.

Capabilities of a representative EBAM machine:

Min. Layer Thickness	Building Volume	Standard Accuracy
0.1 mm	5790 x 1220 x 1220 mm	± 0.05 mm

Table 10: Selected EBAM machine specifications

4.3.4. Vat Photopolymerization

4.3.4.1. Stereolithography (SLA)[24]

Description

In this technology, the build platform is submerged into a vat filled with a liquid resin and an ultraviolet laser solidifies the resin. The light causes chains of molecules to link together, forming solid polymers that create the first layer of the desired 3D product. To create subsequent layers, the build platform is either lowered or raised by the height of one layer, depending on the machine used. If the object is created bottom up, raising the platform, only the photopolymer necessary to keep the bottom of the build vat constantly full is needed, hence bigger volumes can be produced. Support structures are necessary to prevent deflection by gravity and to allow the newly created layers to attach firmly to the existing structure. The finished product is immersed in a chemical bath to remove excess resin and then transferred to an ultraviolet oven to finalize the curing process. Support structures are then removed.

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[24] *A more extensive description of this technology can be found at:*

- *Materialise.* http://www.materialise.com/en/manufacturing/3d-printing-technology/stereolithography
- *Formlabs.* https://formlabs.com/blog/ultimate-guide-to-stereolithography-sla-3d-printing/
- *Machine Design.* http://www.machinedesign.com/3d-printing/what-s-difference-between-stereolithography-and-selective-laser-sintering

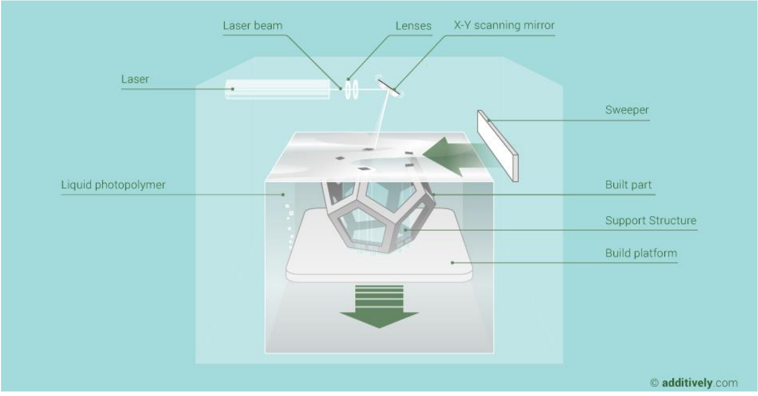

Figure 23: SLA Technology Operating Principle (image courtesy of www.additively.com)

Materials and main uses/applications

Stereolithography uses photopolymer resins and creates objects strong enough to be machined. Product size is limited, depending on the machine used.

Figure 24: Example of a part produced with SLA technology (image courtesy of PADT, Inc.)

An important application of SLA is the production of 3D models for medical use, based on 3D scans of a patient's anatomy. It can also be helpful for diagnosis, surgical planning or for implant design. Apart from medical applications, stereolithography can be used for high detail prototyping in many industries due to the high accuracy and smooth surfaces of the final objects. Accurate models for casting and moulding can also be produced.

Pros and cons:

- Pros: suitable for detailed and realistic resin models, with a variety of material properties including rigid, flexible, rubber-like, opaque, translucent and transparent etc. Easy removal of non-cured material.

- **Cons**: the raw materials are sensitive to UV light, so in the presence of light the product properties can vary with time. Not well suited for functional parts unless non critical ones. Slower than other vat photopolymerization technologies.

Capabilities of a representative SLA machine:

Min. Layer Thickness	Building Volume	Standard Accuracy
0.025 mm	1500 x 750 x 500 mm	± 0.15 mm

Table 11: Selected SLA machine specifications

4.3.4.2. Digital Light Processing (DLP)[25]

Description

This technique is very similar to Stereolithography but instead uses a projector light to solidify the liquid resin rather than a laser. This digital projector conforms the entire layer at once by displaying a single image all across the whole platform. The solidified pattern is formed of square pixels due to the digital screen of the projector, and thus the layer is composed of small rectangular bricks. Once the first layer of photopolymer has solidified, the build platform moves, and the next layer is created. This process continues until the 3D product is obtained. During processing, the object can either be pulled up out of the resin, creating a shallow space at the bottom of the container for uncured resin or it can be sunk into a vat of liquid resin and descend with each layer. When the final product is formed, post-processing is required to remove support material.

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[25] *A more extensive description of this technology can be found at:*

- *Make Parts Fast.* http://www.makepartsfast.com/what-is-dlp-3d-printing/
- *Think3D.* https://www.think3d.in/digital-light-processing-dlp-3d-printing-technology-overview/
- *DLP Texas Instruments.* http://www.ti.com/lit/ml/dlpb008a/dlpb008a.pdf

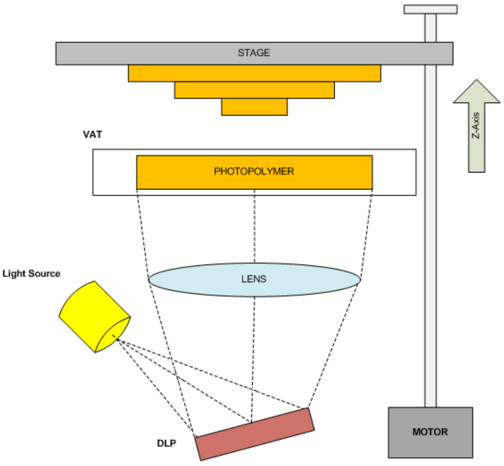

Figure 25: DLP Technology Operating Principle (own creation)

Materials and main uses/applications

The process uses the same photopolymer resins as Stereolithography and products can be machined or customized after the process. It can be faster than Stereolithography because the entire layer is conformed in a singular digital image rather than requiring every point to be formed by a laser.

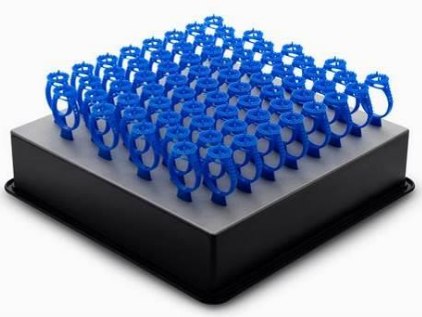

Figure 26: Example of a part produced with DLP technology (image courtesy of Formlabs Inc.)

The accuracy of Digital Light Processing relies on the resolution of the projector, which determines how many pixels are available. The object may be sanded afterwards to remove the square pixel appearance. Main applications include rapid prototyping, patterns for injection moulding, metal casting applications and jewellery.

Pros and cons:

- Pros: suitable for detailed and realistic resin models, with a variety of material properties including rigid, flexible, rubber-like, opaque, translucent and transparent etc. Faster process than stereolithography. Easy removal of non-cured material.

- **Cons**: the raw materials are sensitive to UV light, so in the presence of light the product properties can vary with time. Currently, less production capacity than stereolithography. Not well suited for functional parts unless non-critical ones.

Capabilities of a representative DLP machine:

Min. Layer Thickness	Building Volume	Standard Accuracy
0.05 mm	260 x 160 x 190 mm	± 0.15 mm

Table 12: Selected DLP machine specifications

4.3.4.3. Continuous Digital Light Processing (CDLP)[26]

Description

In the technique sometimes referred to as CLIP (Continuous Liquid Interface Production), the build platform is in contact with a liquid photopolymer resin contained within a vat. Part of the base of the vat (the "window") is transparent to ultraviolet light and a digital light projector creates a continuous sequence of ultra violet images that travel through the window and solidify the resin. The pool of resin is positioned over an oxygen-permeable membrane that creates a dead zone preventing the resin from attaching to the window. Unlike other additive manufacturing technologies, the platform elevates continuously and new resin flows under the object. Therefore, the UV light exposure, the resin renewal and the object elevation are conducted simultaneously.

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[26] *A more extensive description of this technology can be found at:*

- *Carbon 3D.* https://www.carbon3d.com/process/
- *Wikipedia.* https://en.wikipedia.org/wiki/Continuous_Liquid_Interface_Production
- *Article: "Continuous liquid interface production of 3D objects".* http://science.sciencemag.org/content/early/2015/03/18/science.aaa2397.full

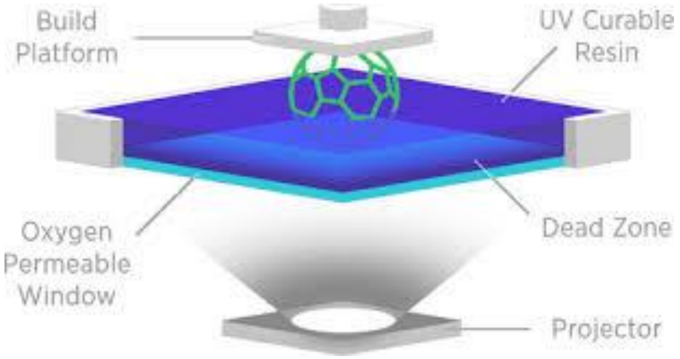

Figure 27: CDLP technology Operating Principle (image courtesy of Carbon3D)

Materials and main uses/applications

This technology uses photopolymer resins such as prototyping acrylate and rigid or elastomeric polyurethane. These materials provide different properties such as good elongation, resilience or temperature resistance. Since it is a continuous process, it does not create any visible layers.

Figure 28: Example of a part produced with CDLP technology (image courtesy of Carbon3D)

Continuous digital light processing is faster than other techniques as it is a continuous process. Some applications include customization of medical devices and, as with other vat photopolymerization technologies, the creation of high resolution prototypes.

Pros and cons:

- Pros: suitable for detailed and realistic resin models, with a variety of material properties including rigid, flexible, rubber-like, opaque, translucent and transparent etc. Faster process than other vat photopolymerization techniques. Easy removal of non-cured material.

- Cons: the raw materials are sensitive to UV light, so in the presence of light the product properties can vary with time. Currently, less production capacity than stereolithography. Not well suited for functional parts unless non-critical ones.

Capabilities of a representative CDLP machine:

Min. Layer Thickness	Building Volume	Standard Accuracy
(Pixels) 0.075 mm	190 x 115 x 325 mm	± 0.05 mm

Table 13: Selected CDLP machine specifications

4.3.5. Material Jetting

4.3.5.1. Material Jetting (MJ)[27]

Description

Material jetting technology jets thin layers of liquid photopolymer through a nozzle that moves horizontally over the build platform on which the object is formed. Drops of material are deposited following the 3D design pattern and an ultraviolet lamp passes over the object, instantly solidifying the polymer. After the first layer is formed, the platform descends, and successive layers are built on top of the previous one, creating the 3D object. For some complex geometries and overhangs support material is required and the machine jets a different, gel-like material. Once all layers are formed, the support material is removed with water or in a solution bath to obtain the finished product.

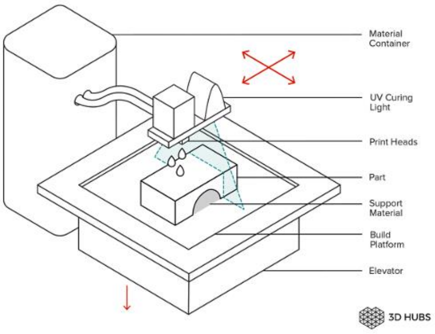

Figure 29: MJ Technology Operating Principle (image courtesy of www.3dhubs.com)

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[27] *A more extensive description of this technology can be found at:*

- *www.additively.com.* https://www.additively.com/en/learn-about/material-jetting
- *DREAM (Design, Research and Education for AM Systems).* http://seb199.me.vt.edu/dreams/material-jetting/
- *Make Parts Fast.* http://www.makepartsfast.com/how-does-3d-printing-material-jetting-work/

Materials and main uses/applications

Various photosensitive resins with different textures, strength, colour and properties can be used. The objects created can be transparent and tough with rubber-like flexibility. Some machines can print several materials simultaneously using multiple jets and create combinations of different properties and characteristics, including multiple colours.

Figure 30: Example of a part produced with MJ technology (image courtesy of Fundación Prodintec)

This technique provides extremely high layer resolution so realistic prototypes with fine details and smooth surfaces can be manufactured. In addition, high accuracy casting patterns can be manufactured for industries such as medical, dental and jewellery manufacture.

Pros and cons:

- Pros: suitable for detailed and realistic resin models, with a variety of material properties including rigid, flexible, rubber-like, opaque, translucent, transparent, etc. Possibility of using multiple colours in the same part. Great ease of handling due to the use of cartridges for raw material feed. Easy removal of non-cured material.

- Cons: the raw materials are sensitive to UV light, so in the presence of light the product properties can vary with time. Not well suited for functional parts unless non critical ones.

Capabilities of a representative MJ machine:

Min. Layer Thickness	Building Volume	Standard Accuracy
0.014 mm	490 x 390 x 200mm	± 0.025 mm

Table 14: Selected MJ machine specifications

4.3.5.2. Nanoparticle Jetting (NJ)[28]

Description

This technique uses inkjet technology to build metal parts from liquid material. The liquid material contains metal nanoparticles in a liquid suspension which is deposited onto the build platform in small drops of liquid. High temperatures evaporate the surrounding liquid and the remaining metal particles are sintered to form the object. The material is delivered in sealed cartridges that are easily inserted into the machine so there is no need to handle metal powders. If support material is needed, it is easily removed afterwards.

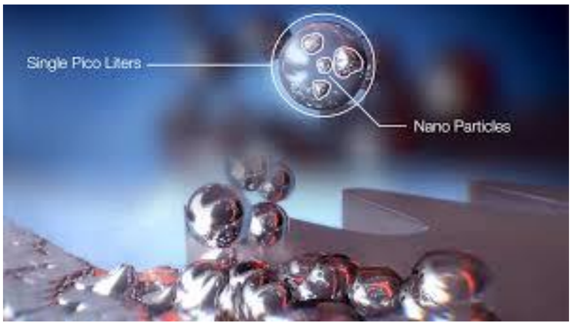

Figure 31: NJ technology Operating Principle (image courtesy of XJet Ltd.)

Materials and main uses/applications

The first material used was stainless steel, but others are currently being developed, such as ceramics.

Due to the ultra-thin layers obtained with nanoparticle jetting, metal parts with high accuracy and fine detail can be manufactured. Almost any geometry can be designed and printed. It has a potential application in flexible electronics.

Pros and cons:

- Pros: suitable for functional and strong metal parts. Higher accuracy than powder bed fusion metal processes.
- Cons: it is currently an emerging technology, so technical data is scarce.

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[28] *A more extensive description of this technology can be found at:*

- *3DPrint.com.* https://3dprint.com/tag/nanoparticle-jetting/

Capabilities of a representative NJ machine:

Min. Layer Thickness	Building Volume	Standard Accuracy
0.002 mm	500 x 250 x 250 mm	Not available

Table 15: Selected NJ machine specs

4.3.5.3. Drop on Demand (DoD)[29]

Description

This technique is similar to material jetting but without the continuous stream of material, and droplets are only deposited where needed. The droplets are released through a nozzle when a thermal or piezoelectric actuator creates a pressure change, allowing the deposit of material to be started and stopped. The material solidifies on deposit and the object is created layer by layer until the finished product is formed. If support material is required, the completed product is inserted into a warm liquid solution to dissolve it.

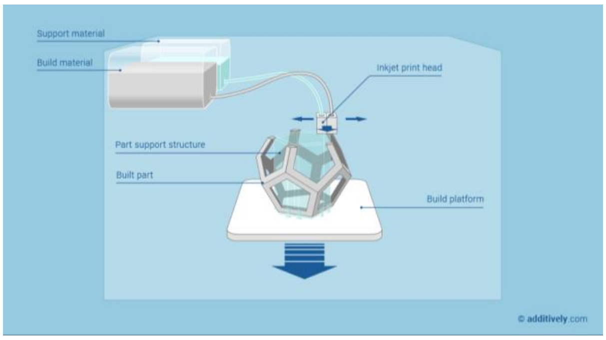

Figure 32: DoD Technology Operating Principle (image courtesy of www.additively.com)

Materials and main uses/applications

The drop on demand process utilizes a wax compound to fabricate the objects. It is loaded into the machine via small solid bars. This technology is able also to print another soluble, sacrificial material to create the support structures.

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[29] *A more extensive description of this technology can be found at:*

- *Article "Drop on Demand 3D Metal Printing".* https://www.flow3d.com/wp-content/uploads/2014/04/Drop-on-Demand-3D-Metal-Printing.pdf

Drop on demand generates complex geometries with high precision for many applications such as lost-wax casting or mould making. These products are used in medical, automobile and dental industries and in the manufacture of jewellery, consumer objects and toys.

Pros and cons:

- Pros: high precision technique for moulding and casting.
- Cons: practical applications are limited to moulding and casting. Volume of produced parts is currently limited.

Capabilities of a representative DoD machine:

Min. Layer Thickness	Building Volume	Standard Accuracy
0.007 mm	150 x 150 x 50 mm	± 0.03 mm

Table 16: Selected DoD machine specifications

4.3.6. Laminated Object Manufacturing (LOM)[30]

Description

Laminated Object Manufacturing uses rolls of adhesive-coated material. The material is heated by another roller, melting the adhesive before the material transfers to the build platform. The selected shape is cut using a laser or a blade, cross hatches are drawn on the rest of the surface to facilitate the extraction of the waste material and the sheet is pressed onto the platform and glued to the previous layer. When this stage finishes, the platform descends. At the same time, the sheet moves and fresh material arrives on top of the object while the previously used material is collected onto a waste roll. This sequence is repeated layer by layer until the object is produced.

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[30] *A more extensive description of this technology can be found at:*

- *LiveScience.* https://www.livescience.com/40310-laminated-object-manufacturing.html
- *Make Parts Fast.* http://www.makepartsfast.com/laminate-object-manufacturing-lom/
- *Sculpteo.* https://www.sculpteo.com/en/glossary/lom-definition/

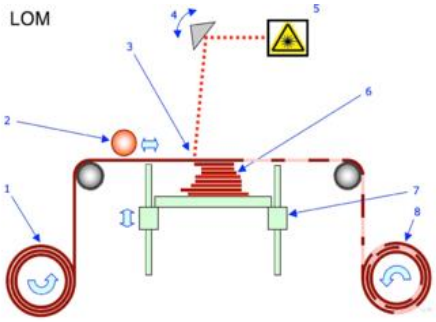

Figure 33: LOM Technology Operating Principle (Image by Laurens van Lieshout under Creative Commons CC BY-SA 3.0 licence, via Wikimedia Commons)

Materials and main uses/applications

The most commonly used materials are paper, composites and plastic. Due to the difficulty of cutting, metallic sheets are less often used in this technique. Laminated object manufacturing does not produce models as accurate as other 3D technologies but since it does not need an enclosed chamber, larger models can be created. This technique has some difficulties in creating complex geometries.

Figure 34: Example of a part produced with LOM technology (image courtesy of INEGI, Institute of Science and Innovation in Mechanical and Industrial Engineering)

Some applications include rapid large prototyping for form and fit testing but not for functional use. Also, rapid tooling or patterns for use in traditional manufacturing, for example in sand moulded casting.

Pros and cons:

- Pros: this technology can manufacture large parts, especially suited to aesthetic purposes.
- Cons: not especially suitable for functional or complex parts, unless used with metal sheets (possible, but not typical).

Capabilities of a representative LOM machine:

Min. Layer Thickness	Building Volume	Standard Accuracy
0.09 mm	250 x 381 x 200 mm	± 0.15 mm

Table 17: Selected LOM machine specifications

4.3.7. Binder Jetting (BJ)[31]

Description

This process spreads a thin layer of powder material over a build platform. A print head then directly deposits a binding agent onto the layer in the desired pattern, binding the powder together. Once the first layer is completed, the build platform descends, and a levelling roller spreads another layer of powder material. It is similar to Selective Laser Sintering but uses a binding agent instead of a sintering laser. Complex shapes can be created because the unbound powder remains around the object, supporting it until the process finishes. When the process finishes, the excess powder is cleaned from the product and it is coated with an adhesive glue to improve its mechanical and structural properties.

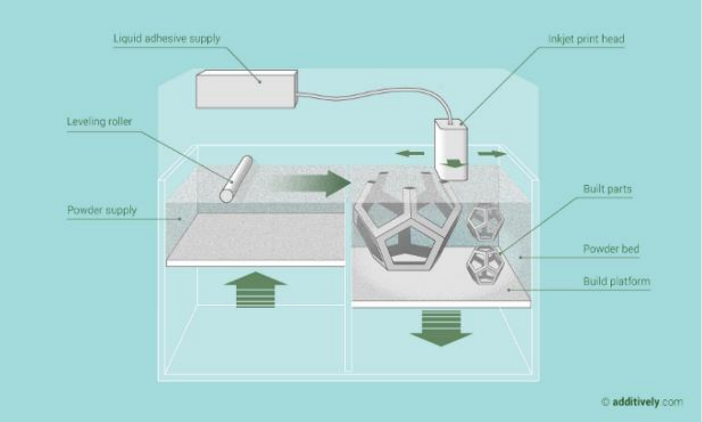

Figure 35: BJ Technology Operating Principle (image courtesy www.additively.com)

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[31] *A more extensive description of this technology can be found at:*

- *ExOne.* http://www.exone.com/Resources/Technology-Overview/What-is-Binder-Jetting
- *DREAM (Design, Research and Education for AM Systems).* http://seb199.me.vt.edu/dreams/binder-jetting/
- *Engineers Garage.* https://www.engineersgarage.com/articles/3d-printing-processes-binder-jetting

Materials and main uses/applications

Binder jetting technology can work with many materials in powder form such as metal, sandstone and ceramics. With sandstone, this technique is able to print in a wide range of colours. Products are weaker than those manufactured using other 3D printing processes, hence the need for the post-processing with adhesive glue.

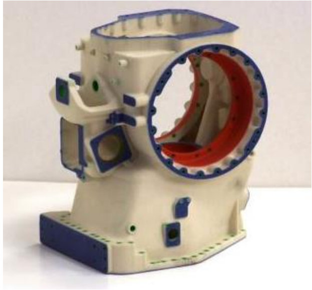

Figure 36: Example of a part produced with BJ technology (image courtesy of Fundación Prodintec)

Due to the multi-colour options, it is often used with sandstone to create architectural models or lifelike sculptures. Other applications include full colour prototyping for visual and form testing, the production of green parts for further processing with other techniques and for casting patterns to fabricate moulds.

Pros and cons:

- Pros: multi-coloured technology for non-functional models.
- Cons: not suited for functional parts.

Capabilities of a representative BJ machine:

Min. Layer Thickness	Building Volume	Standard Accuracy
0.09 mm	250 x 381 x 200 mm	± 0.15 mm

Table 18: Selected BJ machine specifications

4.4. Summary of Additive Manufacturing Technologies

Below is a summary of the described technologies presented:

Tech. group	Specific Tech.	Basic Concept	Materials	Applications	Pros	Cons	Capabilities of representative machines
Powder Bed Fusion	Selective Laser Sintering (SLS)	A laser sinters the powder material layer by layer until creating finished 3D objects	-Polyamides -Polystyrenes -Thermoplastic elastomers	-Rapid prototyping -Customized products -Series of small products -Lightweight objects	-Highly detailed, strong and moderately large plastics parts -No support structures required -Moderate unused material recycling rate	- Rugged surface finish - Curvature of large parts	Example AM machine Min. layer thickness: 0.06 mm Building volume: 700 x 380 x 580 mm Standard accuracy: ± 0.2 mm
Powder Bed Fusion	Direct Metal Laser Sintering (DMLS)	A laser sinters the metal powder material layer by layer and creates a 3D metal object	-Inconel -Aluminium -Stainless steel -Titanium	-Medical implants and prostheses -Functional prototyping -Aerospace industry parts	-Functional and highly detailed, strong and large metal parts -High unused material recycling rate	-Great thermal stress -Requires strong support structures -Requires post-treatments	Example AM machine Min. layer thickness: 0.02 mm Building volume: 800 x 400 x 500 mm Standard accuracy: ± 0.2 mm
Powder Bed Fusion	Selective Laser Melting (SLM)	A laser fully melts the metal powder layer by layer and creates the final product	-Titanium -Cobalt chrome -Aluminium -Stainless steel -Nickel alloys	-Aerospace industry -Medical implants -Prototyping	-Functional and highly detailed, strong and large metal parts -Lower thermal tensions than DMLS	-Considerable thermal stress -Requires strong support structures -Requires post-production treatment	Example AM machine Min. layer thickness: 0.02 mm Building volume: 500 x 280 x 365 mm Standard accuracy: ± 0.2 mm

Tech. group	Specific Tech.	Basic Concept	Materials	Applications	Pros	Cons	Capabilities of representative machines
Powder Bed Fusion	Electron Beam Melting (EBM)	The metal powder layers are melted using an electron beam until the 3D object is manufactured	-Titanium alloys -Cobalt chrome -Nickel-based alloys	-Prototyping -Customized implants -Small series parts	-Functional and strong metal parts - Lower energy consumption compared with other powder-based techniques -More uniformity in the application of heat to the material	-Considerable thermal stress -Requires strong support structures -Requires post-production treatment -Lower scalability and production rate than other powder-based techs	Example AM machine Min. layer thickness: 0.05 mm Building volume: 200 x 200 x 380 mm Standard accuracy: ± 0.2 mm
Powder Bed Fusion	Multi-Jet Fusion (MJF)	Selected material of the powder bed layer is fused where a fusing agent is applied	-Nylon	-Rapid prototyping -Short-run production -Some functional components	-Functional and strong metal parts	-An emerging technology -Some characteristics are inferior to other sintering/melting processes	Example AM machine Min. layer thickness: 0.07 mm Building volume: 380 x 284 x 350 mm Standard accuracy: ± 0.2 mm
Fused Deposition Modelling	Fused Deposition Modelling (FDM)	Consecutive layers of melted plastic are extruded through a nozzle and deposited to create the final object	- ABS -Polycarbonate -Polystyrene -Polyamide -Polylactic acid	-Rapid prototyping -Rapid manufacturing for short runs	-Simple technology -Availability of a wide range of plastic materials - Suitable for some functional parts that are not going to suffer from mechanical stresses	-Produced parts present anisotropy in the Z axis, with poor resistance to pulling tensions perpendicular to the layer's direction -Poor surface finish and tolerances -Requires support structures to prevent drooping	Example AM machine Min. layer thickness: 0.178 mm Building volume: 914 x 610 x 914 mm Standard accuracy: ± 0.15 mm

Tech. group	Specific Tech.	Basic Concept	Materials	Applications	Pros	Cons	Capabilities of representative machines
Direct Energy Deposition	Laser Engineered Net Shape (LENS)	Metal powder is deposited then melted by laser generating the product layer by layer	-Stainless steel -Cobalt alloys -Nickel alloys -Titanium alloys	-Prototyping -Reparations -Short run manufacturing	-Best suited technology for repair or customization of large existing parts	-Poor surface finish and tolerances	Example AM machine Min. layer thickness: 0.025 mm Building volume: 900 x 1500 x 900 mm Standard accuracy: ± 0.25 mm
Direct Energy Deposition	Electron Beam Additive Manufacturing (EBAM)	An electron beam creates a molten puddle into which metal material is directly introduced, solidifying and conforming the layer	-Titanium -Tantalum -Stainless steel -Nickel-based alloys -Copper nickel alloys	-Reparations -Rapid prototyping -Medical implants -Short run manufacturing	-Best suited technology for repair or customization of large existing parts	-Poor surface finish and tolerances	Example AM machine Min. layer thickness: 0.1 mm Building volume: 5790 x 1220 x 1220 mm Standard accuracy: ± 0.05 mm
Vat Photopol.	Stereolithography (SLA)	Successive layers of polymers are formed using an ultraviolet laser that solidifies a liquid resin	-Photopolymer resins	-High detail prototyping -Medical models -Industry models	-Suitable for detailed and realistic resin models -Variety of material properties including rigid, flexible, rubber-like, opaque, translucent and transparent -Easy removal of non-cured material	-Raw materials are sensitive to UV light -Not well suited for functional parts unless non-critical ones -Slower than other vat photopolymerization technologies	Example AM machine Min. layer thickness: 0.025 mm Building volume: 1500 x 750 x 500 mm Standard accuracy: ± 0.15 mm

Tech. group	Specific Tech.	Basic Concept	Materials	Applications	Pros	Cons	Capabilities of representative machines
Vat Photopol.	Digital Light Processing (DLP)	Successive layers of polymers are formed using a projector light that simultaneously solidifies an entire layer the liquid resin	-Photopolymer resins	-Prototyping -Patterns for injection moulding	-Suitable for detailed and realistic resin models -Variety of material properties including rigid, flexible, rubber-like, opaque, translucent and transparent -Faster than stereolithography -Easy removal of non-cured material	-Raw materials are sensitive to UV light - Currently less volume for production capacity than stereolithography -Not well suited for functional parts unless non-critical ones	<u>Example AM machine</u> Min. layer thickness: 0.05 mm Building volume: 260 x 160 x 190 mm Standard accuracy: ± 0.15 mm
Vat Photopol.	Continuous Digital Light Processing (CDLP)	A UV digital light projector solidifies a photopolymer resin solidify onto a platform that is continuously elevating	-Photopolymer resins	-High resolution prototyping -Customized medical devices	-Suitable for detailed and realistic resin models -Variety of material properties including rigid, flexible, rubber-like, opaque, translucent and transparent -Faster than other vat photopolymerization processes -Easy removal of non-cured material	-Raw materials are sensitive to UV light - Currently less volume for production capacity than stereolithography -Not well suited for functional parts unless non-critical ones	<u>Example AM machine</u> Min. layer thickness: (Pixels) 0.075 mm Building volume: 190 x 115 x 325 mm Standard accuracy: ± 0.05 mm

Tech. group	Specific Tech.	Basic Concept	Materials	Applications	Pros	Cons	Capabilities of representative machines
Material Jetting	Material Jetting (MJ)	A nozzle deposits drops of liquid photopolymer that are solidified layer by layer by UV light to create the product	-Photosensitive resins	-Realistic prototypes -Casting patterns	-Suitable for detailed and realistic resin models -Variety of material properties including rigid, flexible, rubber-like, opaque, translucent and transparent - Different colours in the same part - Ease of handling	-Raw materials are sensitive to UV light -Not well suited for functional parts unless non-critical ones	Example AM machine Min. layer thickness: 0.014 mm Building volume: 490 x 390 x 200mm Standard accuracy: ± 0.025
Material Jetting	Nanoparticle jetting (NJ)	A machine jets a suspension of metal nanoparticles. High heat evaporates the liquid and the remaining metal particles are sintered	-Stainless steel	-High detail metal parts	-Suitable for functional and strong metal parts -Higher accuracy than powder bed fusion metal processes	-An emerging technology	Example AM machine Min. layer thickness: 0.002 mm Building volume: 500 x 250 x 250 mm Standard accuracy: Not available

Tech. group	Specific Tech.	Basic Concept	Materials	Applications	Pros	Cons	Capabilities of representative machines
Material Jetting	Drop on Demand (DoD)	Material droplets are deposited only where required using a nozzle that allows the flow to be interrupted. The material solidifies to form the product	-Wax compound	-Lost-wax casting -Mould making	-High precision technique for moulding and casting	-Practical applications are limited to moulding and casting -Volume of the produced parts is currently limited	Example AM machine Min. layer thickness: 0.007 mm Building volume: 150 x 150 x 50 mm Standard accuracy: ± 0.03 mm
Sheet Lamination	Laminated Object Manufacturing (LOM)	Sheets of material are cut in the desired shape with a laser or a blade and glued together to form the 3D object	-Paper -Composites -Plastic	-Large prototyping -Casting patterns	- This technology can manufacture large parts, especially suited for aesthetic purposes	- Not especially suitable for functional or complex parts, unless used with metal sheets (possible, but not typical)	Example AM machine Min. layer thickness: 0.100 mm Building volume: 762 x 610 x 610 mm Standard accuracy: ± 0.10 mm
Binder Jetting	Binder Jetting (BJ)	The powder material is bound with a binding agent deposited by a print head onto the successive layers	-Sandstone -Metal -Ceramics	-Models -Prototyping	- Multi-coloured technology for non-functional models	- Not suited for functional parts	Example AM machine Min. layer thickness:0.09 mm Building volume: 250 x 381 x 200 mm Standard accuracy: ± 0.15 mm

Table 19: Summary of Specific Additive Manufacturing Technologies (own creation)

5. AM Applications for Security and Defence

Due to its ability to eliminate several of the design limitations associated with traditional manufacturing technologies, additive manufacturing has many applications in the field of security and defence. In order for this document to provide an overview of these capabilities, and to provide examples illustrating their possible applications, **this section consists of a classification of applications based on three broad groups: design and development of products for security and defence; the use of technology in field applications; and the use in applications in logistics and support centres (in-house applications).** Note: this is no intended to be a complete review of all possible applications of AM in the context of defence, but a showcase of those that are most relevant and realistic.

First-level applications		**Second level applications-specific applications**
Design and development for Security and Defence	**New products/designs**	- Products/designs not feasible by traditional manufacturing techniques - Non-functioning prototypes - Testing - Manufacturing planning - Customization and savings
	Process/design Optimisation	- Topologic design, structural reinforcement, weight reduction
	Prototyping/small series manufacturing	- First series manufacture and testing of new products - Modification testing
	Manufacturing of serialized products	- AM for "real" parts and products
Field operations support	**Strategic and tactical planning**	- Improving information in the field/field reconnaissance (AM robots/drones) - Operations Planning (3D mock-ups)
	Troops field support	- Equipment customization and accessories - Soldier health monitoring (Sensors/Smart Textiles, printed electronics, etc.) - Specific nutritional needs (AM food) - Field assistance (AM robots/drones)
	Humanitarian Aid/Catastrophe assistance	- Terrain reconnaissance (AM robots/drones): search for survivors - Accessory manufacture - Simple repairs - On demand shelters - 3D printing training
	Isolated operations (submarines, ships, etc.)	- Parts manufacture/replacement - On demand solutions
In-house operations	**Maintenance/repairs**	- Vehicle/machine maintenance and repair - Vehicle/machine customization/accessories - Manual tools

First-level applications		Second level applications-specific applications
	Medical	- Bio printing (e.g.: skin) - Implants - Prostheses/orthoses - Surgical planning and surgical tools
	Construction	- “On demand” structures
	Training	- Adapted control boards for machine/vehicle training - Training (e.g. improvised explosive devices, mines, etc.)

Table 20: Additive manufacturing applications for defence (own creation)

5.1. Design and Development for Security and Defence

5.1.1. New Products/Designs

Certainly, one of the most important advantages of the “layer by layer” manufacturing concept is its **ability to eliminate much of the design constraints present in traditional manufacturing technologies**. This new manufacturing concept makes it possible to make designs with until now impossible geometries, to design and test functional prototypes quickly, to increase the number of design iterations and to speed up the overall process. Additive manufacturing has quickly become a key tool in the creation of new products or the refinement of existing ones, thus increasing the pace of product development and at the same time optimizing the associated costs of generating new products. The variety of products is increased along with the capacity for adapting them to the needs of the user. In the area of security and defence, the applications of AM in the development of new products are virtually innumerable and cover all stages of design including: **the manufacture of non-functional models** during conceptual design; **the manufacture of real scale/functional scale prototypes** in plastic and metallic materials during the test phases; and the production of colour prototypes able to show the distribution of mechanical and heat stresses, etc. in simulation phases.

Selected cases:

UUV's models[32]

For MSubs, a company focused on design and manufacture of submersible vehicles, the manufacture of large scale test models was an essential step in their product development process. Traditionally, they had made extensive use of model makers to produce a limited number of prototypes, each one at high cost, with long production times and inferior mechanical properties (the prototypes tended to be fragile), so they decided to test additive manufacturing for this purpose.

MSubs decided to trial additive manufacturing for the production of their test models and contracted the Additive manufacturing Services of 3T RPD Ltd (UK), resulting in five 1 m long plastic models, costing the same as one traditionally made model.

Synthetic skulls for new defences against blast waves[33]

In this case, AM is not directly being used to make new products, but to recreate the part of the body to be protected from the specific risk of a blast wave. 3D printed skulls are being created by US Army Lab researchers to test products in laboratory experiments that mimic combat-like blast events and develop to prototypes of military helmet pads, shells and other protective equipment.

5.1.2. Process/Design Optimization

No matter the industry, improvement and the increase in competitiveness is often not so much linked to the generation of new processes and products as to the revision of existing ones to improve their characteristics, especially in the search for time and cost savings in the production process.

In this area, there are many specific aspects in which the additive manufacturing greatly contributes to the optimization of the redesign and production processes. One of these is the **reduction in the use of materials.** Particularly in the aerospace industry, there is a growing need to provide structures and components of greater lightness and resistance, which is only possible through technologies capable of manufacturing geometries impossible using traditional methods. The resulting elements

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[32] *Original source:* https://www.3trpd.co.uk/portfolio/submergencemsub-uuvs-modelled-using-am/gallery/defence-case-studies/*. The image used for illustrating this application is courtesy of 3T RPD Ltd.*

[33] *Original source:* http://www.3ders.org/articles/20140808-us-army-to-3d-print-synthetic-skulls.html/*. The image used for illustrating this application is courtesy of the U.S Dep. Defense. The appearance of U.S. Department of Defense visual information does not imply or constitute its endorsement.*

use less material and are therefore lighter, reducing fuel/energy consumption, increasing manoeuvrability and lowering the environmental impact.

Design changes are another aspect in which the additive manufacturing technologies represent a considerable qualitative leap. For example, the high cost of new moulds or tools can act as a deterrent to change in a product's design. **Additive manufacturing allows quick production and manufacture of new prototypes** with which to carry out the required tests prior to final validation of the new product, thus reducing the overall cost of the new design. In this sense, **additive manufacturing is a basic tool for reducing and rationalizing the cost of the product redesign processes**, increasing the capacity of a producer to improve product design.

Selected cases:

Nacelle hinge brackets lightening[34]

An element as apparently insignificant as a nacelle hinge bracket is the perfect example of additive manufacturing being able to significantly improve existing products. In this case, a combined project between EOS and Airbus (EADS) led to a redesign that not only was able to achieve a reduction in weight and a change of material for this part (from steel to titanium), but also to reduce the overall cost.

This redesign reduced the consumption of raw materials by 25% and the CO_2 footprint over the whole lifecycle by almost 40% and resulted in a weight saving of approximately 10 kg per plane, something not achievable for this part with traditional manufacturing technology (rapid investment casting).

New Fuel Tank for a Lockheed Martin Satellite[35]

In 2012, Lockheed Martin SSC (Space Systems Company) was aiming to improve an existing satellite by redesigning its fuel tank in order to increase payload capacity. When evaluating the most appropriate course of action, it was found that traditional CNC (Computer Numerical Control) machining for prototyping and testing was not an option due to cost and time constraints. Using a large format FDM (Fused Deposition Modelling) machine from Stratasys (Stratasys Fortus 900 MC), thermoplastic prototypes of the redesigned tank were produced. The considerable size of the tanks (up to 2 x 1.1 x 1.1 m) meant that the prototypes had to be manufactured in different sections that were subsequently assembled using fixtures that were also AM manufactured.

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[34] *Original source:* https://www.eos.info/press/customer_case_studies/eads. *Image courtesy of Airbus*

[35] *Original source:* https://3dprinting.co.uk/case-studies/lockheed-martin-3d-prints-a-large-prototype-fuel-tank/

5.1.3. Prototyping/Small Series Manufacturing

A product may be designed knowing that a large volume of production will not be required, but rather what are commonly called short series or limited series. This may be due to a number of reasons, but is normally due to the need to develop a limited set of prototypes for further evaluation or the need to respond to a requirement that can be satisfied by a reduced number of units (a few tens or hundreds).

In any of the above cases, as in almost every industrial activity, cost always acts as one of the main limitations when considering the production of a short series. Regardless of their technical capacity, traditional manufacturing technologies are not always suitable options from this point of view, since the principle of "cheap for high production volumes, expensive for low" often applies. This is due to the fact that their consumption of material, energy, demand for tooling, post-processing etc., usually bring with them costs that can only be amortized over a high number of units, significantly increasing the unit cost if the series is short.

In this way, and not always for purely technical reasons, **additive manufacturing is today a basic tool for this type of application, as it allows the quick and cost-effective manufacture of demonstration units or short runs of new products.**

Selected cases:

40 mm M203 grenade launcher[36]

RAMBO is an acronym for Rapid Additively Manufactured Ballistics Ordnance, the result of a six-month project that led to a prototype of grenade launcher similar to the US Army's M203. All 50 parts of the gun, with the exception of the springs and the fasteners, were 3D printed out of steel, aluminium and other materials. The ammunition used in the later test was also 3D printed, obtaining a performance similar to the serial model.

Russian research group successfully tests 3D printed bullets[37]

Using powder metal laser sintering technologies, Russian researchers have 3D printed bullets that perform similarly to traditional bullets. The process is slower than traditional methods, but it could

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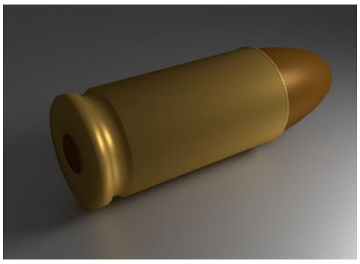
[36] *Original source:* https://gizmodo.com/the-armys-new-3d-printed-grenade-launcher-is-straight-o-1793135356*. The image used for illustrating this application is courtesy of the U.S Dep. Defense. The appearance of U.S. Department of Defense visual information does not imply or constitute its endorsement.*

[37] *Original source:* http://www.3ders.org/articles/20161113-russian-research-group-successfully-tests-3d-printed-bullets.html*. The image used for illustrating this application is by Childish Giant under Creative Commons CC0 licence. url:* https://pixabay.com/es/bala-pistola-munici%C3%B3n-metal-848208/

be used to create specific designs or moulds for multiple bullets. However, it illustrates the dangers associated with individuals having access to 3D printable weapon designs.

Marine Corps Developing 3D Printed Munitions for Greater Precision[38]



The US Marines Corps is experimenting with 3D printing for making customized explosives. Capt. Chris Wood, the co-leader for 3D printing for Deputy Commandant of Installations and Logistics explained: “One of the benefits of being able to precisely control the way that a munition or warhead is ‘grown’ through additive manufacturing is that we think we’ll be able to tailor the blast and associated fragmentation to achieve specific effects for particular targets, heights, collateral damage, or even environmental considerations.”

US Navy’s Trident II D5 Missile[39]

A 3D printed component has been used in a test flight for a high-tech upgrade to the US Navy’s Fleet Ballistic Missile program. The one-inch wide aluminium alloy connector back shell component protects vital cable connectors in the missile and was designed and manufactured entirely using 3D design and 3D printing in half the time it would have taken using traditional methods.

Adapters for infrared beacons for soldier identification[40]

Based on experience coming from soldiers in the field, the US Army’s Expedition Laboratory (Ex Lab) developed additional adapters for infrared beacons for Edgewood Chemical Biological Center's (ECBC) Advanced Design and Manufacturing Division (US Army) enabling ECBC to print the adapters on its own 3-D printers, freeing up the Ex Lab's printer.

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[38] *Original source: https://3dprint.com/151257/marines-3d-printed-munitions/. The image used for illustrating this application is courtesy of ChildishGiant under Creaive Commons CC0 licence.*

[39] *Original source: https://3dprint.com/125470/navy-trident-missile-launch/. The image used for illustrating this application is courtesy of the U.S Dep. Defense. The appearance of U.S. Department of Defense visual information does not imply or constitute its endorsement.*

[40] *Original source: https://www.army.mil/article/178822/army_explores_3_d_printings_future_applications_for_soldiers_force. The image used for illustrating this application is courtesy of the U.S Dep. Defense. The appearance of U.S. Department of Defense visual information does not imply or constitute its endorsement.*

5.1.4. Manufacture of Serialized Products

The application of additive manufacturing technologies to the production of serial products is perhaps one of the most ambitious and important applications of these technologies. Its advantages over traditional manufacturing technologies include: less design restrictions, high product customization capability, less investment in tooling and equipment, shorter time to market. However, there are a number of drawbacks: the use of these technologies for high volumes of production is often costly compared to traditional technologies, there is a smaller variety of materials, they are not always as precise as necessary and from a quality point of view, these technologies are not always capable of providing the reliability of equivalent parts manufactured using conventional technologies.

The disadvantages of additive manufacturing technologies for use in the serial manufacture of products are therefore not insignificant, but in all cases, there are continual advances, which are progressively making these technologies increasingly technically capable and economically competitive. In conjunction with developments in other fields such as standardization and certification, **we will no doubt soon see AM increasingly being introduced into a multitude of fields as a production tool, and no longer only used for development**, testing and validation, or as a prior step to industrialization based on conventional technologies.

Selected cases:

AM for missile production[41]

The consideration of additive manufacturing for serial production is already advanced in the field of missile and propulsion systems. Companies such as MBDA and Raytheon are already including partial AM elements in their products and in the medium term it is quite feasible that these systems may even be manufactured on-site, radically changing traditional supply chains.

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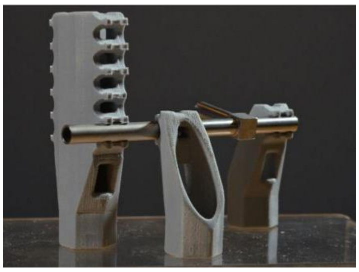
[41] *Original source: http://www.3ders.org/articles/20160714-entirely-3d-printed-missiles-on-the-horizon-says-raytheon-missile-systems-president.html. The image used for illustrating this application is courtesy of the U.S Department of Defense. The appearance of U.S. Department of Defense visual information does not imply or constitute its endorsement.*

Thales puts satellites in orbit with 3D printed elements[42]



In 2015, Thales Alenia Space produced the first antenna mount built in aluminium using additive manufacturing technology and since then, Thales has continued to use this technology for its manufacture of sockets and supports. In January 2017, the company launched into orbit satellites (of the constellation Iridium Next) that contained 79 metallic pieces and 350 tube supports manufactured by additive manufacturing technologies.

5.2. Field Operations Support

5.2.1. Strategic and Tactical Planning

Throughout the history of mankind, technological, productive and logistical capacities have always been decisive when deciding the outcome of many situations of conflict. Together with the value of human resources and their commands, production capacity and the ability to deliver that production to where it was required have historically been key to success or failure.

The flexibility of additive manufacturing therefore represents a significant paradigm shift, providing a considerably greater capacity to design, manufacture, test and implement parts and products "on request"; either on a small scale (e.g. ad-hoc spare parts) or on a large scale (accelerating the development of new devices, vehicles, parts, etc.). Their capacity to **expedite the deployment of new products, change the policies and logistics of the supply chain and to diversify, relocate and bring production centres to where they are needed** is clear.

The examples quoted have impacts at a global level on the value chains involved in strategic and tactical defence processes, but there are also deployment applications, such as terrain reconnaissance as a means to obtain planning intelligence. Here, one of the most immediate applications is the construction and customization of simple drones and unmanned aerial vehicles (UAV), which together with suitable electronic means (the latest advances in consumer electronics are remarkable) allow the design and manufacture of these devices on the ground. In the field of operations planning, the ability of these technologies to quickly and cost-effectively produce scale models and reproductions of terrain, vehicles, units, etc., can be an important planning aid.

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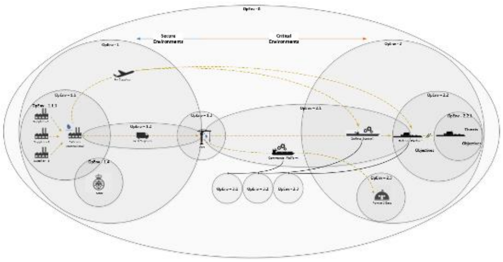
[42] *Original source:* http://www.infoespacial.com/es/2017/05/19/noticia-thales-puesto-orbita-piezas-metalicas-realizadas-impresion.html. *Image courtesy of Thales Alenia Space.*

Selected cases:

3D printed drones for soldiers[43]

Additive manufacturing can be used to custom-make reconnaissance drones for planned missions. When a UAV is required, the soldiers can input the requirements into the mission planning software which digests the information, configures the vehicle and it is printed within 24 hours.

Additive manufacturing for improving logistics[44]



The ability to produce elements on site or in distribution centres closer to their end use is without doubt one of the main operational improvements that additive manufacturing technologies will bring. In recent years, the deployment of additive manufacturing capabilities on site (e.g. by the US Army's Rapid Equipping Force and USS Essex) have provided just a few examples of the technology's ability to eliminate the transport and storage of products. With the continued advancement of these technologies, this ability will undoubtedly be expanded, with a clear potential for profound change and improvement of military logistics systems in the near future.

China's military use of 3D printing for better landscape visualization[45]

3D printing can be used to gain a better understanding of a particular geographical area. In 2014, the Chinese army used this technology to create 3D printed tactical land maps of the city of Lanzhou (capital of Ningxia Hui Autonomous Region) instead of the more costly and slower traditional layout technique.

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[43] *Original source:* http://www.tctmagazine.com/3D-printing-news/us-army-research-engineers-3d-printed-drone-soldiers/. *The image used for illustrating this application is courtesy of the U.S Dep. Defense. The appearance of U.S. Department of Defense visual information does not imply or constitute its endorsement.*

[44] *Original source: Alessandro Busachi et al. PhD. Modelling Applications of Additive manufacturing in Defence Support Services. Image courtesy of Alessandro Busachi.*

[45] *Original source:* https://www.3ders.org/articles/20140223-china-military-uses-3d-printing-to-better-visualize-landscapes.html

5.2.2. Troop Field Support

There are a number of aspects in which additive manufacturing can increase the capacity of human resources deployed in a particular situation or theatre of operations:

- Customized equipment. In many areas, although certain products have different variables and options, there is no real adaptation to individual consumers. For example, in the field of ergonomics, all products have dimensions and characteristics made to suit as many people as possible, without being adapted to any one person or their particular needs. The ability of additive manufacturing to give rise to adapted products is important, increasing the enjoyment of a product designed for the user's individuality, not for the generality of people.

- Field assistance. Additive manufacturing facilities deployed in a theatre of operations will equip human resources with the capability to manufacture parts, spare parts and small devices (such as small drones). Together with design and engineering skills, AM will enable improvisation and, in essence, give a greater capacity for adaptation to the changing needs of the environment.

- Monitoring of information. The concept of additive manufacturing is progressively being implemented in areas such as sensor systems and intelligent fabrics, making it viable to carry out data monitoring (e.g. tracking vital signs of the troops) on the ground.

- Adapted food. Another field in which additive manufacturing is being developed is the 3D printing of food, and not just from a gastronomic/culinary point of view. The principle of layer by layer manufacture will also apply to the manufacture of food with selected nutrients, adaptable to the needs of each situation.

Selected cases:

Field Assistance (maintenance/repair)[46]

Although its capabilities and possibilities are still at test stage, small deployable on site productive facilities containing additive manufacturing technologies are starting to be used to meet the needs arising in the field of operations. One of the most interesting cases is that of the United States Army, which deployed such an installation in Afghanistan in 2014 (US Army's Rapid Equipping Force fabricated laboratories).

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[46] *Original source: https://3dprint.com/165561/3d-printing-in-the-military/. The image used for illustrating this application is courtesy of the U.S Dep. Defense. The appearance of U.S. Department of Defense visual information does not imply or constitute its endorsement.*

One of its achievements was solving an impediment of the horizontal movement of the M249 (light machine gun) due to the bipod attachment. “In less than one week, the Lab developed and fit a new attachment that extends the range of M249 movement.”

AM Breaching Tools[47]

Illustrated by the image on the right, US Army Ex Labs designed and produced this breaching tool, mainly used for opening doors and crates, cutting wires, etc. Based on soldier feedback, first design iterations evolved to different “product” versions, with the Ex Lab team adding contouring to the handle for safety and grip, quick change blades, and hex holes in the handle (in order to make the tool usable as a wrench).

Soldier meals[48]

While it may appear that additive manufacturing is intended for applications more related to parts or structural elements, its ability to selectively add material is being investigated, giving rise to applications in the field of food. Researchers at the Engineering Centre (NSRDEC) in Natick, Massachusetts are developing new MRE (meal ready to eat) concepts tailored to the nutritional needs of each soldier.

Rifle fastener[49]

A replacement element for fastening a rifle inside a vehicle door was designed and produced thanks to an AM machine deployed by Netherlands Defence Material Organisation in Mali in 2017. Based on the geometry of the door and of the rifle itself, a fastening element was designed that could adapt to both. Once the 3D file of the new piece was produced, it could be manufactured and implemented as a replacement for the original part.

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[47] *Original source:* https://www.army.mil/article/178822/army_explores_3_d_printings_future_applications_for_soldiers_force. *The image used for illustrating this application is courtesy of the U.S Dep. Defense. The appearance of U.S. Department of Defense visual information does not imply or constitute its endorsement.*

[48] *Original source:* https://3dprint.com/118070/us-army-3d-print-custom-meals/

[49] *Original source: Nederlands Defence Materiel Organisation. (2017). Article "Seeing is believing".* https://magazines.defensie.nl/materieelgezien/2017/03/mg2017033d-printer

5.2.3. Humanitarian Aid/Catastrophe Assistance

In previous points, the improvisational capacity provided by additive manufacturing technologies was already mentioned. Given an adequate means of production, and supported by design and engineering capabilities, they can enable a rapid response to a changing situation. The context of humanitarian action/disaster response is one of the areas where these capacities may be most important, as the **welfare of people affected by a disaster or in an adverse situation may depend on the ability to quickly address their needs.**

Specific examples include:

- Manufacture of tools and simple accessories, not always available or with unreliable supply: hand tools, utensils as simple as glasses or cutlery, carabiners, clips, etc. Elements that may become essential at any given time.
- Spare parts supply. In situations of shortage, many people may depend on the correct functioning of a single machine or device, which if damaged and in the absence of spare parts may cause them to become endangered. A technology that can make spare parts in a short space of time can be the key to preserving the welfare of people in adverse situations.
- Training. Many of these situations happen in places of conflict, where the presence of mines and potentially deadly artefacts (unfortunately increasingly, including improvised explosive devices) is common. By means of additive manufacturing, it is possible to manufacture replicas of these risky devices in order to train people in their identification and to form deactivation/control teams, without entailing any risk to the people.
- Shelter. The concept of additive manufacturing is extending to construction, from the construction of complete structures in materials such as cement and mortar, to the manufacture of building blocks.

Selected cases:

Simple solutions that can make the difference[50]

In April 2015, an earthquake of 7.8 on the Richter scale caused the death of thousands of people and injured more than 20,000 in Nepal. One of the main problems that arose in the days following the earthquake was leaks in the improvised water distribution system in the refugee camps, which were being repaired by means as unreliable as tape and plastic

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[50] *Original sources:* https://3dprint.com/113155/field-ready-nepal-earthquake/ *and* http://www.rapidreadytech.com/2015/01/field-ready-prints-humanitarian-aid-in-haiti/. *The images used are courtesy of Field Ready Humanitarian Supplies Made-in-the-Field.*

bags. The design and fabrication of a gasket using a simple desktop printer helped alleviate the problem, providing a reliable and durable solution.

The 2010 earthquake in Haiti also affected millions of people and caused (and still causes) medical facilities to suffer from logistical and other problems that make it difficult to resupply specific items. Thanks to the printing of umbilical cord clamps, local midwives are now able to clamp the cord of mothers giving birth in remote areas who were unable to reach a hospital.

3D printing for building structures[51]

The US Army Construction Engineering Research Laboratory (CERL) successfully printed a 50 m² concrete structure, thanks to an AM technology called "Automated Construction of Expeditionary Structures" (ACES) aimed at printing semi-permanent structures in the field of operations. CERL is currently working with NASA to design, build, and test a third-generation concrete.

5.2.4. Isolated Operations (submarines, ships, etc.)

In defence, the implementation of additive manufacturing technologies in a context of isolation is one of the areas where these technologies can have a more direct application. In this case, the potential of these technologies is very much in line with that already described for applications in the field of humanitarian aid/action in the event of catastrophe. However, one of its main virtues is the improvisational capacity and the applications previously described in that case are fully transferable to this field. However, there are situations of prolonged isolation (for example in a ship) in which these technologies may have added values, beyond improvisation. **The presence of a means of additive manufacturing in this type of situation can lead to the development of "embedded projects", arising in response to medium and long term needs in that context of isolation.**

Selected cases:

First US Navy Warship with a 3D printer[52]

In 2014, the amphibious assault ship USS Essex installed a permanent 3D printer that has since been used for various purposes: manufacturing elements such as disposable medical supplies; new parts for existing resources (e.g. a new cap for an oil tank); and even small custom 3D printed quadcopters. In this last

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[51] *Original source:* https://www.army.mil/article/192824/army_enhances_3_d_technology_to_build_structures. *The image used for illustrating this application is courtesy of the U.S Dep. Defense. The appearance of U.S. Department of Defense visual information does not imply or constitute its endorsement.*

[52] *Original source:* http://breakingdefense.com/2014/04/navy-carrier-is-taking-3d-printer-to-sea-dont-expect-a-revolution/. *The image used for illustrating this application is courtesy of the U.S Dep. Defense. The appearance of U.S. Department of Defense visual information does not imply or constitute its endorsement.*

case, files and models of the drones were sent to the ship via satellite connection, so once 3D printed and assembled with electronic components that were already stored on the ship, this device could be used for reconnaissance purposes.

AM Radio Clasp aboard USS Harry S Truman[53]

Self-sustainability at sea is a major priority and a reason why this particular branch of the military might home in on the benefits of 3D printing. The USS Harry S. Truman's on board Fab Lab redesigned handheld radio clasps that were constantly breaking. This resulted in a fast replacement while also saving a considerable amount of money. As Lt. Casey Staidl declared "It doesn't look pretty, it's not a real sexy innovation, but that alone has saved us a ton of money. In the past 2½ years, Truman has spent $146,000 just on these pigtail attachments alone."

A wheel gear manufactured aboard PLA's Harbin Destroyer[54]

China is also testing and implementing additive manufacturing for repair jobs. Towards the end of 2014, the Harbin Destroyer suffered from the breakage of a wheel gear while performing counterpiracy manoeuvres in the Gulf of Aden, Arabian Sea, leaving the ship with a diminished capability to manoeuvre. Fortunately, this ship was equipped with additive manufacturing means and fully equipped for producing the required spare part.

5.3. In-house Operations

5.3.1. Maintenance/Repairs

The combination of facilities to manufacture replacement parts and to repair existing parts is perhaps one of the factors with a greater transformative potential in terms of value chains associated with the field of defence, a field that is highly resource intensive and therefore very demanding of solutions that ensures the best outcome every time.

Thus, **the ability of additive manufacturing to replicate a part at any time is one of its most important characteristics and applications**, since even in the absence of the original 3D design, with the appropriate scanning technologies it is possible to replicate it. This gives technology owners an unprecedented capacity and autonomy for the maintenance and repair of their resources, a task that

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[53] *Original source:* https://editorial.3dprint.com/136997/uss-harry-s-truman-3d-lab/

[54] *Original source:* https://3dprint.com/35981/china-pla-navy-3d-printing/. *Image by DoD photo by Petty Officer 2nd Class Felix Garza, U. S. Navy [Public domain], via Wikimedia Commons.*

historically depended on a supply structure and logistics that was often detrimental in terms of time and cost.

Although 3D printing technologies are, in the collective imagination, very closely linked to the manufacture of a part/product from scratch, the great variety of existing technologies also makes some of them particularly suitable for the repair and re-processing of existing parts. This is the case of additive manufacturing technologies based on Fused Direct Energy Deposition (FDED), capable of adding the worn/lost material in the section of the part where is necessary.

Selected cases:

Keeping old planes active with additive manufacturing[55]

The Israeli Air Force's Aerial Maintenance Unit (AMU) is utilizing in-house 3D printing technology to help repair their aging fleet of F-15 fighter jets. In order to make replacement parts, the AMU uses a 3D camera to produce a 3D file that can be quickly printed. Although metal 3D printing is widely used, AMU has been using plastic polymer materials that have good strength and performance while operating in mid-air.

Repair of worn elements[56]

The cost and lead times for replacing certain elements (a M1 Abrams tank turbine, M911 and M1070 Heavy Transport Systems spindles) using traditional manufacturing technologies were considerably high, so the US Army evaluated the possibility of making repairs using additive manufacturing technologies instead of manufacturing new parts. This achieved a significant reduction of costs and lead-time in all cases.

5.3.2. Medical

The capacity of additive manufacturing to give rise to **personalized products and elements is undoubtedly the most important element in assessing its value in the field of medicine**, where three very clear fields of applications can be highlighted:

- Surgery planning: there have been many cases in which the complexity of the injuries or diseases of a patient have required the manufacture of replicas (skulls, hearts, faces, etc.) to enable familiarisation and to develop a strategy for a subsequent surgical intervention in order to increase the chances of success.

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[55] *Original source: https://3dprint.com/130515/iaf-3d-printed-parts/. Image courtesy of the Israel Defense Forces. The appearance of Israel Defense Forces visual information does not imply or constitute its endorsement*

[56] *Original source:* http://www.sme.org/uploadedFiles/Smart_Manufacturing_Education_Series/Nikodinovski.pdf

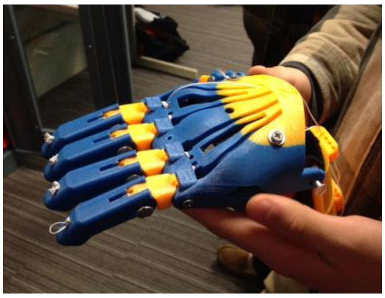
- Prosthetics and implants: as a result of the freedom of design that additive manufacturing technologies provide and the development of AM materials that are light and biocompatible, AM is making a considerable impact in this field. In conjunction with the progressive advances in biomechanics, it is realistic to imagine a not so distant future where the functionality of a lost or impaired body part can be replicated with high fidelity by a prosthesis.

  While we are a long way from being able to bio-print complex organs, recent advances are resulting in simpler organs such as skin, and in materials that form part of living tissue, such as collagen.

- Surgical tools. Surgery requires a wide variety of tools which through the use of additive manufacture can be created, customized and adapted to the needs of the operation and to the surgeon, greatly increasing the chances of success of the operation.

Selected cases:

E-NABLE Community[57]



The e-NABLE Community is a group of individuals from all over the world that aims to use 3D printers to create free 3D-printed hands and arms for those in need of an upper limb assistive device, focusing especially on children and war veterans. This project has created several files and tutorials for the design and manufacture of adapted and cheap prosthesis for people with impaired upper limbs, taking into account functional diversity (providing wrist powered, elbow powered, and single finger designs).

US Military aiming to digitalize soldiers for body "replacements"[58]

The US Military is collaborating with the University of Nevada to create 3D digital copies of its soldiers in order to be able to use the data for medical purposes. One of these purposes would be the construction of adapted replacement structures, such as elements lost, bone fragments and, in the future and with more advanced bio printing technologies, soft tissues.

5.3.3. Training

Although the most interesting applications of additive manufacturing are commonly related to the manufacture of product parts and functional prototypes, there are other groups of applications that are also interesting, including the field of training. The **ability to manufacture functional models that represent real elements is an important support to training programs with** representations adapted

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[57] *Original source:* http://enablingthefuture.org/, *Image courtesy of Weston High School Library under Creative Commons CC BY-SA 2.0 licence.*

[58] *Original source:* http://www.globalfuturist.org/2017/01/digital-clones-will-let-us-army-3d-print-new-body-parts-in-battle-to-treat-injured-soldiers/

to the needs of the trainer. In the field of simulation, the development of new devices and vehicles, as well as the training of personnel for their use, can be supported by the manufacture of simulators using additive manufacturing technologies, with very low costs in comparison with traditional manufacturing technologies.

DDDM saves USD 800,000 and 3 years development time[59]

Trainer Development Flight (TDF) is a facility that designs, develops and manufactures training aids for the US Air Force and all branches of the US Department of Defense. These items are used in numerous training environments, including avionics, weapons and fuel systems, medical readiness, HVAC (heat, ventilation, and air conditioning) and telecommunications systems. “Because most of our projects are either one-of-a-kind or very low volume, conventional methods become very expensive”, commented Mitchell Weatherly, Chief of the TDF. The TDF uses direct digital manufacturing to fabricate the majority of its training products.

Using 3D printing to help clear landmines[60]

Removing landmines in all affected countries would have an enormous cost in terms of both money and also human lives. With the help of MIT and the Singapore University for Technology and Design, a kit of a suitcase containing ten 3D printed replicas of explosive devices has been designed. Landmine clearing workers can use them to train in the deactivation of mines instead of learning from books or PowerPoint presentations.

3D printing for improvised explosive devices identifications and deactivation[61]

The Terrorist Explosive Device Analytical Center, a part of the US Federal Bureau of Investigation (FBI), focused on analysing and investigating explosive devices. In order to be able to study the growing number of explosive devices, which its operatives had to face, in 2014, they acquired a machine capable of manufacturing parts in different opaque and transparent plastic resins, with which they have since been able to reproduce and study different improvised explosive devices (IEDs) and train people in their handling.

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[59] *Original source:* https://3dprinting.co.uk/wp-content/uploads/2016/09/case-study-sheppard-air-force-base.pdf

[60] *Original source:* https://3dprint.com/97417/rid-world-of-landmines/. *Image courtesy of AOTM.*

[61] *Original source:* http://www.3dprinterworld.com/article/fbi-use-3d-printing-for-bomb-research. *The image used for illustrating this application is courtesy of the U.S Dep. Defense. The appearance of U.S. Department of Defense visual information does not imply or constitute its endorsement.*

6. Current Capabilities of AM

6.1. An Overview of AM Capabilities for Defence

When conducting a general review of how existing capabilities in the field of additive manufacturing may respond to the current needs of the security and defence sector, it is first necessary to outline the **overall "map" of this technology when it comes to defence stakeholders**:

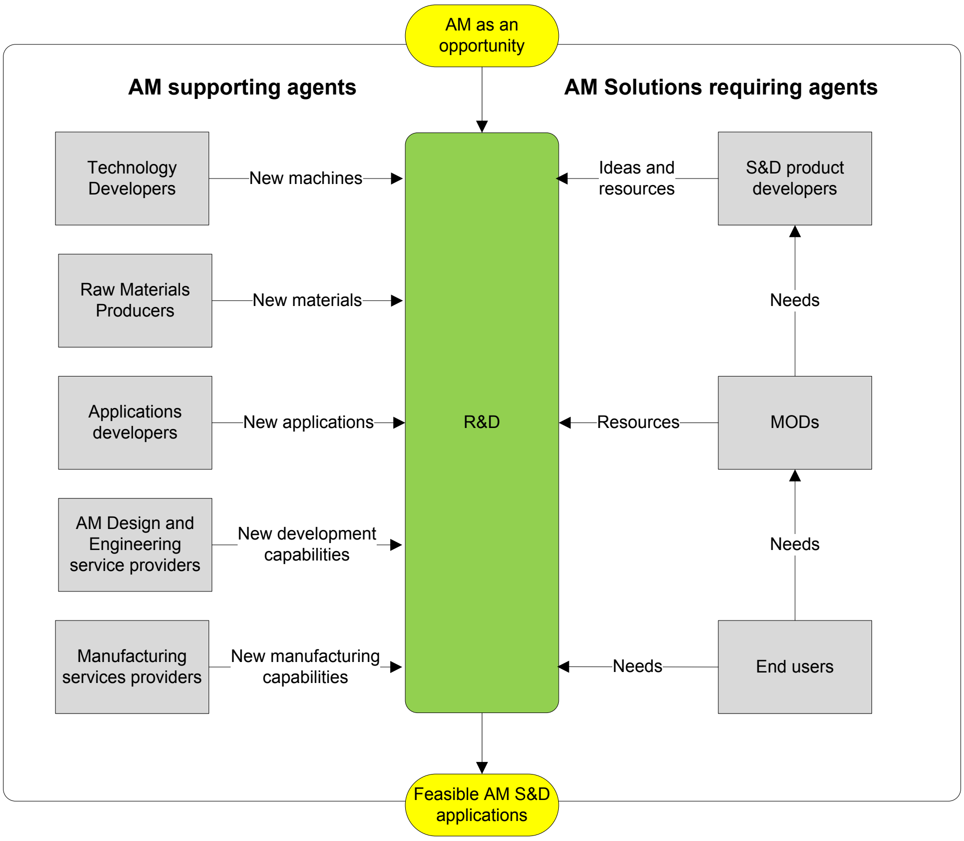

Figure 37: Stakeholders map regarding AM and S&D sector (own creation)

At present, two main groups of stakeholders can be identified:

- **S&D stakeholders that require or can benefit from AM solutions**:
    - Product and solution developers. To its full extent, the structure of suppliers that fuel the performance of the defence sector have the need and the ability to offer solutions and products that are progressively more competitive. Nowadays this

involves the ability to offer not only better products and solutions, but also significant improvements in customization and delivery capabilities.

  - MODs. The ministries of defence of different countries are essential agents for the implementation of any solution or product based on additive manufacturing technologies, since they have the capacity to assess needs arising from their command structure, while also having resources that can enable the provision of AM means and products.

  - End users. The end users at various levels in the defence sector (from field work to the logistics organization) are knowledgeable about the problems and needs of their work, and therefore are an important source of ideas when assessing the development of new products and solutions.

- **Agents that support the development of AM products and applications:**

  - Developers of AM technologies. Manufacturers that enable the move from the concept of layer by layer manufacturing to the supply of 3D printers, using a variety of technologies and materials.

  - Producers of raw materials for AM. Different additive manufacturing technologies require raw materials with specific characteristics. This has resulted in a range of material suppliers able to provide the necessary raw materials.

  - Application developers. Between the solution demanders and the technology developers, exist organizations with AM capabilities and with the scientific and technological experience to generate new applications with AM in mind. This is done with the aim of achieving technical improvements and competitive advantages over traditional manufacturing processes.

  - Design and engineering services specialized in AM. The characteristics of AM technologies mean that the design of products and services for their use must take into account a series of criteria and principles that demand expert knowledge.

  - Additive manufacturing services. To date, the considerable cost of AM equipment has resulted in the proliferation of organizations that, having made a considerable investment in this type of equipment, monetize it by providing 3D printing services to third parties.

Given the increasing importance of additive manufacturing technologies, their variety, and the variability of their applications, the environment of organizations associated with these technologies is increasing and changing. For this reason, a summary of the organizations that currently play a leading role in each AM technology or application would only serve as a partial representation of the environment of the organizations currently working in AM. That said, perhaps **the most representative phenomenon associated with additive manufacturing today is the development and**

implementation of online platforms that serve as hubs[62] **for accessing different additive manufacturing organizations and services.** Some of the most representative online services include: Shapeways, 3D Hubs, i.materialise, Stratasys Direct, Sculpteo, Protolabs and Ponoko. However, organizations such as Wohler Associates, regularly publish studies of the additive manufacturing environment and its evolution, through which it is possible to keep updated in further detail.

6.2. Significant Projects

Over the last few years, additive manufacturing has been a technology based on which numerous high interest projects have been developed, whose purpose has been to strengthen and consolidate the capacities that these technologies can bring to their potential users. In the area of public financial support, **European policies have traditionally centralized this support within the Framework Program schemes and the current H2020 scheme** (from which national and regional policies of the EU member countries are derived or greatly influenced). **Although these schemes do not specifically support military or defence projects, there are a number of projects that are worthy of mention**, as they generate results that will undoubtedly be applicable to the Security and Defence sector, and which are representative of the efforts made to evolve AM technology and bring it to full potential. These are[63]:

Project	Acronym	Years	Summary of Results	Budget
Additive Manufacturing Aiming Towards Zero Waste & Efficient Production of High-Tech Metal Products	AMAZE	2013 - 2017	The overarching goal of AMAZE is to rapidly produce large defect-free additively-manufactured metallic components up to 2 metres in size, ideally with close to zero waste, for use in the following high-tech sectors namely: aeronautics, space, automotive, nuclear fusion and tooling. The project will design, demonstrate and deliver a modular streamlined work-flow at factory level, offering maximum processing flexibility during AM, a major reduction in non-added-value delays, as well as a 50% reduction in shop-floor space compared with conventional factories.	EUR 18,295 541.46
MANufacturing decision and supply chain management SYStem for additive manufacturing	MANSYS	2013 - 2016	Twelve partners teamed up to develop e-supply chain management tools and facilitate the mass adoption of 3D printing, enabling businesses to move beyond current successes with plastic products to metal products. The supply chain management system accounts for all steps and options in the supply chain, providing a one-touch turnkey solution. MANSYS resulted in a decision support software assisting designers and engineers that do not necessarily have AM background or experience to decide whether 3D printing is applicable for specific metal AM parts.	EUR 4,405 531.92

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[62] *All3DP. (n.d.).* https://all3dp.com/1/best-online-3d-printing-service-3d-print-services/

[63] *Original source for the project list:* http://cordis.europa.eu/projects/home_en.html/

Project	Acronym	Years	Summary of Results	Budget
High resolution electron beam melting	HIRESEBM	2011 - 2015	To date, the design of metallic medical implants with porous structures is restricted by manufacturing technologies not being able to implement complex 3D geometries with high enough resolution. The HIRESEBM team modified a partner EBM system to achieve the smallest possible beam spot size (< 50 µm) and enhance the distribution of fine powders needed for implant manufacture. HIRESEBM's manufacturing technology will enable optimised bone ingrowth into titanium implants produced by project partners.	EUR 1,404 732
Future RepAIR and Maintenance for Aerospace industry	REPAIR	2013 - 2016	The EU-funded RepAIR (Future repair and maintenance for aerospace industry) project set out to reduce the maintenance, repair and overhaul (MRO) costs in the aerospace industry through AM with less waste and a shorter lead time. Condition monitoring and predictive health management concepts were adapted to AM parts triggering the MRO process, estimating remaining useful lifetimes of parts and facilitating demand driven scheduling.	EUR 5,979 564.01
High performance production line for Small Series Metal Parts	HYPROLINE	2012 - 2015	Within the EU-funded project HYPROLINE (High-performance production line for small series metal parts), researchers demonstrated a high-performance 3D printing production line for serial fabrication of customised high-quality small metal parts. Coupled with this line is a high-speed finishing line using laser polishing. HYPROLINE's sophisticated machine consists of a carousel unit that has room for 100 pallets and a robot that picks and places non-finished components, extracts finished products and adds specific modules. The pallets pass underneath a patented 3D metal inkjet printer (Digital Metal) on a fixed Z-axis. A key part of this machine is a laser scanner that compares the finished 3D prints with the 3D models used for them, while a laser ablation module polishes parts and removes any excess material.	EUR 4,017 939.50
Hybrid INDustrial CONstruction through a 3D printing "all-in-one" machine for large-scale advanced manufacturing and building processes	HINDCON	2016 - 2019	HINDCON project aims to adapt manufacturing technologies to the construction sector, advancing towards industrialisation, and overcoming the limitations of actual approach for introducing Additive and Subtractive Manufacturing in construction activities. The main aim of the HINDCON project is to develop and demonstrate a hybrid machine regarding 3D printing technologies with concrete materials focused on the industrialization of the Construction Industry, delivering to this sector an innovative technology that reduces environmental impact at the same time it reduces dramatically economic costs.	EUR 4,798 205
Development of ceramic and multi material components by additive manufacturing methods for personalized medical products	CerAMfacturing	2015 - 2018	The cerAMfacturing project will develop a completely new approach for ceramic multi material additive manufacturing which will allow series production of customised and multifunctional components for manifold applications for obtaining property combinations, like electrical conductive/electrical insulating, dense/porous or two-coloured components. The cerAMfacturing project will provide the technical equipment for combining AM steps with conventional ceramic shaping routes.	EUR 5,121 799.50

Project	Acronym	Years	Summary of Results	Budget
Driving up Reliability and Efficiency of Additive manufacturing	DREAM	2016 - 2019	The aim of DREAM is to improve significantly the performances of laser Powder Bed Fusion (PBF) of titanium, aluminium, and steel components in terms of speed, costs, material use, and reliability, also using a LCA/LCC approach, whilst producing work pieces with controlled and significantly increased fatigue life, as well with higher strength-to-weight ratios. The project, thanks to the three end-users involved, is focused on components for prosthetic, automotive, and moulding applications to optimize the procedure for three different materials, respectively titanium, aluminium, and steel.	EUR 3,242 435
Mini Factories for 3D printing of Large Industrial Composite Structures	3D-COMPETE		3D-COMPETE will provide the wind energy sector with a low-cost solution for manufacturing the complex and heavy structural parts of wind blades. The proposed innovation is the use of an additive manufacturing process, automated fibre placement (AFP), which will enable the automation of the process.	EUR 71,429
Additive manufacturing Optimization and Simulation Platform for repairing and re-manufacturing of aerospace components	AMOS	2016 - 2020	This project aims to conduct fundamental research to understand the material integrity through chosen Direct Energy Deposition (DED) Additive manufacturing processes, the accuracy and limitations of these deposition processes, effective defect geometry mapping and generation methods, and automated and hybrid Direct Energy Deposition Additive manufacturing (AM) processes and post-deposition machining strategies.	EUR 1,396 188.75
Flexible Mini-Factory for local and customized production in a container	CassaMobile	2013 - 2016	CassaMobile investigated a mobile, flexible, modular, small-footprint manufacturing system in a transportable container that can be easily configured for different products and processes. The container format allows on-site manufacturing anywhere, enabling the benefits of localised service delivery without duplication of equipment at multiple locations. The concept has been designed to fulfil demanding criteria for the production of customised, high value, high quality products including medical devices. The container has been developed to demonstrate three different use cases addressing (I) maker and educational communities, (II) medical orthotics and (III) individual industrial gripping and clamping products.	EUR 8,747 873.19
Industrial and regional valorisation of FoF Additive manufacturing Projects	FoFAM	2015 - 2016	FoFAM project takes up the challenge of clustering technology developments on AM and place them into defined value chains in lead markets for Europe. The project intends to identify gaps for business development and to attack them with specific actions and timeline. It also includes high involvement of European regions to ensure an efficient use of structural funds associated to them. FoFAM also address not only technological aspects but also aims at identifying other horizontal economical and societal issues that will be taken into consideration to ensure AM industrial deployment.	EUR 348,210

Table 21: selection of remarkable AM projects (own creation)

6.3. R&D Funding for Activities Based on Additive Manufacturing at the European Level

The current funding framework for boosting and supporting R&D activities at European level is currently composed of a number of instruments (mainly Structural and Investment Funds, Horizon 2020, COSME and ERASMUS+) which do not support the implementation of exclusively military projects, although they can support projects that are suitable for dual use (civil and military) provided that the basis is civilian use.

Navigating the above-mentioned instruments and understanding the scope of activities that might lend themselves to dual use and therefore fundable, is a task of some complexity. Publications such as "EU Funding for Dual Use: Guide for Regions and SMEs"[64] can shed light on the current possibilities of financing the development of dual-use AM applications in the civil and defence fields.

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[64] *European Comission. (2014). EU funding for Dual Use: Guide for Regions and SMEs.*

7. Looking to Patents to Measure AM Strength among Defence Industry

When it is necessary to evaluate the importance of a trend in the state of the art, **patents are an indispensable source of information, since they are directly linked to the commercial expectations placed on the solutions and products associated with a certain technology.** Thus, analysis of data such as the evolution of the number of patents applied for over the years, the main applicants, the main patent families, etc. is very useful. Thanks to the use of selected patent databases, valuable data can be obtained to establish the impact of a technology on the market and to predict the impact it may have in the coming years.

The strategy followed in this case has been based on a search that covers the main defence contractors[65] (Defense News 2016 list, which includes the 100 main contractors in the defence field in 2016 by turnover volume) with the theme (patent title/abstract) “additive manufacturing”.

Some of the most important conclusions are:

- Patent applications by year. The data show how, **since 2012, there has been a significant increase in number of patent applications by the main defence contractors**, doubling year by year:

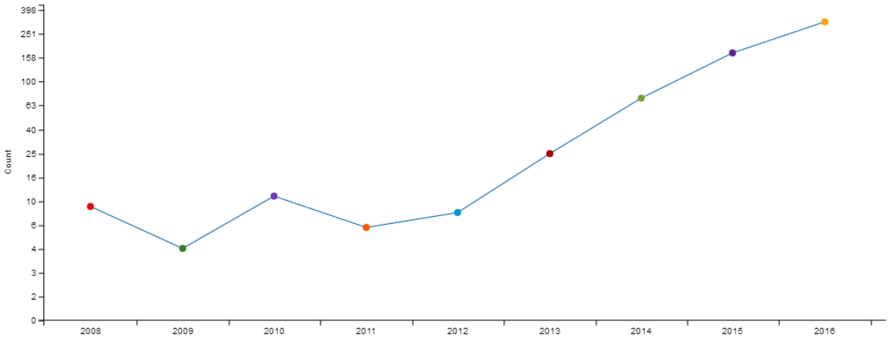

Figure 38: Time evolution of patent applications by AM TOP 100 subcontractor (own creation)

Comparing these figures with the total number of patents granted related to “additive manufacturing” in the same period, it can be seen that the **number of patents by this group of 100 subcontractors is significant, comprising 20% of the total number of AM patents granted** (it is remarkable that in 2008, all the patents granted were to defence

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[65] *Defense News.* http://people.defensenews.com/top-100/

contractors), indicating that the defence sector acts as an engine of development and implementation of the AM technologies.

Year	All AM citing patents	Top 100 Defence contractors	% Defence Contractors
2008	9	9	100.00%
2009	8	4	50.00%
2010	26	11	42.31%
2011	42	6	14.29%
2012	69	8	11.59%
2013	169	25	14.79%
2014	352	73	20.74%
2015	858	175	20.40%
2016	1451	319	21.98%

Table 22: Evolution of AM citing patents (own creation)

- Main Patent Applicators. It is also interesting to study who are the **most active defence contractors when it comes to patents** related to additive manufacturing:

Rank	Company	Country	2015 Defence Revenue (USD m)	2015 Total Revenue (USD m)	% Rev. Defence	Nº. AM-related patents
1	Lockheed Martin	US	40,596.00	46,132.00	88.00%	8
2	Boeing	US	30,388.00	96,114.00	31.62%	63
3	BAE Systems	UK	25,278.08	27,357.31	92.40%	38
4	Raytheon	US	21,619.71	23,247.00	93.00%	22
7	Airbus	Netherlands	12,776.10	71,539.50	17.86%	13
13	United Technologies Corporation	US	6,780.00	56,500.00	12.00%	369
14	Rolls-Royce	UK	4,790.28	19,795.40	24.20%	10
15	Honeywell	US	4,715.00	38,581.00	12.22%	53
45	Aerojet Rocketdyne	US	1,708.30	1,708.30	100.00%	14

Table 23: main defence AM citing patents applicants (own creation)

8. AM in the Field: Recent Experiences

From the point of view of potential applications in the S&D sector, perhaps the greatest immediate effect is currently being experienced in the area of product development, where the current capabilities of technology make it ideal for tasks related to the generation and manufacture of elements and products up to prototype phase. It is therefore worth highlighting experiences more focused on the **use of these technologies by end users within the sector** and the level of application currently achieved. Results may be less advanced but are totally illustrative of the future potential of this type of application in the medium term.

8.1. European Experiences

At European level, there are a number of very recent experiences that illustrate the potential uses of AM technology in the operations field:

- The major Defence R&D organization in Norway, the **Norwegian Defence Research Establishment (FFI)**, has recently developed a series of processes aimed at testing the capabilities of AM technologies and the possibility to deploy them in the form of standalone facilities. To this end, in 2016, a naval exercise in cooperation with the Norwegian Navy and MARCSS was carried out, in which 31 different objects were produced in a variety of plastic materials in an open water environment (on board the 2,100-ton patrol vessel KV Barentshav). This exercise allowed FFI to assess these technologies in an isolated and changing maritime environment.

Figure 39: KV Barentshav patrol vessel and some parts produced during the FFI AM naval exercise

- Another notable project in this country is the generation of mobile infrastructures capable of carrying and deploying additive manufacturing capabilities. In 2015 Fieldmade in collaboration with FFI (Norwegian Defence Research Institute) launched the **NOMAD** (Norwegian Mobile Additive Development) project that achieved a first minimum viable product (MVP) stage within Q1, 2016, consisting of a container equipped with additive manufacturing machinery and quality control facilities. Fieldmade have since developed a new unit that enables production of spare parts in polymer, composites and smaller metal components in one unit, this by leveraging both FDM and SLS AM processes in-field. This unit is anticipated to be tested in the first half of 2018 and has a planned attendance at NATOs TRJE18 in Q3, 2018. The NOMAD concept is focused on becoming one of the first commercial solution providers of in-field AM facilities and digital supply systems of content focused towards defence activities, thanks to the efforts made by the Norwegian company **Fieldmade AS**.

Figure 40: NOMAD AM facility (images courtesy of FieldMade)

- Already cited in section 6.2.2 as an example of AM applications in the field, the **Netherlands Defence Material Organisation** has recently developed an AM test facility in Mali[66], where an FDM AM machine was deployed and used for various cases. As part of this exercise, spare parts for non-essential elements were manufactured, including the development and manufacture of various fastening and adjustment systems, sleeves and other elements of current use.

  Perhaps one of the most illustrative cases was the development and manufacture of a replacement element for fastening a rifle to a vehicle, in substitution of a previously implemented makeshift solution which was found non-optimal. Based on the geometry of the vehicle's door and of the rifle itself, a fastening element was designed that could adapt to both and which could support a reasonable level of stress. Once the 3D file of the new piece was produced, it could be manufactured and implemented as a new and improved solution.

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[66] *Nederlands Defence Materiel Organisation. (2017). Article "Seeing is believing".* https://magazines.defensie.nl/materieelgezien/2017/03/mg2017033d-printer

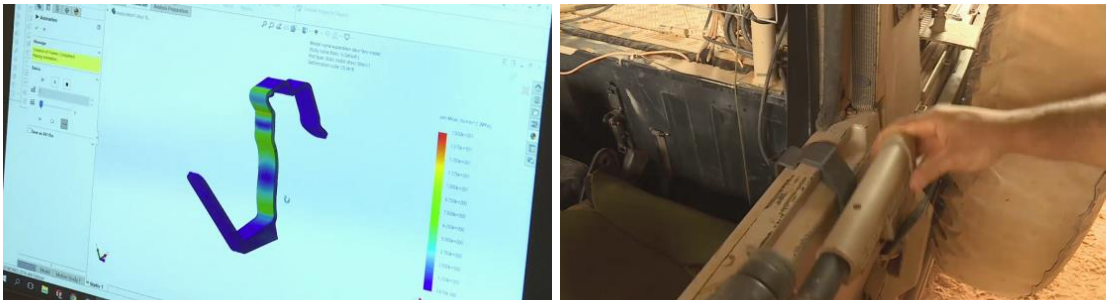

Figure 41: Example of part produced by the Netherlands Defence Material Organisation in Mali (images courtesy of Netherlands Defence Material Organisation)

- Related to the project giving rise to this document (**AMFaD**), a self-contained AM facility was developed in order to demonstrate the feasibility of deploying these technologies in support of military operations and to demonstrate the operational utility of AM technologies. The design of the 3D-printing lab included the selection of equipment that could be installed in a standard container, meeting the requirements of a military airlift.

Figure 42: AM facility deployed at Zaragoza (images courtesy of TankaLab)

In order to be considered deployable, the 3D-printing lab must be independent, self-contained and self-sufficient and must fully meet air transport regulations. To achieve these objectives, the **EDA 3D-printing Lab's** performance was tested prior to and during deployment, producing parts to demonstrate the utility of the facility. The simulated deployment scenario was the EDA-sponsored European Advanced Airlift Tactics Training Course (EAATTC 173), which took place in the **Zaragoza airbase (Spain)** during 22 May - 9 June 2017. The 3D-printing Lab was successfully deployed and the test flight of the AM lab was pivotal to demonstrating the feasibility of its deployment by air. During the deployment, the AM lab generated a lot of interest from the multinational units involved in EAATTC 17-3. The deployment also underscored the strong interest and potential of AM technologies across all military branches (pilots, maintenance, technicians, and logistical support).

8.2. The US Experience

The case of the armed American forces is worth analysing in greater detail, being the longest-lived AM implementation and being carried out by what may be considered to be the world's leading power in the field of defence[67].

In July 2012, a **Mobile Expeditionary Lab was sent to a U.S. Army base in Kandahar, in the south of Afghanistan, in order to provide onsite engineering capability in a remote area**. It was produced as a part of the army's three-year USD 9.7 million contract with a large engineering company, Exponent Inc. This Fablab was deployed by the Rapid Equipping Force, a U.S. Army organization that provides immediate technical assistance to soldiers and carried equipment such as a 3D printer and a device known as a Computer Numerical Control Machining system. The requirements of this project were numerous and included quick assistance to troops, creating prototype solutions and support during humanitarian emergencies.

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[67] *Global Firepower. (n.d.). 2017 Military Strength Ranking.* https://www.globalfirepower.com/countries-listing.asp

Figure 43: US Army Mobile Expeditionary Lab (image courtesy of U.S Dep. Defense. The appearance of U.S. Department of Defense visual information does not imply or constitute its endorsement.)

The Rapid Equipping Force modified a standard 20-foot shipping container (measuring 6.05 m long, 2.6 m high and 2.44 m wide) and installed high-tech machines and tools so that it could work as a mobile production lab. The cost of this production lab is around USD 2.8 million, and it **carries a 3D rapid prototyping printer, a CNC machine, and other tools and machines such as plasma cutters, welders, saws, and routers**. It also includes satellite communications equipment, allowing the two specialized engineers in each lab to connect with other engineers to help resolve problems. The container is equipped with its own generator, heating and cooling systems, providing a stable environment for the laboratory machines. It can be transported by truck or airlifted by helicopter to the desired area.

The high-tech additive manufacturing machines carried in the container **perform many applications and fulfil many needs that could not previously be carried out with traditional manufacturing systems in a combat environment.** Another advantage to having this lab onsite is the connection of the engineer to the soldier, creating a dialog in order to solve problems. The soldier has the experience of military issues and the engineer is able to create the specific design that is needed in each situation. In addition, due to the facility and rapidness of creating 3D prototypes or mock-ups, the soldiers can give an immediate feedback to improve or change the design before its final selection. The solution's 3D designs can be uploaded to establish a catalogue or database so that when similar problems occur elsewhere the object can be immediately printed without redesigning it. The main idea of this Fablab is to bring the means to create solutions to the source of the problem rather than providing long distance resources. Using this, supply chains and times are reduced, and the soldiers get their solution sooner.

There are **many examples of how this project in Afghanistan helped to resolve real problems in the field**[68]:

- When the troops reported a problem with the bipod attachment of the M249 light machine gun, because it did not allow for horizontal movement, the engineers on the ExLab used the 3D printer to prototype a new attachment, extending the range of movement. Following feedback from the soldiers, the solution was optimized, and it was manufactured within a week.

- To prevent the valve stems of military vehicle tires from being torn off by obstacles, the Lab created 3D plastic guard prototypes. They tested fit and form and after several iterations, the final metal guard was manufactured with a CNC machine and installed in relatively short time.

- The lab created a 3D printed mount to enable IED (improvised explosive device) detectors to work at night, illuminating the environment without interfering with the systems.

Many other examples can be added to this list such as shield cases to protect batteries from the Afghanistan heat, parts to repair robots, converters for batteries, and brackets enabling soldiers to use a variety of weapons with the Ironman backpack.

Nevertheless, several limitations or problems must be considered, one of them being the **Expeditionary Lab's vulnerability to becoming an enemy's objective, since it is an important fount of military resources.**

The Mobile Expeditionary Lab helped to demonstrate how these systems can be implanted in the field and improve the solutions that it offers. Besides in assistance to troops foreign countries, future uses of the Fablab include assisting in natural disasters and with humanitarian efforts. The 3D technology carried in this lab will increase its impact in the future, and it will become faster and cheaper.

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[68] *Rapid Equipping Force US Army. (n.d.).* http://www.ref.army.mil/refforward/

Strategic Study

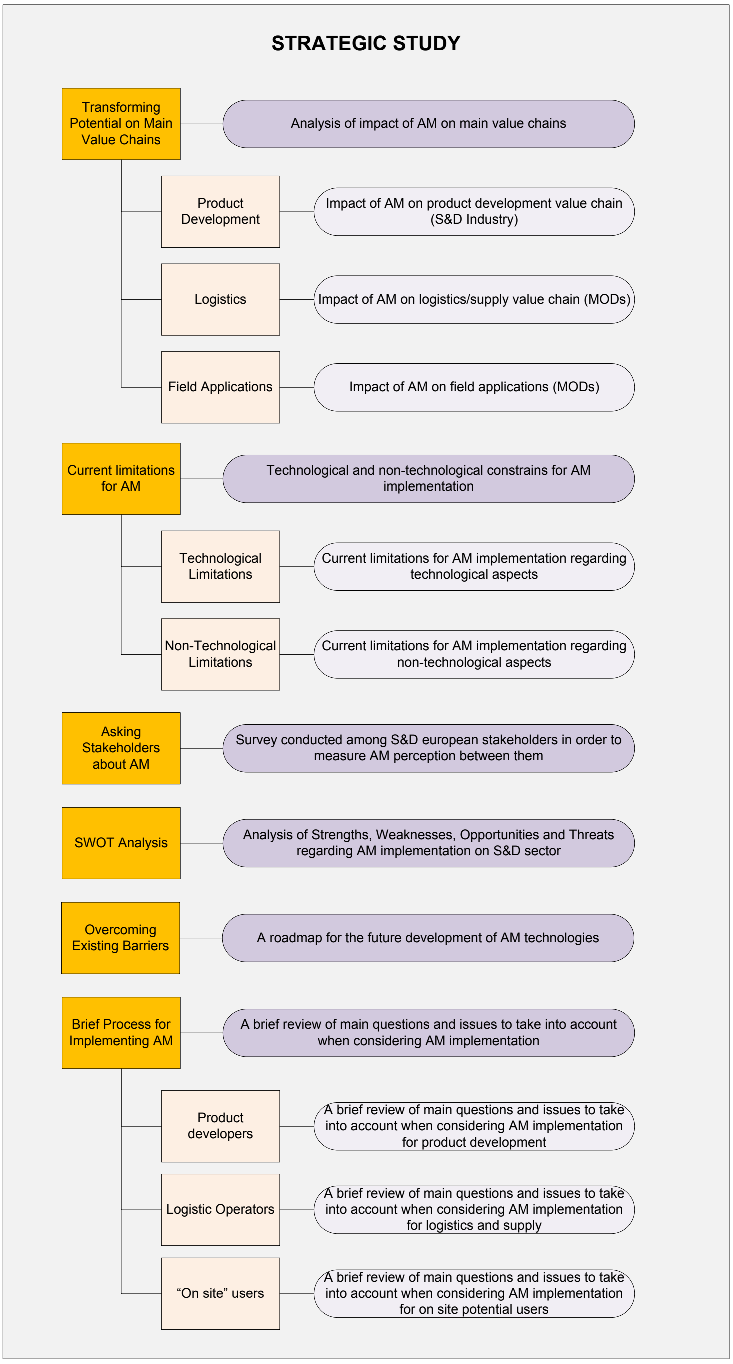

Figure 44: Basic structure of the Strategic Study

9. Transformation Potential: Impact on Value Chains

9.1. Value Chain Concept

Although the concept of the value chain can have different meanings, they all revolve around the original concept developed by Michael Porter in 1985[69], which envisaged organizations as a set of subsystems/processes, all of them forming **a set of activities that have the potential to transform some inputs into products or services (outputs) to create value for its customers.** From an activity analysis point of view, the value chains approach is based on the systems and activities that should lead to value creation and not on organizational structures (areas, departments, units, etc.)

Thus, the analysis of any business, activity, or as in the case of the present document, **the analysis of the impact of the introduction of a new technology, can be realized from the perspective of the value chain.**

9.2. Defining Value Chains to Study the Impact of AM on the Security and Defence Sector[70]

When identifying value chains within the Security and Defence sector that allow the evaluation of the potential impact of additive manufacturing technologies, it is **necessary to consider first which global level activities can lead to value chains that are illustrative of the Defence sector.** In this sense, and from the moment that systems of social organization first gave rise to the emergence of states, **the management of the Security and Defence activities of each country has had the following main agents**:

- Government agencies/Ministries of Defence (MODs). The main protagonists in the sector, developing policies related to the security and defence of each state, creating management infrastructure, technical resources and human resources. They assign budgets for the provision and maintenance of resources and are, ultimately, the driving force behind all operations within the framework of security and defence.

  This category may include public bodies or public participating organizations aimed at consolidating, promoting and boosting security and defence activities, either within their own territory or in activities that include allies and strategic partners.

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[69] *Porter, M. (1985). Competitive Advantage: Creating and sustaining superior performance.*

[70] *Defined value chains are the result of experience gained by Fundación Prodintec and MBDA through their years of AM experience.*

- Security and Defence (S&D) industry. Private or public participating organizations, whose main line of business is the development, production and supply of products and services for state security and defence activities.

- Other industries. Private or public organizations that develop, produce and supply products and services not specific to but useful for the activities of state security and defence.

Bearing this in mind, **MODs are the "engine of activity" of the security and defence sector and in order to carry out their activity, a series of resource needs (products or services) must be satisfied in the most effective and efficient way.** These needs may be supplied **either by MOD management or by other agents** capable of generating and providing the necessary resources. **Thus, the value chain approach can be firstly implemented to assure the resources (inputs) required for S&D activity from a MOD point of view.** As a result of this consideration, there are two clearly identifiable main activities that contribute to the fulfilment of this resource demand:

- Product development. As in any other sector, Security and Defence sector is by itself the basis of a market with its own characteristics, which demands customized products tailored to the evolution of its needs.

  This activity generates a **product development value chain** whose main input is the needs arising in the environment of the Security and Defence sector and whose output is the generation of new products. The agents that must enable a value chain capable of converting the inputs into the expected outputs are the S & D Industry.

- Provision of resources. If there are global activities and agents responsible for developing the products demanded by the market, it can be assumed that the buyers in that market will, independently of other specific objectives, pursue the aim to guarantee the provision of resources for their organizations. In this case, the main input would be the need for provision of resources and the expected output is the satisfaction of that need. In the context of this project, the agents responsible for this transformation will be government agencies (MODs) through different levels of resource management. The identifiable value chain for the provision of resources is therefore the **logistic value chain**, being the "set of means and methods necessary to carry out the organization of a company, or a service" (Dictionary of the Royal Academy of the Spanish Language[71]).

These two value chains can be analysed to establish how the emergence of additive manufacturing technologies can impact upon them, but it should be borne in mind that new main lines of activity can arise, in turn creating new value chains. One of the main characteristics of additive manufacturing technologies is that, by considerably reducing the distance between design and a tangible element/product, **the incorporation of additive manufacturing technologies into operational environments related to Security and Defence is a real possibility.** These technologies have the

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[71] *Spanish Royal Academy of Language. (n.d.). Royal Spanish Academy of Language.* http://dle.rae.es/?w=diccionario

potential to provide manufacturing capacity only previously available to traditional producers and therefore to provide MODs with a capacity for defining, developing and implementing their own solutions. In this way, **the capacity provided by additive manufacturing technologies has the ability to lead to the generation of new solutions in the MOD environment and therefore opens the door to the generation of a new “field applications” activity and value chain.**

Viewed from a general point of view, these three value chains cover each and every one of the activities and sub activities necessary to ensure the development, manufacture and provision of products and services. The diagram below shows how these value chains are the necessary support for the satisfaction of resource needs within the security and defence sector:

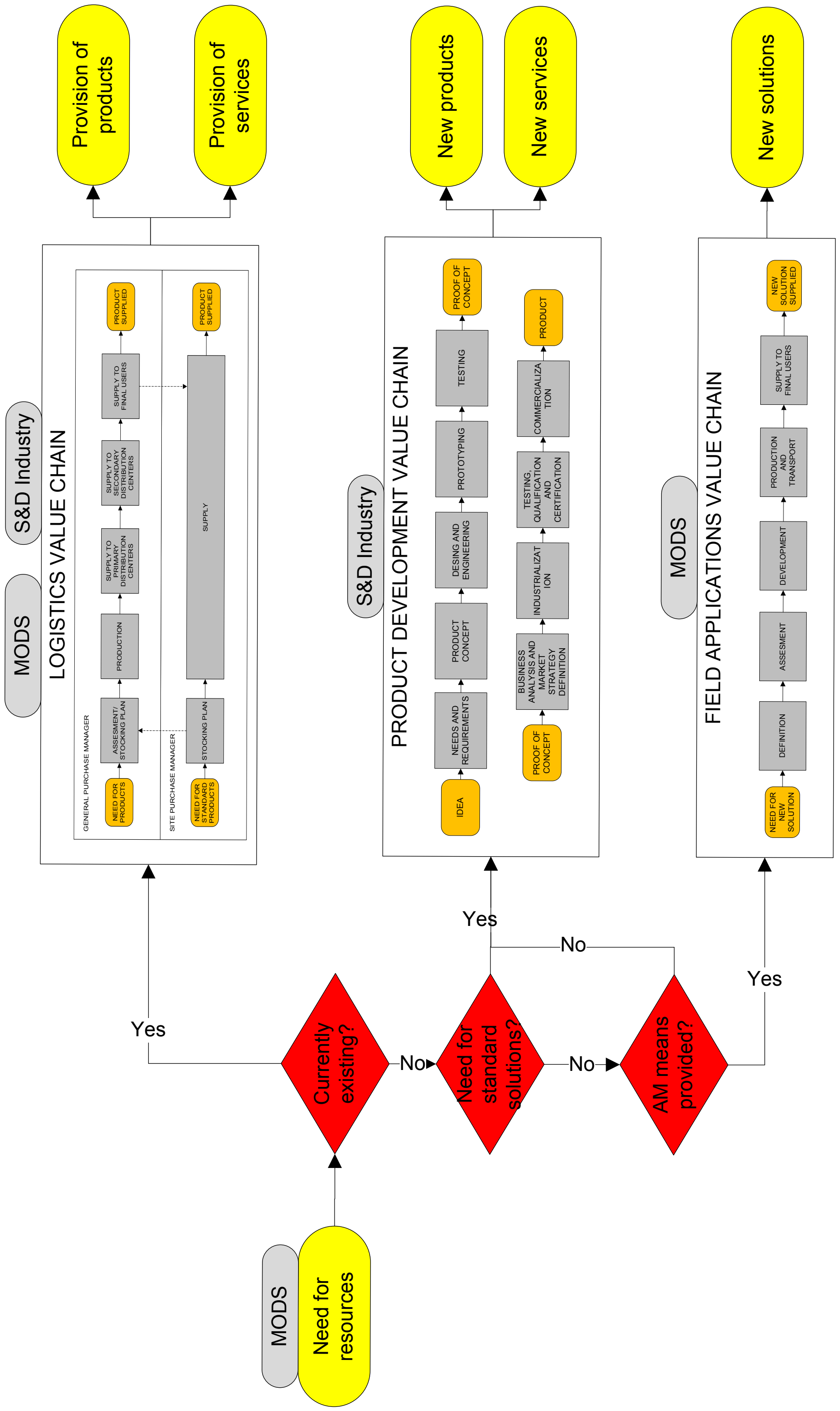


Figure 45: Defined value chains for analysing AM impact (own creation)

9.3. Main Identifiable Value Chains for Studying AM impact on Security and Defence Sector

In order to establish how additive manufacturing can impact on the field of Security and Defence, an analysis has been carried out based on the definition of three value chains:

- **Product development value chain**. This value chain represents the development of a new product or the evolution of an existing one, demonstrating how additive manufacturing impacts on the entire process of generation, development and market introduction of the same.

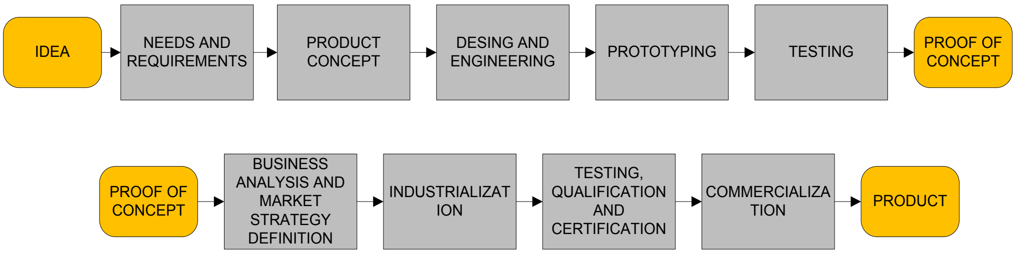


Figure 46: Product development value chain (own creation)

- **Logistics value chain**. Logistics is undoubtedly a fundamental part of all supply processes, since it is necessary to ensure that the products arrive to the end users on time and in the necessary form.

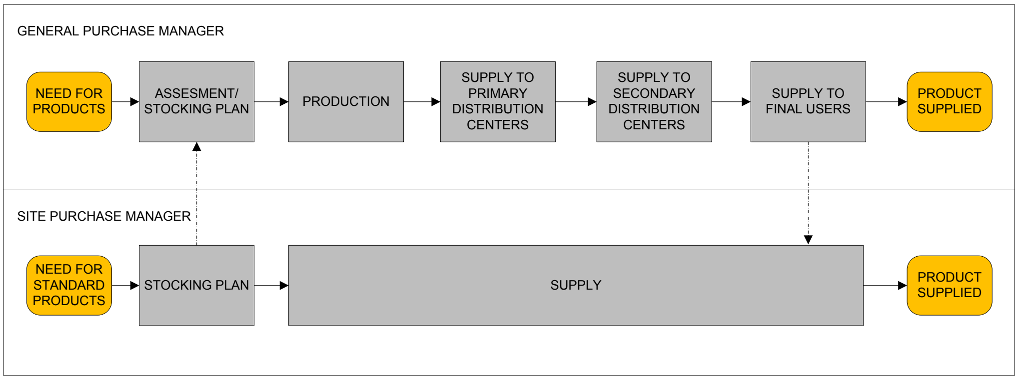


Figure 47: Logistics value chain (own creation)

- **Field applications value chain**. Although many of the needs of an end user can be satisfied with existing products, new "solutions" are sometimes required i.e. the generation, development and provision of new products with capacity to solve new needs.

Figure 48: New solutions value chain (own creation)

9.4. Value Chain Analysis

9.4.1. Product Development

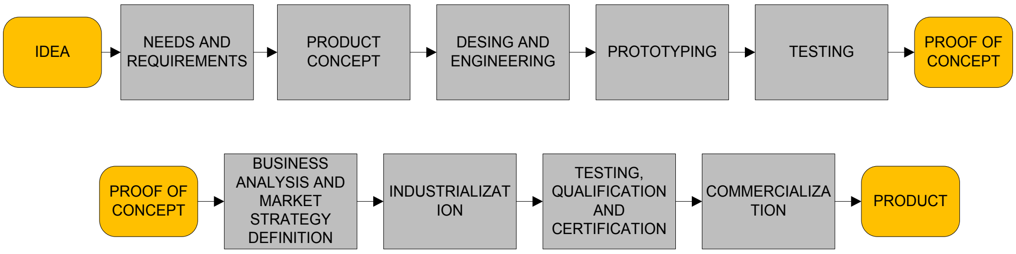
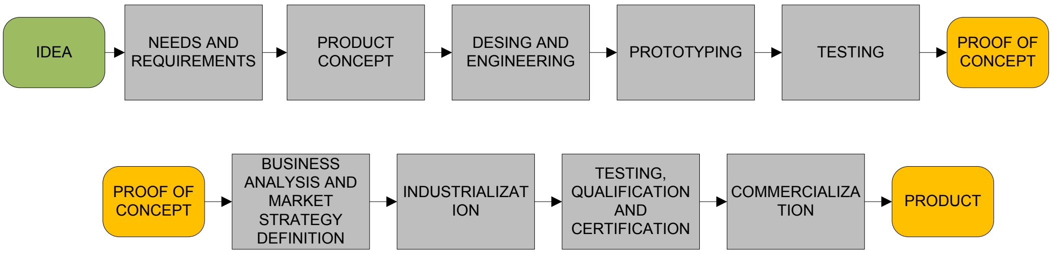


Figure 49: Product development value chain (own creation)

The development of a product is a complex process, in which several successive steps are required to make it possible to turn an idea into a marketable product. Although each developer can identify a process with its own entity, the basic of this process are described below:

- Idea: first approach to a desired product.
- Need and requirements definitions: definition of needs and requirements for the desired product.
- Product concepts: realization of the first formal conceptual approaches in the form of 2D and 3D designs.
- Design and engineering: operational solutions are defined, implemented and integrated, giving the desired product the capacity to meet the established needs and requirements.
- Prototyping: action of manufacturing one or several first functional units of the desired product.
- Testing: this stage will determine the capacity of the prototype to respond positively to the needs and requirements initially defined.
- Proof of concept: first demonstration of the validity of the original idea and concepts.
- Market Strategy: positioning and commercialization strategies.
- Industrialization: serialization of the product.
- Qualification and Certification: quality and reproducibility assurance.
- Commercialization: logistical capacity to deliver a product to end users assurance.
- Product: final product to be launched in the market.

9.4.1.1. AM Impact on Value Chain Step: Idea[72]



- **Value Chain Step Description**: every product begins with an initial idea, a first approach to the desired product. An idea can be formulated very simply (a few descriptive words or phrases) or in a complex way (a report that can include first sketches and conceptual approaches), but in all cases the idea is the **beginning of a complex process** that, managed in a satisfactory way, leads to a new product.

- **AM Potential Impact on this step**: as the first approach to a new product, the level of detail of an idea can vary, but in any case, and whenever the knowledge of the staff that is working on the idea makes it possible, this idea is reflected in mock-ups, even prior to a detailed definition of requirements and functions of the product sought. These **mock-ups are of great help in valuing and discarding ideas, especially because they make them tangible** for those who can decide whether to invest resources in those ideas development. Thus, even in this first step, AM technologies can be an important support to give form and to present these ideas, making them tangible.

- **Pros**:

    - Currently, there are many models of AM desktop machines suitable for this type of application (slightly restricted by materials, size and quality requirements).

    - Low cost of this type of machine and associated materials, usage and maintenance.

    - The requirements to use of this type of AM technology (user training, post-processing needs, etc.) makes them very accessible for the vast majority of potential users.

- **Cons**:
    - Due to the potential advantages and the ease of access to the referenced technologies, there are no significant limitations to be taken into account. The only limitation would be that this requires staff with 3D design capabilities, but this applies to all product development processes, and not only those where AM can be a pivotal technology.

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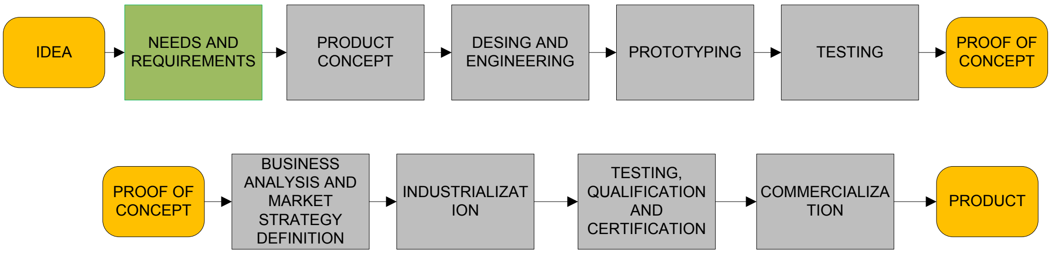
9.4.1.2. AM Impact on Value Chain Step: Needs and Requirements[73]



- **Value Chain Step Description:** once an idea exists, the next logical step is the **definition of needs and requirements for the desired product.** At this stage, the efforts are focused on describing all those characteristics and functions of the product sought, trying to give rise to a clear formulation from which to set design goals. This stage is totally determinant of the product to be developed, since it establishes what is expected of the final product and is the "mirror" against which the obtained results will be compared.

- **AM Potential Impact on this step**: as in the previous stage, the use of AM technologies is especially associated with the **production of mock-ups and first conceptual approximations of the product to be developed**, so the impacts are the same.

- **Pros**: (same as previous stage)
  - Currently, there are many models of AM desktop machines suitable for this type of application (slightly restricted by materials, size and quality requirements).
  - Low cost of this type of machine and associated materials, usage and maintenance.
  - The requirements to use of this type of AM technology (user training, post-processing needs, etc.) makes them very accessible for the vast majority of potential users.

- **Cons**: (same as previous stage)
  - Due to the potential advantages and the ease of access to the referenced technologies, there are no significant limitations to be taken into account. The only limitation would be that this would require staff with 3D design capabilities, but this applies to all product development processes, and not only those where AM can be a pivotal technology.

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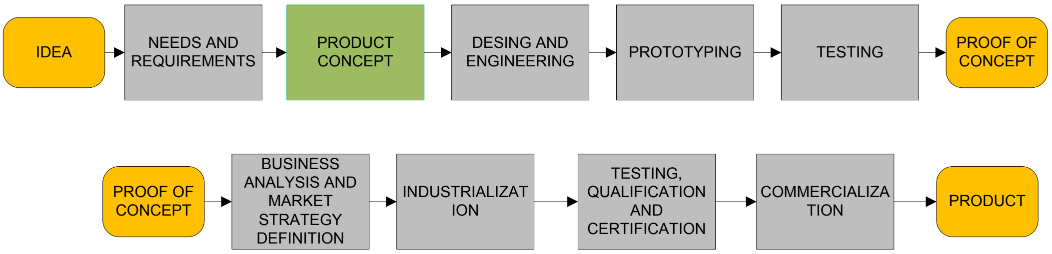
9.4.1.3. AM Impact on Value Chain Step: Product Concept[74]



- **Value Chain Step Description:** once the needs and requirements associated with the product to be developed have been identified in detail, the conceptual development of the new product properly begins.

  This stage always involves the **realization of the first formal conceptual approaches in the form of 2D and 3D designs**, but may also involve (in the case of more complex products) the exploration of **certain concepts to the point of demonstrating the validity of the principles on which they are based.** This situation is very common in the development of highly complex and technological innovations, where the development of a product also involves the development of a previously untested new technology. In these cases, there may often be a principle of theoretical functioning, but it is not proven feasible until it is put into practice. Depending on the complexity of the final product, this stage can range from activities purely associated with graphic representation and preliminary design, to the production of validators for testing a theoretical principle of operation, necessary to demonstrate the capacity of the concept to meet the defined needs and requirements.

  This stage ends with the selection of at least one design concept from which to develop a complete design and engineering project, capable of giving rise to a first functional version (prototype) of the product sought.

- **AM Potential Impact on this step**: the complexity of this stage may vary, so the potential uses of additive manufacturing in this stage are also varied, **from 3D scale representations of the first conceptual product designs, to the manufacture of validators** to test the feasibility of a concept of operation. In the case of 3D scale models, their advantages are similar to those in previous stages, but in the latter case, AM undoubtedly contributes a differential capability. The capacity to design and manufacture validators is totally determining, since it allows the generation of the information necessary to proceed with product development, reducing uncertainties and process times.

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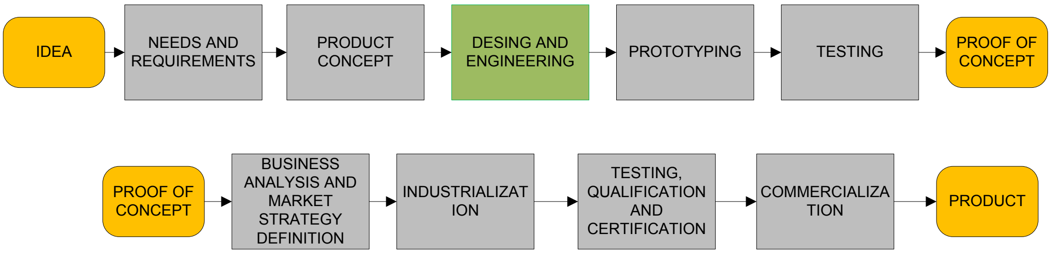
- **Pros**:
    - When there are no technical uncertainties (there are not doubts about the capability of the concept to be manufactured and for it to work), the advantages provided by AM technologies are the same as in previous stages, as this stage does not have specific requirements or limitations.
    - When validators are required before investing more resources, this technology can lead to the manufacturing of validators within the required costs and process times.
- **Cons**:
    - If AM is required for the development and manufacture of validators, the level of technology required may be substantially higher than for a mere conceptual representation depending on its specifications (material, precision, durability of the validator, etc.): complex validators will require more expensive machines and materials, increasingly more complex machine handling and maintenance, significant post-processing stages (especially for metal parts) and requirements for specially trained and dedicated staff.

9.4.1.4. AM Impact on Value Chain Step: Design and Engineering[75]



- **Value Chain Step Description:** the design and engineering of a product is undoubtedly the most decisive stage in its development, since it is where the **operational solutions are defined, implemented and integrated, giving the product the capacity to meet the established needs and requirements**. It is at this stage that designers and engineers apply their knowledge and experience, giving rise to manufacturing plans, 3D models, descriptive documentation, etc., which in turn give rise to the first complete (manufacturable) definition of the product.

  One of the main characteristics of this stage is that it is highly dependent on the manufacturing technologies that are available/accessible for subsequent prototyping and

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manufacturing stages, so design and engineering work must be adapted to (or will be limited by) the available manufacturing technologies.

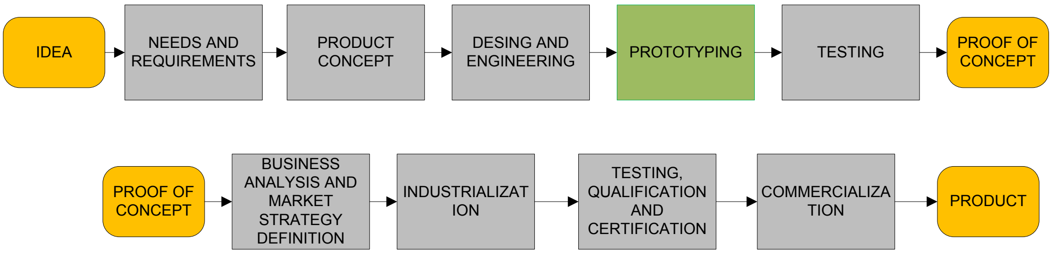
- **AM Potential Impact on this step**: undoubtedly, the design and engineering stage is the one that benefits most from the introduction of additive manufacturing technologies. Reasons for this include: the elimination of design barriers (non-manufacturable geometries) that exist with traditional technologies; an acceleration of the transition from "drawing board to workshop"; the **elimination of costs and processing times associated with the design and manufacture of tooling; and finally, an increase in the number of design iterations and functional prototypes possible**, due to the reduction of cost and time.

  Thus, in the presence of a suitable additive manufacturing technology (materials, precision, etc.) the benefits are remarkable, specifically leading to a reduction in the required time for the generation of the first functional product prototypes and a considerable increase in the innovative capabilities of the final product.

- **Pros**:
  - Even this stage is commonly strongly focused on "desktop work" and depending on the complexity and duration of this stage, partial validation of subsequent design and engineering sub-stages could be required, so similar AM capabilities for manufacturing validators or prototype parts could provide similar advantages.

- **Cons**:
  - The level of AM technology required may be substantially higher than for a mere conceptual representation: more expensive machines and materials; increasingly more complex machine handling and maintenance; presence of significant post-processing stages (especially for metal parts); and requirements for specially trained and dedicated staff.

9.4.1.5. AM Impact on Value Chain Step: Prototyping[76]



- **Value Chain Step Description:** as a direct continuation of the design and engineering work, **prototyping is the action of manufacturing one or several first functional units of the required product** which, after being tested and evaluated can determine the ability of the product to satisfy the proposed needs and requirements. On the contrary, it may indicate the need to perform further design and engineering iterations to achieve the desired result or may even, depending on the constraints of time and cost, terminate the entire process despite not having arrived at the expected result.

  This phase, which was already shaping the previous one, has a great impact on the overall process in terms of time and cost, since it is where the developer of the product may incur external costs (materials, subcontracting, etc.) and additional processing times, depending on the technologies used.

- **AM Potential Impact on this step**: it is necessary to take into account that the manufacture of one or several prototype units can have a substantial impact in terms of time and cost, especially when using traditional technologies usually focused on the production of high volumes. These technologies are often expensive for the manufacture of small numbers of units. Their technical characteristics (use of material, energy consumption, need for accessory tools, etc.) are indeed economically more advantageous for higher volumes of production since the indirect costs of each unit (tooling, energy consumption and labour, etc.) are amortized.

  Additive manufacturing gives this part of the process a totally decisive capacity, since it **eliminates accessory elements and makes a more efficient use of the raw materials, thus greatly reducing the cost and time associated with the manufacture of the first functional units.** The use of additive manufacturing at this stage of the development process of a product is undoubtedly one of the areas in which this technology has the most impact.

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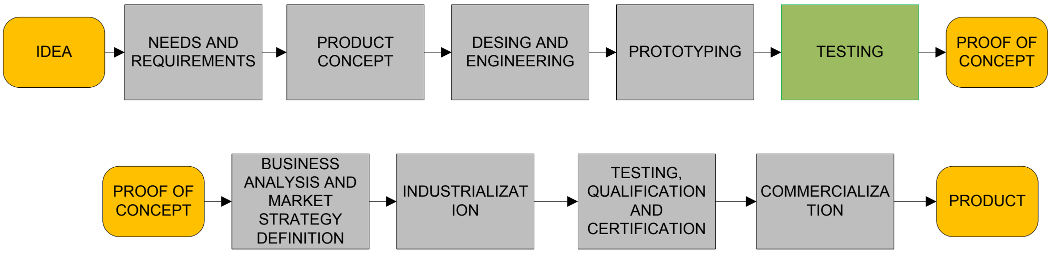
- **Pros**:
  - The advantage of passing from a 3D model to a functional prototype is clear. The possibility of making prototypes in a variety of materials and the elimination of ancillary costs such as tooling, etc. leads to a significant increase in the use of available resources, therefore increasing the potential scope of this and successive steps.
  - These technologies can reduce the "distance" between a functional prototype and the final product, by providing more options when designing and manufacturing the prototype.
- **Cons**:
  - The level of AM technology required may be substantially higher than for a mere conceptual representation: more expensive machines and materials; increasingly more complex machine handling and maintenance; presence of significant post-processing stages (especially for metal parts); and requirements for specially trained and dedicated staff.
  - Current AM technologies do not provide "a single machine for everything". For example, depending on the manufacturing material, the required manufacturing means may be different, and their capabilities may in turn be different as well.

9.4.1.6. AM Impact on Value Chain Step: Testing[77]



- **Value Chain Step Description:** once a functional prototype has been manufactured, the **testing and validation stage will allow the determination of its capacity to fulfil the needs and requirements** initially defined. The ability and agility to do this depends to a large extent on the availability of functional prototype units for this work, determined by the funds and time available to manufacture them, which in turn will depend on the technologies used.

- **AM Potential Impact on this step**: as has been described, in terms of time and cost investment, AM technologies may be more efficient and economical than traditional

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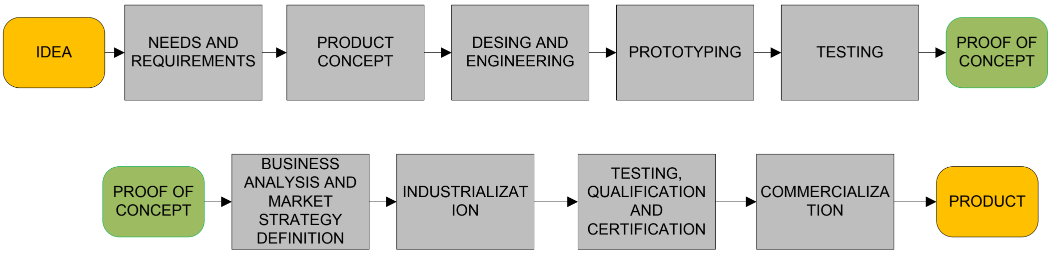
technologies, resulting in lower unit cost prototypes. The resultant decrease in costs and process times allows for the production of a greater number of prototypes as well as a **greater number of design and manufacturing iterations. In essence, AM technologies allow for a higher return on investment when used in the stages giving rise to the first functional units of a product.**

- **Pros**:
    - Due to the ability of these technologies to accelerate and reduce the cost of producing prototypes and validators, it is possible to increase the scope of this stage, thanks to the production of a greater number of prototypes, or the possibility of introducing redesigns in a much more agile and efficient way.
- **Cons**:
    - Where previous stages have made use of AM technologies suitable for the designed prototypes (and being applicable then the same disadvantages), increased capacity for producing the required number of units for the test programmes may be required.

9.4.1.7. AM Impact on Value Chain Step: Proof of Concept[78]



- **Value Chain Step Description:** once previous stages have been carried out satisfactorily, the result of the process is a **first demonstration of the validity of an idea to be put into practice and become a new product**, or at least a development that satisfies the needs and requirements that were originally defined.

  Given satisfactory test results, the transition from the prototype to the final product may be more or less direct, depending on the characteristics of the product, but there will always be a series of steps to ensure the transition:

    - The existence of a market and potential customers for the final product.

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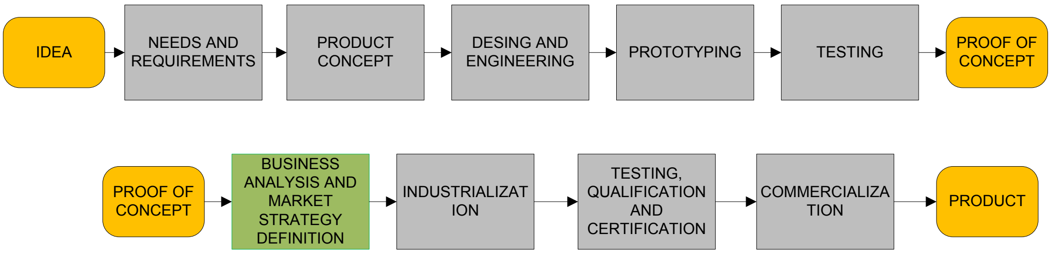
  - The ability to continuously and repetitively manufacture the product, complying with the quality criteria and defined standards, with admissible costs.
  - The existence of a network, infrastructure and logistics for the commercialization of the product.

- **AM Potential Impact on this step**: in many of the stages outlined, AM technologies have an interesting potential, being determinant in some of them (industrialization) and having a high impact on others (e.g. exploration of the market). These interactions are presented in later chapters.

9.4.1.8. AM Impact on Value Chain Step: Business Analysis and Market Strategy Definition[79]



- **Value Chain Step Description: as part of market analysis**, once **an organization has generated the first functional units of a new product, these can be part of its positioning and commercialization strategy.** Of course, even before starting the development of a new idea, the organization will probably have made market studies that will have led to that idea, but at this point it is especially critical to have a product (or at least a prototype) that can be demonstrated and be used to gather interest from potential customers. It may even lead to suggestions of improvements that can be incorporated before moving to the industrialization of the product.

- **AM Potential Impact on this step**: at this stage, where a product is being announced and while suggestions of improvements following its interaction with potential customers are still possible, it is important to have test/demonstration units available. Normally, the **number of units needed during this stage of the process will still be low and therefore the same technologies that were used for the manufacture of prototypes will be suitable for this type of uses**. Additive manufacturing can bring to this stage the capacity described in earlier stages – the production of reduced numbers of units at a reasonable unit cost. Thus exploratory market stages can undoubtedly benefit greatly from these technologies, because of their great cost/result ratio for reduced volumes of units.

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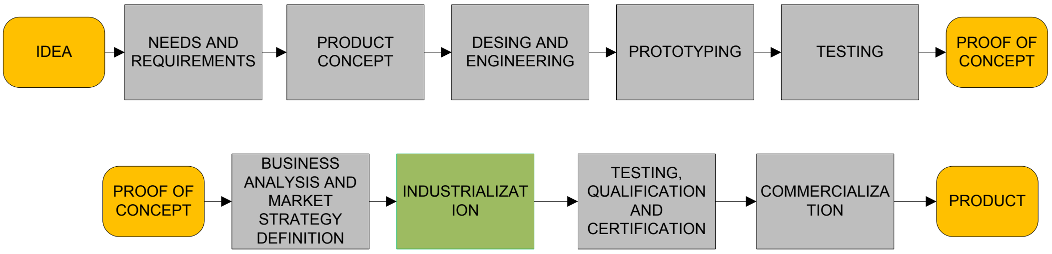
- **Pros**:
    - An important limitation during the initial stages of making a product, known to its potential users, is the availability of sample units. Thus, the benefit of having a technology with the capacity to produce additional demonstration units as required is a significant one and AM can provide a clear advantage over other technologies.
- **Cons**:
    - Depending on the number of prototype units required for a first approach to the market, greater capacities for producing the required number of units may be required.

9.4.1.9. AM Impact on Value Chain Step: Industrialization[80]



- **Value Chain Step Description:** once a functional unit is available, the most critical next step is undoubtedly industrialization since **this part of the process determines not only the configuration, final characteristics and quality of the product, but also establishes the cost and structure of its associated supply and logistics.**

  Sometimes, usually in products with high customization and reduced production volume, the transition from the functional prototype to the final product can be short, since a reduced volume means its unit production cost will not benefit from the implementation of technologies more suited for high production volumes. In this case, the final product does not vary greatly with respect to the prototype. In other cases, and especially when production volumes are high, an industrialization process more suited to the production of larger number of units with the lowest possible unit cost will be required.

- **AM Potential Impact on this step**: additive manufacturing technologies have a **disadvantage compared to traditional technologies as, while they are efficient in the use of energy and material, there is no potential to vary the unit cost**; no matter if a few number of units is produced or hundreds of units are produced, the unit cost remains the same. This means that

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when estimating a high volume of manufacturing units, it is necessary to explore the implementation of cheaper manufacturing technologies.

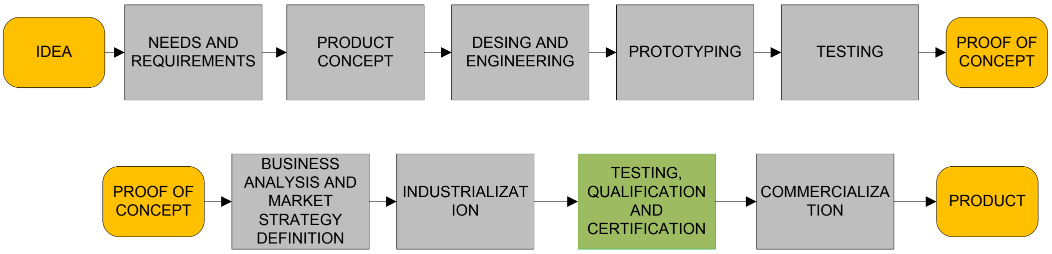
The need to look for manufacturing technologies different from those used for the manufacture of the first functional prototypes may require revision and adaptation to the product design if that which has been manufactured with an additive manufacturing technology cannot be directly manufactured using a traditional technology. This can lead to a second stage of design and engineering, prior to obtaining an industrialized product suitable for the market.

In any case, **the use of the additive manufacture in the previous steps will still have been decisive in optimizing time and cost associated with the production of a first functional version** of the end product.

- Pros:
    - At present, in those cases where the number of units to be produced is reduced or the added value of a product manufactured by AM is high, it is feasible that its serial manufacture can be carried out with these same technologies, although they will have to be endorsed by a process of qualification and certification to ensure the quality and reproducibility of the process. In this case, the modification of the developed prototype will be minor and the complexity of issues faced at this stage will be reduced.
    - If manufacture by AM technologies is possible, it also opens up a whole series of possibilities for commercialization and distribution that are not possible with other technologies. A production process that is completely framed within the concept of digital industry can reduce the resources needed for production and simplify the transportation of the product to the customer, even allowing the “make it yourself” concept to become a reality.
    - If a continuous manufacture by AM technologies is not possible and additional design and engineering stages are necessary, the considerable reduction of time, efforts and money expenditure prior to this stage will have had an overall positive effect on the whole process.
- Cons:
    - Since current AM technologies do not benefit form a decrease in the unit cost with the increase in the number of units to be produced, the final decision to use AM for serial production depends on the desired number of units. In general, when a high number of units is planned, AM technologies tend to lead to higher costs than with other technologies (assuming that other technologies would be able to successfully manufacture a product that would meet the same defined needs and requirements). This is of course subject to a specific assessment for each case.

- In those cases when a serial production based on AM technologies is not economically efficient and, in those cases, where other technologies cannot reproduce the design obtained thanks to AM, additional steps of redesign and engineering will be required, in order to make the product manufacturable and cost effective for said technologies.

9.4.1.10. AM Impact on Value Chain Step: Testing, Qualification and Certification[81]



- **Value Chain Step Description:** in order to launch a new product to the market, there are **two aspects that are vital to ensure a productive capacity sustainable over time: quality and reproducibility. This is achieved by qualifying and certifying** a process, through the accreditation that the production process (including machines, workers, operations, etc.) is able to provide the expected quality and reproducibility.

  This stage is highly dependent on the technologies implemented the production, since these define the processes involved: machines, required training, previous and subsequent processing and finishing operations, raw material control, product control, etc.

  AM Potential Impact on this step: once an additive manufacturing technology is selected as the main or complementary part of the manufacturing process of a product, one of the **main challenges is the determination of the qualification and certification of the processes involved.** Currently, this can be a challenge in relation to AM technologies due to the novelty of these technologies and the lack of experience both internally and regarding normative schemes that serve as guides for the realization of these processes.

- **Pros**:
  - The disadvantage that AM technologies present in this field compared with more traditional technologies will be short-lived, since with time they will become standard,

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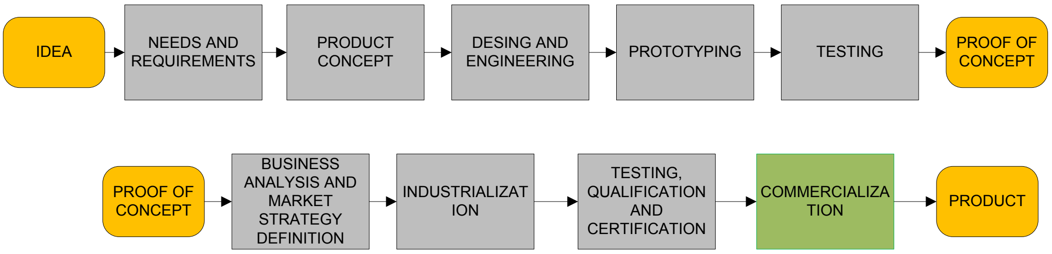
[81] *The contents of this chapter are the result of experience gained by Fundación Prodintec and MBDA through their years of AM experience.*

more experience will be gained, and solid standards will back up its implementation at the industrial level.

- **Cons**:
    - Due to the lack of extended practical experience and standard qualification and certifications processes, this area is one of the main limitations for AM implementation, due to the uncertainty that potential users can face on an industrial scale.
    - Due to these current shortfalls, organizations that want to implement AM beyond the prototype stage face a lack of guidance. Those who decide to implement these technologies will have to invest significant resources in this area.

9.4.1.11. AM Impact on Value Chain Step: Commercialization[82]



- **Value Chain Step Description:** marketing is the fundamental objective of every product, being the logical consequence of a process that has involved the investment of considerable amount of resources and time. Although at this stage the technological challenge of developing a new product has already been overcome, there are other **challenges, fundamentally associated with the logistical capacity to deliver a product to end users at the lowest cost possible.**

  There are products that due to their characteristics (complexity, size of parts, etc.) will continue to be produced in factories in the traditional style (centralized production) and then distributed through large logistics networks. However, in other cases, the concept of "digital industry" may be the basis for a significant relocation of factories and a decrease in the distance between the product and its end users, even allowing the "make it yourself" concept possible for products with characteristics that enable them to be manufactured using machinery accessible to the end user.

- **AM Potential Impact on this step: in products that can be manufactured totally or partially through AM technologies, a strong impact is expected on the associated logistics chains.**

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Progressively more capable and more accessible in terms of costs, these technologies can be implemented at anytime and anywhere in the world, significantly reducing the logistics network required for the distribution of products that were previously manufactured centrally, increasing the agility in the distribution, reducing its cost and giving rise to a more flexible and capable structure of production and distribution.

There will also be products that by their characteristics can be directly manufactured by end users with the appropriate technologies, so that the transformation of marketing schemes will be total in these cases, going from “selling a product” to “selling the right to manufacture that product”, because in essence, the user will become a licensed manufacturer with the right to produce that product for himself (and possibly becoming a distributor).

- **Pros**:
    - Additive manufacturing has the potential to lead to a paradigm shift in product distribution, since these technologies are based on the ability to print a 3D model that, given a machine that meets certain requirements, makes its manufacture possible at any moment and anywhere in the world.
    - This opens the door to shortening the geographical gap between the production sites and the end users and therefore the simplification of the supply chains, while bringing about the interesting opportunity that a customer who has the appropriate means can “buy” the 3D model and “make it himself”.
- **Cons**:
    - The delocalization of the manufacture or the “make it yourself” manufacture can lead not only to the delocalization of the physical manufacture itself, but also to the transfer of the quality control tasks associated with those products. In the most extreme case in which a customer buys the right to manufacture a product and not the product itself, the quality control tasks are transferred entirely to the customer, which also implies another not insignificant paradigm shift.

9.4.1.12. Product Development Value Chain Summary

Chain value Step	Brief Description	AM PROS	AM CONS
Idea	First definition of a desired product	Availability of several different low-cost solutions, requiring reduced knowledge for handling	Need for staff with 3D designing capabilities
Needs and requirements	Description of the expected characteristics and functions of the product sought	Availability of several different low-cost solutions, requiring reduced knowledge for handling	Need for staff with 3D designing capabilities
Product concept	Realization of the first formal conceptual approaches in the form of 2D and 3D designs/Validation of operating principles	Availability of several different low-cost solutions, requiring reduced knowledge for handling Low cost and quickly produced validators	When validators are required, AM required technologies implementation can be substantially more complex than in previous stages
Design and engineering	Through design and engineering skills, development of plans, 3D model and documentation to make the product concept manufacturable	Even primarily focused on “desktop work” validation of partial results could be possible thanks to the manufacture of validators or prototype parts	When validators/prototype parts are required, AM required technologies implementation can be substantially more complex than in previous stages
Prototyping	Manufacturing one or several first functional units of the sought product	From 3D model to a functional prototype in one step Important decrease of cost compared with traditional technologies	AM required technologies implementation can be complex Currently there is no a “single machine for everything”
Testing	Determining the capacity of the prototype to respond positively to the needs and requirements initially defined	Increase of the scope due to the ability of AM to accelerate and reduce the cost of producing prototypes	Depending on the number of prototype units required, greater AM capacities would be required

Chain value Step	Brief Description	AM PROS	AM CONS
Proof of Concept	The result of the process up to this moment is a first demonstration of the validity of an idea to be put into practice and become a new product	—	—
Business Analysis and Marketing Strategy Definition	First insights into making public/testing the product on potential customers	AM provides the capacity to manufacture demonstration units whenever required	Depending on the number of prototype units required, greater AM capacities would be required
Industrialization	Transition from the functional prototype to the final product	Technically feasible and economically efficient for short series production Opens up new possibilities regarding commercialization	Technically feasible but usually not economically efficient for larger series production Requirement for additional design and engineering stages
Testing and Qualification	Ensuring quality and reproducibility	AM technologies will become standard through time	The lack of extended practical experience and standard qualification and certifications processes
Commercialization	Marketing and distribution of the final product	Paradigm shift in product manufacturing and distribution “Make it yourself” for specific products	Delocalisation/transfer to the customer of quality control tasks
Product	—	—	—

Table 24: Product development value chain summary (own creation)

9.4.2. Logistics Value Chain

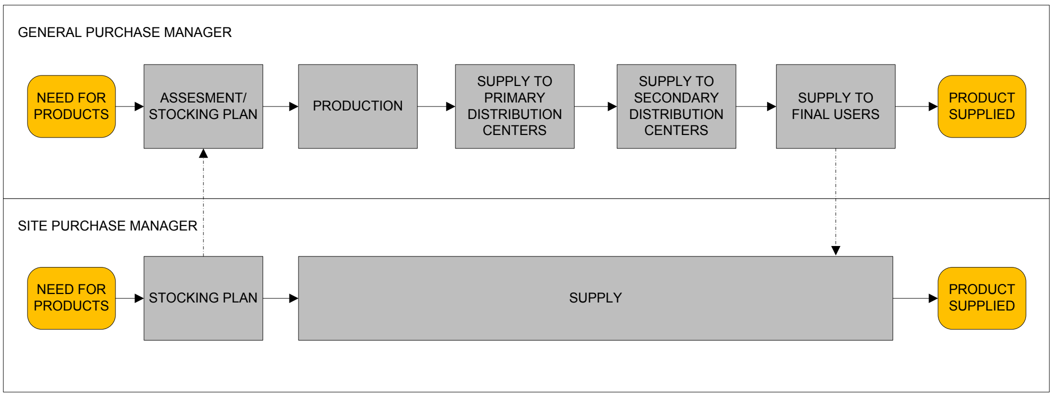


Figure 50: Logistics value chain (own creation)

Without a doubt and even beyond the capacity of a product to meet a particular need, **the logistics of a product in an area such as Defence is the most critical aspect**. In this sense, **any process or logistic operation can be seen as a linear process**, in which:

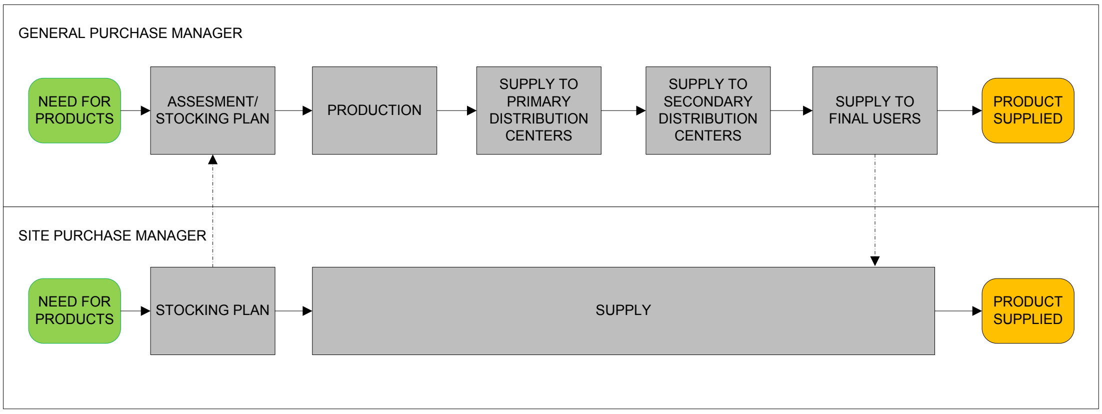
- All tasks stem from an original supply need, which starts with the end users and which is transferred through internal communication and approval chains which establish a forecast of materials and supplies.

- For certain logistics managers (those closest to the need or who are themselves the ones who generated the supply need), the logistics process consists of a “waiting period” until final delivery. For more global managers, it is a process that can go through different stages.

- While the request to a supplier can be answered more or less immediately by the existence of stock, the evolution of the different productive sectors, the optimization of costs and the proliferation of adapted products make the “just in time” philosophy more common. In this sense, both the productive capacity and the location of the productive facilities have a strong impact on the logistics activity, being decisive in the transport tasks necessary for the product to reach the final user.

- Once a product is manufactured, and assuming that all applicable quality processes are carried out within this stage, transport to the end user can involve different stages of distribution, depending on the distance from the product to the end user, the type of product, the necessary controls before its acceptance, etc.

9.4.2.1. AM Impact on Value Chain Step: Need for products[83]



- **Value Chain Step Description:** the beginning of any logistic process is the **initial definition of a procurement need**, relative to products or services. This definition will be associated with a series of data characteristics, such as the product references, the quantity to be procured, the desired date of supply, etc. This initial definition will later trigger a series of subsequent steps, all of them focused on fulfilling the satisfaction of the need indicated.

- **AM Potential Impact on this step**: from a logistics point of view, additive manufacturing has the clear ability to modify the way in which operators plan and meet supply needs: **bringing productive activity closer to the end user, personalizing and adapting products, eliminating transport flows**, eliminating storage, etc.

  The possibility of manufacturing certain products by AM, as well as the added possibilities that this technology contributes, will cause a considerable change in the logistical processes associated with these products. **For many of them, the traditional systems of stock and supply will be replaced by more dynamic and agile systems** in which the planning of the provision of resources can benefit from shorter delivery times and added possibilities of product customization.

- **Pros**:

  - The possibility of manufacturing products from an AM-based manufacturing process will allow the decentralization of production facilities, which will be able to approach the end user or even be present in the end user's own facilities, reducing deadlines.

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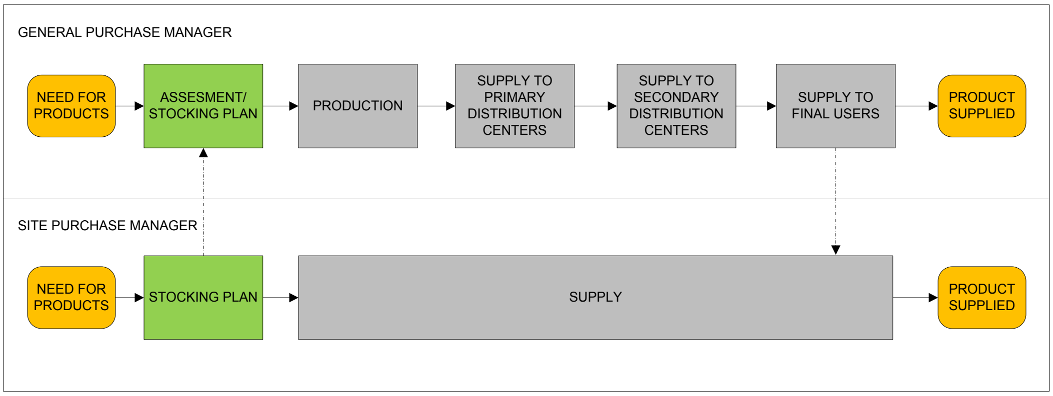
[83] *The contents of this chapter are the result of experience gained by Fundación Prodintec and MBDA through their years of AM experience.*

- The customization permitted by additive manufacturing will have a high impact on the logistics processes, since together with the dispersion of the productive facilities, it will allow the agile development and provision of modified products.
- Such an approach to the end user and the added capabilities will reduce the flows and times associated with the transportation of products and reduce storage needs.

- **Cons**:
  - Although the technologies of additive manufacturing can favour an approach of the productive facilities to the end user, the variability of products and technologies means that not all of them will benefit in the same way.
  - The use of the above advantages involves a technical-economic evaluation which is difficult to generalize: although in some cases they may be a clear advantage over traditional production and supply processes, others will require a more detailed evaluation.
  - The processes of quality assurance will be modified in an important way, even transferring to the end user himself if he is the producer.

9.4.2.2. AM Impact on Value Chain Step: Stocking Plan[84]



- **Value Chain Step Description:** once a need for provision arises, it is introduced into a **collection plan of variable complexity, depending on the level of management or the size of the logistics centre responsible for defining the plan.** The purpose of these plans is to guarantee the provision of the necessary resources at different levels, ensuring they are put into service in the most effective and efficient way.

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[84] *The contents of this chapter are the result of experience gained by Fundación Prodintec and MBDA through their years of AM experience.*

- **AM Potential Impact on this step**: From a technical point of view (the very realization of the collection plans), the additive manufacture does not have a direct impact on this step. However, the possibility that **this technology is able to modify the production and transport structures of a great quantity of goods** is sufficiently important to consider that this technology may have a strong impact on the way in which a logistics manager can design his collection plan. There is now a **possibility of changing from a scenario of production centres and static transport lines to one where the means of production may not only be closer but may also form part of a network with variable capacities,** depending on the product and volume of units. This implies a whole series of changes to be taken into account.

- **Pros**:

    - Additive manufacturing will allow a considerable reduction in supply times for many products, the reduction or disappearance of stocks and the move to a just-in-time philosophy.

    - The incorporation of additive manufacturing means as a production resource will increase the degree of control of the logistic operator on certain products.

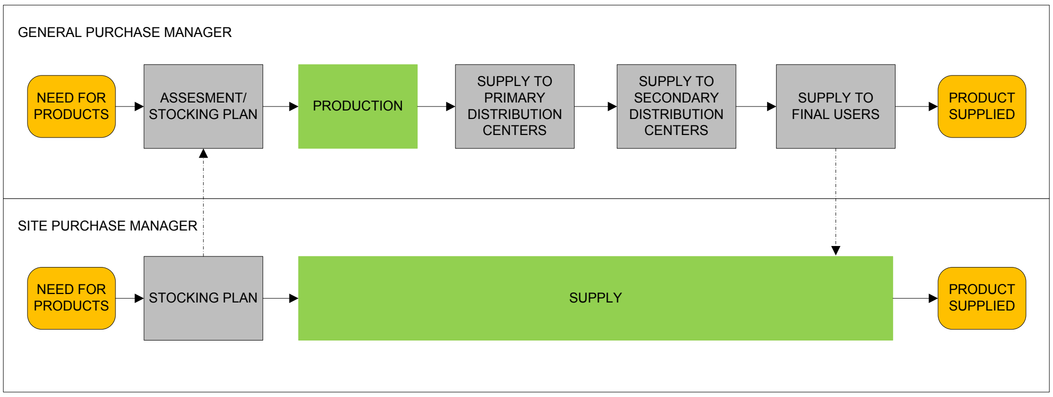
    - The planning activity will benefit from greater flexibility and ability to deal with contingencies.

- **Cons**:

    - The price of products manufactured using additive manufacturing technologies may be higher, so overall decisions about their provision must be taken into account and not only temporary factors.

    - Production through additive manufacturing technologies can be realized not only by the end user or the original producer, but also by third parties. This provides great flexibility, but in turn introduces complexities in the form of management of suppliers, as well as in the quality control of these products before putting them into service.

9.4.2.3. AM Impact on Value Chain Step: Production[85]



- **Value Chain Step Description:** production is the stage that gives rise to the **generation of a product** and which in turn gives rise to a whole series of previous and subsequent logistical processes. The supply capacity of a given product is strongly dependent on the existing production capacity, so that the use of different technologies gives rise to different capacities.

- **AM Potential Impact on this step**: traditional manufacturing processes usually respond to a productive model in which a large number of manufacturing facilities and resources are concentrated at the same geographical point, giving rise to large-scale processes capable of producing high numbers of units per unit of time, with an optimized cost and a level of homogeneous quality. On the contrary, **additive manufacturing technologies are nowadays considerably less scalable, resulting in higher unit costs, but with the fundamental advantage of being available even at the point where the products are to be used, eliminating production, dispatch and quality control stages.** This creates the need for logistics operators to be able to see themselves not only as mere recipients of a product generated by a supplier, but as an active part of the evaluation of production alternatives.

- **Pros**:
    - Additive manufacturing has the potential to outsource the production of products, potentially reducing supply times and increasing flexibility.
    - The possibility of manufacturing a product through additive manufacturing technologies opens possibilities in relation to the acquisition of products, being able to evolve from the acquisition of the product itself to the acquisition of the right to manufacture.

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[85] *The contents of this chapter are the result of experience gained by Fundación Prodintec and MBDA through their years of AM experience.*

  - This, in turn, opens up the possibility not only of manufacturing with own means, but also of having networks of nearby suppliers of 3D printing services capable of producing such products.

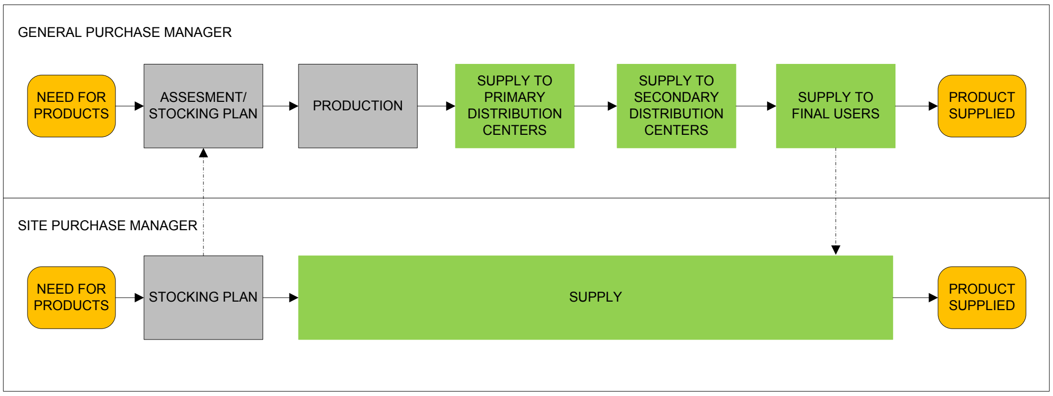
- **Cons**:

  - The possible relocation and dispersal of production, in addition to the characteristics of the AM technologies, means that the unit price of a product manufactured with these technologies tends to be greater than with traditional production means.

  - The relocation of production facilities and the possibility of transferring the right of manufacture to second or third parties introduce insecurities as to the quality of the products, by transferring the quality assurance process to those parties.

  - The maximum use of the potential networks of suppliers of additive manufacturing services requires close knowledge and monitoring in order to establish and accredit their different capacities.

9.4.2.4. AM Impact on Value Chain Step: Supply[86]



- **Value Chain Step Description:** from the point of view of logistics, **transportation and supply** is one of the most critical steps of the whole process since it does not contribute a direct value to the final product, but can have a considerable impact on aspects such as the timing of supply and the total price of the product.

- **AM Potential Impact on this step**: the impact of additive manufacture on the transportation and final supply of products is fundamentally due to its ability to bring production centres

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[86] *The contents of this chapter are the result of experience gained by Fundación Prodintec and MBDA through their years of AM experience.*

closer to the end user. With respect to this, additive manufacturing will give rise to a series of new situations:

  - **Transfer of production facilities to the end user, for products of low complexity and/or low production volume.** Thus, the end user (thinking of “end user” as an organization as a whole) will not only define a need for provision, but also have control over the entire production process.
  - **Transfer of production facilities to intermediate points, for products of medium complexity and/or average production volumes.** There will be products whose demand cannot plausibly be met in the end user's facilities, but they will be feasible in “advanced” positions or intermediate distribution centres, which can now also be production sites.
  - **Use of additive manufacturing services suppliers.** Not all production activities based on AM will have to be concentrated on one supplier, but can be based on a policy of sale or assignment of manufacturing rights. Different products may be manufactured by different AM service providers, resulting in a flexible network of suppliers.
  - **Centralization of AM production.** The volume and/or complexity of some products that can only be manufactured using AM technologies may require the emergence of large production centres based on this technology. These would have similar limitations to those of traditional technologies in terms of transport and supply, but would have a manufacturing flexibility and a considerably higher change management capacity.

- Pros:
  - In general, the use of additive manufacturing technologies for production can lead to a movement of the productive centres towards the end user, simplifying networks and reducing times for transport and supply.
  - This increases the control and degree of influence of logistics operators on the supply process, giving rise to more flexible structures than traditional ones.
  - In turn and considering that production may no longer depend on the original producer, there is an increased capacity to react to unforeseen needs.

- Cons:
  - Use of the different supply scenarios described requires an important knowledge about internal production capacities, as well as those of end user or third-party suppliers of additive manufacturing services.
  - The greater flexibility in production, and therefore in supply and transport, adds a new dimension to the planning activity, which may require the adaptation of existing planning tools.

9.4.2.5. Logistics Value Chain Summary

Chain value Step	Brief Description	AM PROS	AM CONS
NEED FOR PRODUCTS	Initial definition of a procurement need relating to products or services.	Decentralization of production facilities Personalization Reduction of flows and times associated with transport of products	Not all products will benefit from AM Each product will require a technical-economic evaluation The processes of quality assurance will be significantly modified
ASSESMENT/ STOCKING PLAN	Ensure the provision of the necessary resources to the different levels, in a time that ensures putting them into service in the most effective and efficient way.	Reduction of supply times, reduction or elimination of stocks Increase in the degree of control Ability to deal with unforeseen circumstances	Price of products manufactured using AM technologies will in principle be higher Complexities in supplier management as well as in quality control
PRODUCTION	Stage that gives rise to the generation of a product and which in turn generates a series of previous and subsequent logistical processes.	Relocation and dispersion of production of products → reduction of supply times and increase flexibility Acquisition of the product itself → acquisition of the manufacturing right Possibility of having networks of nearby suppliers of 3D printing services	Unit price of a product manufactured with AM may be higher than with traditional ones Uncertainty about the quality of the products when transferring the processes of assurance Requires knowledge and monitoring of AM suppliers in order to establish and accredit their capacities
SUPPLY	Although not providing a direct value to the final product, it has a considerable impact on aspects such as the timing of supply and the total product.	Approach of the productive centres towards the end user Increased control and degree of influence of logistics operators on the supply process Reaction capacity is increased	Requires knowledge about own production capacities as well as those of suppliers of AM services Adaptation of existing planning tools
PRODUCT SUPPLIED	——	——	——

Table 25: Logistics value chain summary (own creation)

9.4.3. Field Applications Value Chain

Figure 51: New solutions value chain (own creation)

There are several **needs that can arise in the operating environment itself, e.g. products, product customizations, accessories, etc.**, whose need may arise at a given time, and for which the market does not offer a solution, or a solution is not accessible in time by means of current manufacturing technologies/logistics processes.

In this case, "solutions" are required: elements that can quickly be designed and manufactured, so that in a few hours or days an idea can become a solution, without having to consider other complexities. **This approach is possible when there are productive means that allow such development to be carried out without the complexities of a typical product development process** (i.e. one that depends on an external supplier with the appropriate capacities).

There are **many areas in which this type of capability can be of great use,** some examples being:

- Repairs and corrective maintenance. In certain situations, the breakage or wear of a non-part may become a problem of maximum magnitude if this impedes normal operations and if there are no means to obtain the part within an acceptable timeframe. In such cases, the power to "design" and manufacture the piece without needing a machine and operator, or even a person with basic engineering and design skills can make a big difference.

- Resolution of difficulties or operational problems. Sometimes, a problem may not be the lack of a product/element, but the inability to fully adapt it to its expected function. This may be due to a changing environment, physical and functional diversity of people, new uses for which they are not prepared, etc. Sometimes the ability to adapt/customize the functionality of an element can be as simple as designing and making an adapted clip, replacing one part with another that is more user-friendly, making an accessory that allows the combined use of several elements, etc.

The above are just two examples of situations in which the existence of own means of manufacture of some elements can be key to the generation of solutions that can have a high impact in the operating environment; **AM field applications**. In addition, although by definition, these "solutions" are born as non-standard, their **capacity for replication and expansion beyond the original need can lead to standardized solutions and products**, developed by those people that generated the original need.

9.4.3.1. AM Impact on Value Chain Step: Need for New Solution[87]

- **Value Chain Step Description: when a need is not covered by the existing products in the market, or they are not accessible due to time or geographical limitations, a new solution is required** that allows a certain problem or operational complication to be overcome and without which normal activity could be easily compromised.

- **AM Potential Impact on this step**: if there is one remarkable aspect of additive manufacturing technologies (whether in a manufacturing environment or in a user environment), it is its ability to turn a 3D design into something tangible in a matter of hours, providing a responsiveness to unforeseen and unparalleled needs. Thus, **the availability of additive manufacturing facilities at points where an unforeseen need may arise or where simple but useful solutions can be manufactured and tested**, are the basis of the value that AM technologies can offer when used directly in an operating environment.

- **Pros**:

    - Substantially increases the capacity to devise and develop solutions for specific or recurring needs.

    - The ability to use additive manufacturing technologies to provide quick solutions to failures and unforeseeable operational problems undoubtedly provides an important operational advantage.

    - Users stop being mere receivers of products and elements, and can be an active part of improving them, devising and developing accessories, extensions and improvements.

    - With AM facilities available in the operating environment, they provide means for creating new solutions which can then be shared and later evolved in a more global product scope.

- **Cons**:

    - The ability to develop new solutions in the field is directly dependent on the capacity and knowledge of human resources in design and engineering therein.

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[87] *The contents of this chapter are the result of experience gained by Fundación Prodintec and MBDA through their years of AM experience.*

- In an environment in which an additive manufacturing machine can be an important part of the activity, these capabilities are critical resources whose control and correct management must be assured: access to resources, control of information used and generated, etc.

- The maximum use of the solutions generated requires their systematic management and communication, so they are not restricted to specific localized uses and can be used in a broader operating environment.

- The non-existence of unique additive manufacturing technologies, as well as the possible post-processing needs of solutions can increase the complexity of their implementation. In this sense, packaged solutions are required for use in the operating environment.

9.4.3.2. AM Impact on Value Chain Step: Definition[88]

- **Value Chain Step Description: every new solution must be defined** in order to ensure that it has the capacity to cover the needs. It is important that the initial stage of the development of a new solution is agile but systematic. Not only must the actual need be understood at this stage, but also the final operating environment and ultimately any condition that may influence the success of the solution.

- **AM Potential Impact on this step**: clearly, the **incorporation of additive manufacturing into a process of generating new solutions removes the constraints associated with the absence of manufacturing technologies in the field**, or the presence of more traditional, more limited manufacturing means. Additive manufacturing allows the evolution from “improvisation” and the generation of punctual and non-durable solutions (to needs that may be not so punctual and repetitive) to the generation of solutions which can evolve and become a permanent solution.

- **Pros**:

    - The creative freedom provided by AM technologies is unparalleled, causing a qualitative leap in the ability to react and adapt to problems and needs. From “using what we have to provide a solution” to “creating that solution from scratch”.

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[88] *The contents of this chapter are the result of experience gained by Fundación Prodintec and MBDA through their years of AM experience.*

    - Having these types of capabilities broadens the capacity of groups of people to be proactive in defining improvements and posing solutions to existing problems.
    - Short time frames to see tangible solutions that meet needs.
    - Significant potential for improvement once the first solutions are generated, based on the definition of successive improvements and their implementation once initial testing has been carried out.

- **Cons**:
    - Although the technologies of additive manufacturing have remarkable capacities, each of them has its peculiarities and limitations that the definition stage must take into account: materials, geometric limitations, etc.
    - The possibility that users become "producers" of the solution to their needs adds the complexity of having internal systems to manage and control access to these resources.
    - Both the needs and the information generated as a result of its management are important assets, which managed without a certain control can lead to leaks of critical information.

9.4.3.3. AM Impact on Value Chain Step: Assessment and Development[89]

- **Value Chain Step Description:** when a solution to a problem or need cannot be satisfied by improvised means, the traditional processes of generation of new solutions require an agent able to evaluate and develop a solution. Even simple elements of low complexity can cause problems that traditionally can only be satisfied by a supplier with capacity to evaluate, develop and supply such elements. In this sense, **traditional technologies require a stage of need assessment, in which the technical feasibility of providing a solution can be established, as well as evaluating the associated time and cost.**

- **AM Potential Impact on this step**: there will be solutions that, due to their complexity or scope, will in many cases depend on external valuation processes such as the ones mentioned. However, in **less complex cases, it will be simpler to assess the feasibility of a solution and the suitability of AM technology**, and if suitable, to proceed to develop and manufacture it,

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[89] *The contents of this chapter are the result of experience gained by Fundación Prodintec and MBDA through their years of AM experience.*

with no more limitations or constraints than the availability of raw materials. This does not mean that there are no internal evaluation processes of a solution before proceeding to its development and manufacture (since all production, even at a small level, consumes resources), but the "ownership" of this process is transferred to the end user and not to an external entity with commercial interests.

- Pros:
    - The end user is the "owner" of the whole process: defining the need, evaluating the best way to reach a solution and developing, manufacturing and implementing it.
    - Many technical solutions require only basic knowledge of design and engineering, so the processes of generation and prior assessment of solutions tend to be agile.
    - The evaluation of a need, as well as the proposal of solutions is carried out by personnel directly associated with the environment where they are generated, bringing a significant operational advantage.
- Cons:
    - Not all solutions will be possible with a single additive manufacturing machine; in this sense, the available means and materials are perhaps the strongest limitation in offering solutions for all needs that may arise.
    - Although personnel with an expert degree of competence and experience will not generally be required, the definition and assessment of needs and the development of solutions require the presence of technical personnel with sufficient competence. Without such capacity, this work must be outsourced or carried out by staff in other locations, who may not be so in touch with the need.

9.4.3.4. AM Impact on Value Chain Step: Production and Supply[90]

- **Value Chain Step Description:** the stages of production and supply are those that guarantee:
  - The **manufacture of the solution** to the stated need.
  - The **transport and delivery** of this solution to end user.

  Traditionally these are parts of the overall process in which the end user has no capacity to act, being tasks that generally depend on third parties (production), or agents, or infrastructures of transport and supply in which the end user is a mere receiver.

- **AM Potential Impact on this step**: in the present context, **additive manufacturing technologies have the ability to turn the end user into a manufacturer**, allowing the move from mere ideas to tangible elements in a considerably more agile way than in traditional manufacturing paradigms in which customers and suppliers are clearly differentiated entities.

  Although it is **still too early to generalize and to state that every end user will have, thanks to these technologies, a total capacity of "self-generation" of solutions** (much development of these technologies is still needed in both technological and non-technological areas), it has already been demonstrated that **with the right means, a large number of needs and problems are solvable thanks to these technologies.**

  The characteristics of these technologies make it possible to take into account different scenarios for manufacturing: using own facilities or by means available in nearby locations, use of selected suppliers, etc.

- **Pros**:
  - The versatility of additive manufacturing technologies, and their accessibility (technical and economic), make it feasible to implement them in different locations, without necessarily involving large investments in time and cost (e.g. FDM machines).
  - Different environments can be considered for production: decentralization of means of production to end users or to intermediate positions, use of near capacities, etc.

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[90] *The contents of this chapter are the result of experience gained by Fundación Prodintec and MBDA through their years of AM experience.*

  - The advantages associated with the close proximity of the origin of the need to the developer and manufacturer of the solution gives rise to design iterations and very agile improvements not possible with traditional processes.

- **Cons**:
  - When the solutions require the use of more advanced materials (e.g., metallic or high mechanical capacity plastics), the machines themselves and the post-processes required to treat the parts increase the complexity of the installation and the requirement of personnel.
  - Increasing complexity also makes it difficult to deploy all-purpose AM facilities directly to the end users due to cost and maintenance requirements.
  - There is still a lack of "bundled" facilities that allow the rapid transport and deployment of AM facilities with full capacity.

9.4.3.5. Field Applications Value Chain Summary

Chain value Step	Brief Description	AM Pros	AM Cons
NEED FOR NEW PRODUCT	Generation of a need to give rise to a new solution that allows a problem or operational complication to be overcome.	Substantial increase in own capacity to devise and develop solutions Users cease to be mere recipients of products and elements Ability to generate first prototypes of solutions that have shown their functionality	The ability to develop new solutions is directly dependent on the ability and knowledge of human resources in design and engineering Critical resources, whose control and correct management must be ensured The maximum use of the solutions generated requires the existence of systematic management and communication of these solutions AM packaged solutions are required

Chain value Step	**Brief Description**	**AM Pros**	**AM Cons**
DEFINITION	Every new solution demands an agile but systematic definition.	The creative freedom provided by additive manufacturing technologies is unparalleled Extends the ability of groups of people to be proactive Short deadlines for seeing solutions manufactured	Limitations of each AM technology Necessity for internal processes that manage and systematize access to these resources Information leaks
ASSESMENT DEVELOPMENT	Evaluation of the need, in which the technical feasibility of providing a solution can be established, as well as evaluating the time and cost associated with its later development.	The end user is the “owner” of the whole process: defining the need, evaluating the best way to reach a solution and developing, manufacturing and implementing it “Home-made” assessment, the processes of generation and prior appraisal of solutions tend to be agile The evaluation of a need, as well as the proposal of solutions is carried out by personnel directly associated to the problem	Not all solutions will be possible with any additive machine The definition and assessment of needs, and the development of solutions require the presence of technical staff with sufficient competence
PRODUCTION AND TRANSPORT SUPPLY TO FINAL USERS	The stages of production and supply are those that guarantee: - The manufacture of the solution for the stated need. - The transport and delivery of this solution to end users.	Feasible to implement certain AM technologies in different locations, without large investments in time and cost Different environments can be considered for production Advantages associated with a close proximity of the origin of the need to the developer and manufacturer of the need	Machines and the post-processing required to treat advanced materials increase the complexity of the facilities and the personnel requirement Difficult to deploy of “all-purpose” AM facilities directly to end users Lack of “bundled” facilities that allow the rapid transport and deployment of AM facilities
NEW PRODUCT SUPPLIED	—	—	—

Table 26: New Solutions value chain summary (own creation)

9.5. Graphical Summary of Most Important Pros and Cons for Each Value Chain

As a summary of the main pros and cons identified throughout the analysis of the previously defined value chains, the following can be identified as the main aspects outlined for each one:

- **Product development.**
  - Main pros: it is clear that additive manufacturing is an important tool when developing new and improved products due to: the possibility to eliminate design restrictions; the acceleration of the development processes (thanks to the ability to directly manufacture from a 3D file and to the elimination of fixed costs); and greater potential to offshore production and distribution.
  - Main cons: additive manufacturing technologies are not economically advantageous for medium or large manufacturing volumes, and aspects such as the lack of quality standards and recognizable certification schemes, as well as the need for specialization for their implementation, currently act as considerable entry barriers.
- **Logistics.**
  - Main pros: from a logistics point of view, additive manufacturing has an important capacity to bring manufacturing closer to the point of use, giving innumerable advantages in the field of logistics and increasing control over the entire process. Additional versatility can be added when own AM means are provided.
  - Main cons: the changes in the logistics paradigm that the introduction of AM may cause may bring about new problems, such as an increase in the complexity of supplier management, the lack of adapted tools for logistics management, and other issues associated with the transfer of quality control responsibilities when manufacturing is passed from the original producer to other organizations.
- **AM field applications.**
  - Main pros: the main advantages in this area are related to the added capacity given by the availability of own AM manufacturing means, such as the ability to define solutions to problems on the field and, from a general point of view, greater operational and adaptation capabilities.
  - Main cons: the great diversity of technologies, the current lack of “bundled” AM facilities and the need for specially trained personnel are undoubtedly the most important limitations to be taken into account.

The following is a graphical summary of these main advantages and disadvantages:

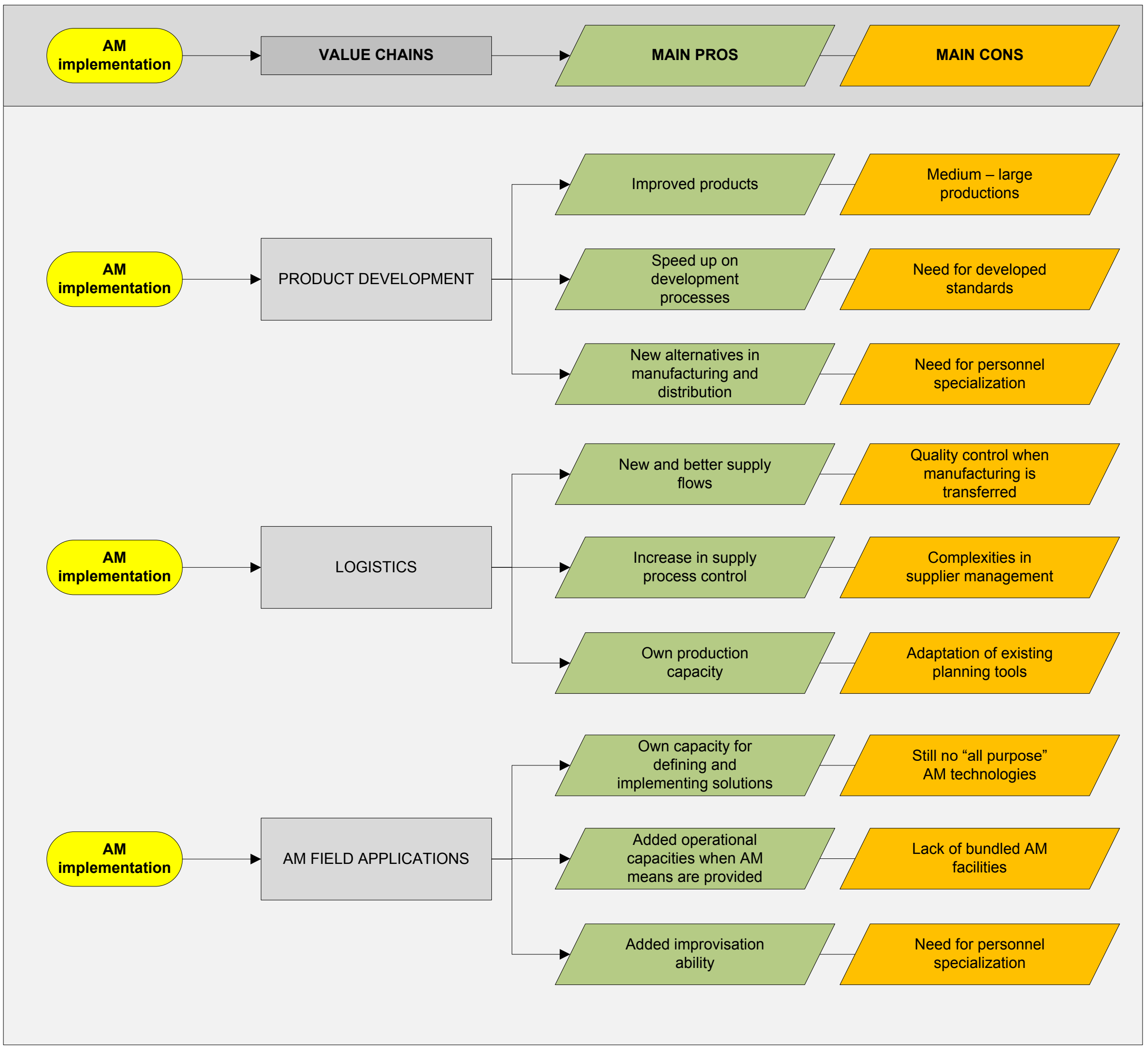

Figure 52: Summary of AM technologies Pros vs Cons for defined value chains (own creation)

10. Current Limitations of AM Implementation[91]

As with any other technology, additive manufacturing has a number of **limitations, associated with both the characteristics of existing technologies and their current state of development.** When assessing possible limitations, and especially with a technology that has the potential to change the traditional paradigms in the manufacturing field, two different types of limitations should be considered:

- **Technological limitations**: those inherent to the very characteristics of additive manufacturing technologies, only solvable through a development and increase of their capacities of the current technologies.

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[91] *This chapter has been developed as a summary of the most common and well-known current AM limitations from both technical and non-technical points of view, thanks to the analysis of the following sources of information:*

- Sofiane Guessasma, W. Z. (n.d.). Challenges of additive manufacturing technologies from an optimisation perspective. International Journal for Simulation and Multidisciplinary Design Optimization.

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- Bryan J. Voge. Intellectual Property and Additive Manufacturing / 3D Printing: Strategies and Challenges of Applying Traditional IP Laws to a Transformative Technology. Minnesota Journal of Law, Science & Technology. 2016.

- Roland Berger. Additive Manufacturing-next generation (AMnx) Study. 2016.

- Evan L.Pettus, Lt Col. Building a Competitive Edge with Additive Manufacturing. 2013. Air War Colleague Air University, USAF

- Ramon Knulst. 3D printing of marine spares, a case study on the acceptance in the maritime industry. Open Universiteit, Nederland. 2016.

- Daniel Hund. Metal AM in the automotive industry: New vehicle structures, series components for the luxury market and beyond. Metal Additive Manufacturing. 2016.

- Standardization Roadmap for Additive Manufacturing. America Makes & ANSI Additive Manufacturing Standardization Collaborative (AMSC). 2017.

- **Non-technological limitations: those associated with elements that, due to lack of adaptation to or experience of additive manufacturing technologies, impede the full exploitation of the capabilities of the technology.**

This study has tried to present the most important limitations currently associated with additive manufacturing technologies, which are presented graphically in the following diagrams:

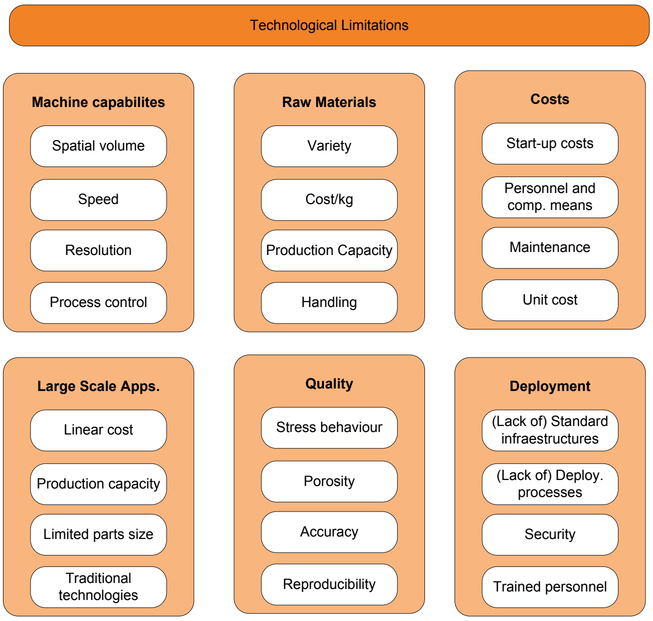

Figure 53: Summary of AM technological limitations (own creation)

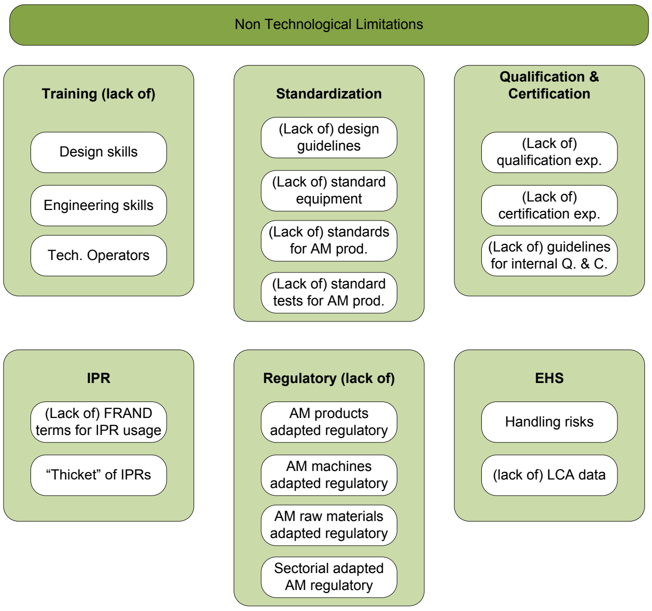

Figure 54: Summary of AM non-technological limitations (own creation)

10.1. Technological Limitations

10.1.1. Machine capabilities

- Spatial Volume: although there is a great variety of AM technologies, most of them are characterized by the fact that the spatial volume of manufacture is relatively small (compared to traditional technologies), normally less than one cubic metre (although technologies based on the use of robotic arms or movement on big axes have ostensibly greater volumes). Hence, most of them do not have the capacity to build very large pieces, requiring fragmentation and assembly by different means.

- Speed: layer by-layer manufacturing processes are generally slower than traditional roughing or shaping methods. The speed of all AM technologies is determined by: the height of the parts to be manufactured (more height means more layers); the amount of material per layer; the thickness of each layer (thinner layers means more layers); and the speed of the process of forming each layer (articulated arms, lasers, inkjet printers, etc.).

- Resolution: not all the technologies have the same capacity to reproduce detail. In general, they are limited by the thickness of layers (in current technologies the minimum thickness is several tens of microns, limiting the resolution in the Z axis), as well as the limitations inherent in each technology (particle size in power bed-based technologies, injection head thickness in FDM technologies, etc.) In this sense, they are at least one or two orders of accuracy behind traditional technologies when reproducing details and providing very high precision.

- Process control: one of the main limitations of current technologies is that they do not yet comprehensively integrate tools for the active control of the manufacturing process. Although they may operate unattended, these machines often lack control tools beyond the visual control; taking into account that an AM manufacturing process can last for several hours or even days, being able to have real-time information about the manufacture will be necessary to be able to act preventively before possible deviations occur.

10.1.2. Raw Materials

- Variety: although the availability of materials for additive manufacturing is in continuous evolution and very common manufacturing materials (PLA, polyamide, steels, etc.) are available in addition to other high specification materials (carbon fibres, titanium, etc.), the range of materials is still limited compared to those available in traditional technologies. This is fundamentally due to the fact that raw materials need to be specifically developed for AM in order to be processable and to ensure the mechanical properties of the parts made.

- Cost/kg: at present, the cost of the same raw materials for additive manufacturing may be one or even two orders of magnitude higher than for traditional technologies. The need to carry out additional processing (e.g. the atomization of particulate material) as well as the reduced manufacturing volume compared with materials for traditional technologies make the materials comparatively expensive. However, since additive manufacturing technologies cannot currently compete in manufacturing capacity with traditional ones, the comparison should take into account that additive manufacturing technologies are usually focused on comparatively small quantities.

- **Production Capacity**: although it cannot be said that that the current market for raw materials for additive manufacturing technologies is suffering from scarcity, it is for the moment a relatively small market. The most demanding materials (metals) depend on a limited market of suppliers compared with much larger markets that supply those same materials for traditional technologies.

- **Handling**: while there are materials whose handling poses no risk to health, there are others for which a number of precautions are required. Particularly when using particulate materials, the risks associated with their aspiration or even the possibility of inflammation in the presence of air or a source of heat, must be taken into account and the necessary precautions taken.

10.1.3. Costs

- **Start-up costs**: some technologies such as FDM are available as desktop machines, capable of transferring the capabilities of additive manufacturing to potential users in an economical way, but these machines have limited uses, mainly illustrative or non-mechanical functionality. When looking at AM technology at what could be considered an “industrial” capacity, the cost of such machines requires investment of several tens or even hundreds of thousands of euros.

- **Personnel and complementary means**: although the principles of operation of these technologies may be simple, to be able to take full advantage of them requires a certain level of design skill so it should be considered that more than a simple machine operator will be required. Additionally, some of the technologies require post-processing (thermostabilization, post-machining, surface treatments, etc.) so investment in additive manufacturing technology must take into account these added costs.

- **Maintenance**: all additive manufacturing technologies need a certain level of maintenance and the more advanced and capable the technology, the more demanding the maintenance. For example, the intensive use of additive manufacturing technologies based on the bonding of particulate metal material may cost up to several tens of thousands of euros per year.

- **Unit Cost**: starting from a base in which a small piece can either be made by a traditional technology or by additive manufacturing, the costs associated with the AM manufacture of a unit will always be significantly higher (when considering a traditional serial productions of thousands of units). Additive manufacturing technologies differ, but as a rule, all will require more manufacturing time and more energy, and although they will consume less material this is unlikely to compensate for the additional cost of time and energy.

10.1.4. Large Scale Applications

- Linear cost: traditional technologies usually display “non-linear” costs; the per-unit cost is lower the higher the manufacturing volume (cost depends mainly on the amortization of fixed assets). While it is possible to find optimizations in certain additive technologies (for example, in fusion power technologies, the unit cost will be smaller the larger the occupancy of the manufacturing volume), they are generally linear technologies. The cost of the unit produced is not dependent on the volume of production but on the cost of energy, raw material, and labour.

- Production capacity: currently, there are no high-capacity additive manufacturing technologies (capable of producing hundreds or thousands of units in reduced time) and greater capacity is only achievable through the addition of more additive manufacturing machines. Thus, they are used predominantly for prototypes or short series.

- Limited parts size: as described above, with the exception of additive manufacturing technologies using robotic arms (or similar systems for the movement of systems in large volumes), the maximum dimensions of manufactured parts are usually less than one cubic metre. This requires larger pieces to be fragmented and then assembled with matching materials.

- Traditional technologies: the success of traditional technologies is a significant impediment in the advancement of additive manufacturing technologies. Although they have several limitations, they have proved their worth for many industrial processes in the production of large volumes of the same product.

10.1.5. Quality

- Stress behaviour: some additive manufacturing technologies present mechanical limitations, the clearest example being FDM plastic technologies, where the deposition of the molten material layer by layer limits the cohesion between them, and therefore their resistance to stress traction on the Z-axis. This is not the case in powder bed processes where the heat source applied to each layer is sufficient to achieve a greater cohesion with the material of previous layers.

- Porosity: technologies based on the bonding of particulate material may have voids or pores between particles. Although these voids are very small, they can lead to leaks and poor mechanical properties when used in applications that manage fluids at high pressures.

- Accuracy: the accuracy of these technologies is currently limited by properties such as layer thickness/particle size, as well as by the precision of the mechanical and non-mechanical means used to deposit or shape the material. The accuracy of these technologies can reach around 100 microns in the most precise cases and if greater precision is needed, it is usually necessary to complement the additive manufacturing with subsequent processing.

- Reproducibility: although the various technologies use machines in which standard precisions and resolutions can be ensured, their characteristics mean total reproducibility is not guaranteed. As an example, the laser sintering technology for bonding metal powder often uses a laser beam that is directed towards the different points of each layer using a mirror system. Because of this, the angle of incidence of the laser will vary depending on the point of the layer on which it acts and it is impossible to ensure that the laser is exerting the same amount of energy per unit area at every point in each layer, giving rise to different degrees of union at various points in a part.

10.1.6. Deployment

- (Lack of) Standard infrastructures: the wide variety of additive manufacturing technologies and the considerable number of machines available for each technology, means that its application from an industrial point of view requires a considerable infrastructure, including raw material storage or necessary post-treatments. “Bundled” facilities in the field of additive manufacturing technologies do not yet exist and organizations interested in this technology must investigate the options in order to have an overview.

- (Lack of) Deployment Processes: just as the existence of bundled infrastructures is currently missing, so are “turnkey” projects, which can guide an organization through the industrial exploitation of an additive manufacturing process. This is also influenced by the lack of developed and consolidated standards in this area, which always help support the adoption of a new technology.

- Security: from the point of view of security, and especially in environments such as defence, resources associated with additive manufacturing can be identified as highly critical, providing users with capabilities they otherwise would not have. Hence, access to these resources, and especially the information generated by them, must be managed with regard to security, so that they do not fall into the wrong hands.

- Trained personnel: as with any new technology, specialized or trained personnel are required, both for the operation of the machines and for the designs they use. The latter is especially important since, as for any manufacturing technology, knowledge of the technology is needed to know the capacities and limitations that must be taken into account during the design process; a knowledge that currently, given the novelty of these technologies, comes not only from training but from direct experience.

10.2. Non-Technological Limitations

10.2.1. Training (Lack of)

- Design skills: as with any other manufacturing technology, additive manufacturing requires not only personnel capable of operating the machines, but those also of sufficient competence to apply the capacities and limitations of the technology to the design process. For example, some of the technologies require the addition of support structures that prevent the drooping of some layers onto others during the manufacturing process; defining these structures effectively and efficiently requires some depth of knowledge of the technology.

- Engineering skills: from an engineering point of view, additive manufacturing provides the ability to make a more rational use of the material and to give rise to equally resistant but lighter parts and structures (this is of particular interest for sectors such as aerospace, or for those products in which a smaller weight facilitates handling). This requires considerable engineering knowledge (calculation, simulation, etc.) to get the most out of these technologies and to produce clearly improved products compared to those manufacturable with traditional technologies.

- Technical operators: of all aspects related to training, training in the use of machines may be one of the most developed, but it is always necessary to take into account that, as with any other manufacturing technology, these technologies will require the specific training of the personnel authorized for handling.

10.2.2. Standardization

- (Lack of) design guidelines: the existence of different additive manufacturing technologies means that each of them has its own peculiarities and that in practice it is difficult to generalize how to design for additive manufacturing technologies. In this sense, the main route of organizations for learning is the experience itself, which although effective is not always desirable for a large implementation. Although current software products have begun to include help systems, they do not yet have the potential or capabilities necessary to assist them in a more comprehensive and complete way.

- (Lack of) standard equipment: just as there are different additive manufacturing technologies, there is also a wide availability of machines for each of them and there are currently no features that can be considered standard. Thus, each of them has different materials specifications, manufacturing volumes, precisions, layer thicknesses, etc., making it difficult for potential users to have a clear idea about their capabilities or to make an informed comparison between them. This is also applicable to any equipment, which may be required for the processing/recycling of materials or the post-processing of manufactured parts.

- (Lack of) standards for AM production: although a whole series of standards associated with additive manufacturing are in development[92], they are not yet fully developed. Additionally,

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[92] *See ISO Technical Committee 261's work on the definition of a whole range of standards associated with additive manufacturing:* https://www.iso.org/committee/629086.html

experience in the implementation of additive manufacturing processes from an industrial point of view is scarce and information lacking.

- (Lack of) standard tests for AM products: one of the main concerns regarding additive manufacturing technologies arises from doubts about its ability to give rise to parts and products with similar capacities and behaviours to those obtained with traditional manufacturing technologies. As mentioned, the particularities of each process may have an impact on the subsequent behaviour of the part or product, requiring a standard process to ensure the quality and reliability.

10.2.3. Qualification & Certification

- (Lack of) qualification experience: the lack of standards associated with additive manufacturing technologies means that when an organization wants to incorporate some of them into its manufacturing processes, it must do so according to its own criteria and systems, which implies significant efforts and resource investment. Hence, the existence of prior experience that can be transferred to other organizations is reduced, as the existing know-how tends to be a strategic resource.

- (Lack of) certification experience: as in the previous case, organizations lack references in relation to how to accredit the capacity of a manufacturing process that makes use of AM technologies, again depending fundamentally on own efforts and/or joint work with collaborators and clients, to give rise to processes that are traceable, recognizable and credible by all interested parties.

- (Lack of) guidelines for internal quality and control: the current lack of publicly accessible, detailed guides to implementation processes, qualification and certification of AM manufacturing technologies, where both the possibilities/constraints and the certainties/ uncertainties are clearly identified, prevents these technologies from being seriously considered by potential users.

10.2.4. Intellectual and Industrial Property Rights (IPR)

- (Lack of) FRAND (Fair, Reasonable, and Non Discriminatory) terms for IPR usage: the ability of additive manufacturing technologies to manufacture almost any element from a 3D file, as well as the ease with which such 3D files can be transferred digitally, has a whole series of implications when evaluating possible rights and associated infringements. In this regard, at the industrial level, there is a lack of a recognizable framework providing security to the market. This security is fundamental in order to determine clearly the associated IPRs, as well as the rights and conditions for their fair use.

- “Thicket” of IPRs: not only is the lack of a clear environment for the use of technology at the IP level problematic, but this subject itself is a highly complex issue, where usually only expert advice can solve certain questions.

10.2.5. Regulation

- AM products regulations: from a regulatory point of view, there is currently no specific legislation governing products manufactured using additive technologies. While in sectors such as medical-sanitary, agencies such as the American FDA are making significant efforts to try to regulate the development and use of these products, generally any effort in this regard is still more attributable to self-regulation at sectorial level, than to the existence of legal frameworks.

- AM machines adapted regulatory: in the same way that the previous section highlighted the non-existence of standard equipment, nor is there currently any regulation of these devices, beyond the obligation to apply the CE mark certification process (as with any machine) at the European level.

- AM raw materials adapted regulatory: the reliability of the raw material to meet the specifications necessary to ensure a determined result is a fundamental step in ensuring market confidence in additive manufacturing technologies. In this sense, it is necessary both to clarify the position of AM raw materials within existing controls and to develop new ones.

- Sectorial adapted AM regulatory: the market is broad and the use of the same technology in different sectors is often associated with different characteristics and requirements. In this sense, the novelty of these technologies means that we are still at an early point of implementation and regulatory frameworks applicable to different sectors (where appropriate) have not yet been developed.

10.2.6. Environment, Health and Safety (EHS)

- Handling risks: some of the additive manufacturing technologies do not present particularly significant risks in their use, but in other cases the handling of materials and parts, the use of machines, etc. require the use of PPE (personal protective equipment) and the application of systems to ensure a safe working environment. Each technology requires a clear vision of the associated risks, so that they can be taken into account as an additional planning element.

- (Lack of) LCA (Life-Cycle Assessment) data: although there is common understanding that, from an environmental point of view, additive manufacturing technologies generate less impact, and although the literature associated with this aspect is progressively growing, there is a lack of global studies with the ability to establish how additive manufacturing performs in comparison with traditional technologies.

11. Asking Stakeholders about the Future of AM

11.1. Survey Conducted

As part of the project that backs this study, **it was decided to carry out a survey to ask organizations that work in the field of Defence about their perception and experience of additive manufacturing technologies.**

A questionnaire was developed to collect information about the implementation, use and future prospects of additive manufacturing in the field of Security and Defence, with the following fundamental characteristics:

- Open to any organization with presence/interest in additive manufacturing technologies and their current and possible applications in the field of Security and Defence.
- The objective of the survey was to identify the following points (each dependent on the characteristics and experience of the organization): main uses and limitations of the current technologies (for organizations with experience in Security and Defence and with the technologies of AM manufacturing); the main barriers of entry and limitations for their implementation (for organizations without experience of AM manufacture, or that have not yet worked in Security and Defence applications); and the future prospects that different organizations perceive for these technologies.

11.2. Questionnaire

The questionnaire was divided into four sections:

A. BASIC DATA: a simple characterization of the organization, its nationality, and its type (public body, research technology organization, defence industry, or other).

B. EXPANDED INFORMATION: further information about the stakeholder, with questions adapted to the type of organization.

C. ADDITIVE MANUFACTURING TECHNOLOGIES - EXPERIENCE: some questions regarding specific stakeholder's experience/lack of experience with AM.

D. ADDITIVE MANUFACTURING TECHNOLOGIES - FUTURE: for all types of organization, questions about the most important elements in relation to the future of AM technologies and their implementation.

As the following diagram shows, the survey could take different paths depending on the type of organization and the stakeholder's experience of AM:

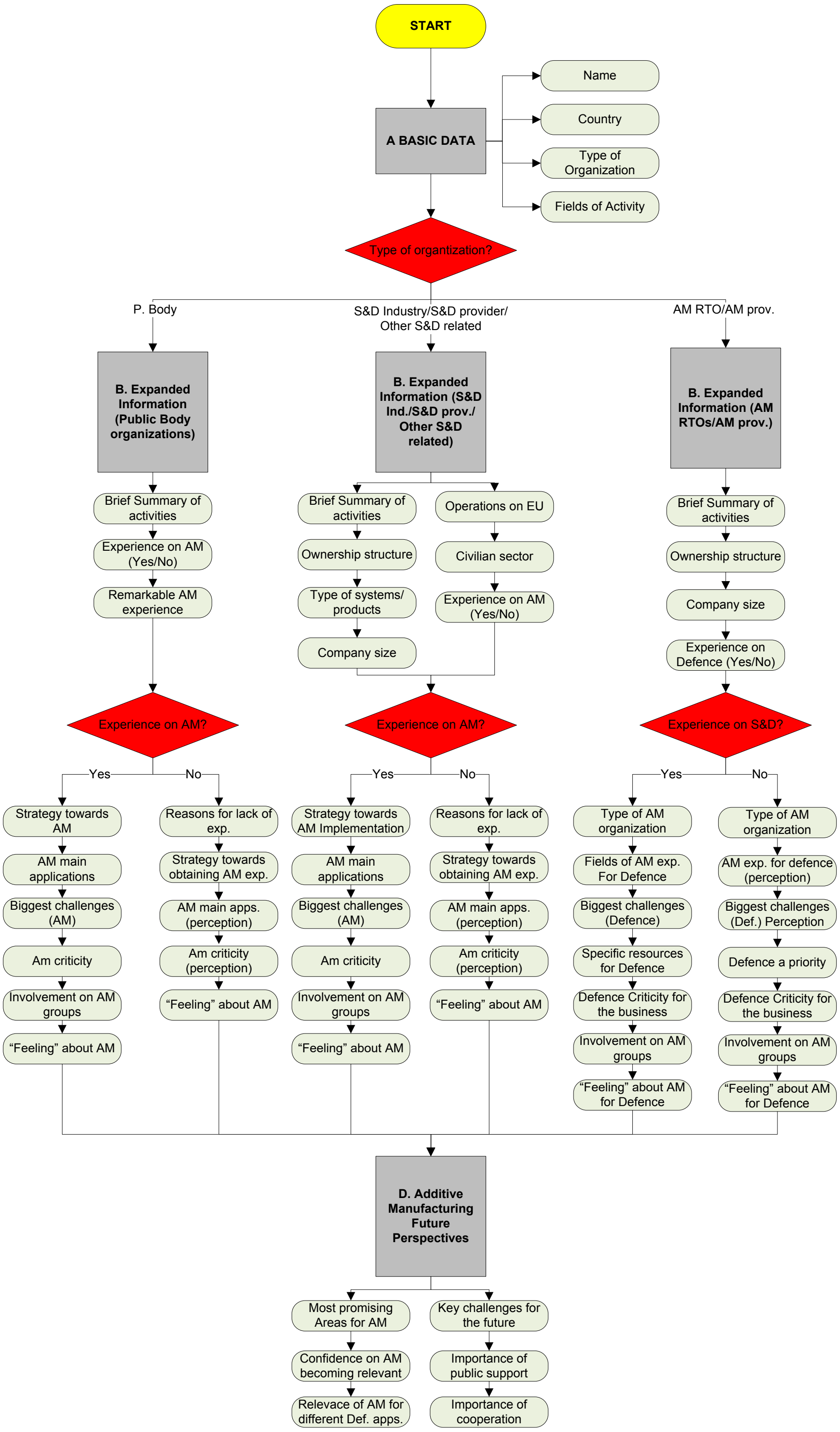


Figure 55: Conducted survey scheme (own creation)

11.3. Core Indicators

The basic data of the respondents is as follows:

Number of respondents	73 Experts 72 Organizations
Type of respondents	15 Public Bodies
	22 Security and Defence (S&D) Industries
	14 Research and Technology Organizations (RTOs)
	22 AM Providers
Represented Countries	Austria (1.4%), Belgium (15.1%), Estonia (6.8%), Finland (6.8%), France (11.0%), Germany (8.2%), Greece (4.1%), Ireland (2.7%), Italy (6.8%), Latvia (1.4%), Netherlands (6.8%), Norway (1.4%), Portugal (2.7%), Slovenia (2.7%), Spain (9.6%), Sweden (4.1%), Switzerland (1.4%), United Kingdom (6.8%).

Table 27: Conducted survey Core Indicators (own creation)

11.4. Main Survey Facts

The following are some of the most interesting results of the conducted survey:

- **Experience of AM/experience in Defence**
    - More than 80% of S&D organizations have some experience of AM and 50% have more than 2 years of experience.
    - Regarding the experience of AM organizations (RTOs or AM providers) within the S&D sector, the amount of organizations having a broad experience (>5 years) is low. However, the percentage of non-S&D experienced organizations and the percentage of organizations with less than 2 years of experience on S&D is significant (around 50%).
    - AM-experienced S&D organizations have mainly focused on acquiring AM technologies, and to a lesser extent in working closely with AM partners.

These facts indicate a possible gap between surveyed S&D organizations and AM provider/RTOs that, not having previously gained experience in the S&D sector, may not have been considered by AM-experienced S&D organizations when obtaining that experience.

- **AM main applications**
  - It is notable that prototyping is currently the main application (nearly 90%) for S&D AM-experienced organizations, followed by research and development (>75%), tooling (60%) and the production of final parts (55%). Looking at S&D organizations with no experience of AM, prototyping is perceived as the main application for AM (nearly 75%).
  - Comparing this data with AM-experienced public bodies, prototyping is also the main application, although the next placed application is repair/spare parts (more than 65%) and research and development (nearly 45%). However, public bodies with no experience of AM clearly perceive AM as a tools for manufacturing repairs and spare parts (100%), followed by research and development (80%), production of final parts (60%), and the remainder of the proposed applications (all of them at least 40%) with the exception of "testing" (0%).

  It appears that there is a lack of correlation between different types of stakeholders regarding their appreciation of AM applications.

- **AM biggest implementation challenges for AM-experienced organizations**
  - In general, for AM-experienced organizations, qualification and certification is the main concern (>70%), followed by know-how and talent needs (60%) (although here there is a significant difference between S&D organizations (>70%) and Public Bodies (40%)). To a limited extent, economical and technical aspects are also of concern to some organizations.
- **AM criticality for public bodies and S&D organizations**
  - No large difference is seen between AM-experienced public bodies and S&D organizations, since more than 75% declare that AM is critical for the future (already critical or critical in the mid-term).
- **S&D business criticality for AM RTOS and AM providers**
  - One of the most interesting facts of this survey is that globally, more than 55% of AM RTOs and AM Providers do not currently see S&D business as critical.
- **AM platform membership**
  - One thing to highlight is that more than 50% of S&D organizations with experience of AM are not integrated in any AM platform, while more than 70% of AM RTOs and AM providers do take part on this kind of platform.
- **Most promising areas for AM**
  - The majority of contacted organizations think that prototyping/small series will continue to be the main application in the future (nearly 80%), followed by product customization (>60%), new materials, product development and sales (nearly 55%).
  - There are some differences in perception between AM-experienced and non AM-experienced organizations. In certain applications ("prototyping/small series

manufacturing" and "product customization"), the latter are pretty certain (100%) about the utility of AM, about 20-30% ahead of the AM experienced organizations.

    - If one looks for specific applications seen as "essential" or "very relevant", there are three clear leaders: "medical and surgery" (>60%), "evolution of aerospace/naval/terrestrial unit" (>60%) and "vehicle/machinery maintenance repairs" (approximately 55%).
    - Most people surveyed think that AM will not be clearly focused on either in-house operations or field operations.
    - It is notable than AM-experienced S&D organizations do not see operational support opportunities. This is logical since their businesses are more focused on providing products/services than field support, but indicates a gap in their knowledge of possible applications.

- **AM: Key challenges for future AM exploitation**
    - Qualification and certification is once more the main challenges for the future, being the only one close to 60% (surpassing it for S&D organizations). Quality-related challenges came second.
    - It is notable that AM technologies are perceived as immature by nearly 50% of S&D organizations.

- **Appreciation of the importance of cooperation and public support for exploiting AM**
    - These are perceived as relevant issues, with 70% of respondents considering cooperation to be essential or very relevant, and more than 55% of respondents considering public support to be essential or very relevant.

12. SWOT Analysis

Throughout this document, a number of advantages and limitations associated with additive manufacturing technologies have been correlated, both directly and indirectly. These can be included within the framework of a SWOT analysis (strengths, weaknesses, opportunities and threats), summarized in the following table:

Weaknesses		**Threats**	
1	Lack of technological maturity	1	Lack of practical experience
2	Cost and investment of initial implementation	2	Lack of regulatory and standardization frameworks
3	Lack of knowledge of potential users	3	Lack of guides and guidance
4	Lack of bundled and deployable equipment	4	Lack of IPR framework
5	Lack of decision making systems	5	Lack of specialized staff
Strengths		**Opportunities**	
1	Manufacturing from 3D models	1	Development of new and improved products
2	Manufacturing of functional prototypes and short series	2	Logistical optimization
3	Technologies adapted to different uses	3	Creation of manufacturing capacities “in the field”
4	Decrease in the time and cost of developing new products	4	End user as generator of technical solutions
5	Increased manufacturing and supply options	5	New possibilities of interaction with suppliers and collaborators

Table 28: SWOT analysis table (own creation)

A further description of each of the indicated aspects is provided below:

Weaknesses

- Lack of technological maturity. It is clear that additive manufacturing technologies are far from fully mature and that the means currently available probably do not reflect all the capabilities and characteristics that these technologies will achieve in the near future. Nowadays, despite current capabilities, it offers a number of important advantages, but with a number of technical limitations that makes their use in a productive environment still limited.

- Costs and investments for initial implementation. As with any new technology, its degree of implementation cannot yet be considered broad, indicating that the costs associated with its implementation are considerable (particularly in technologies oriented to the development of functional elements) and especially when comparing with current economic performance (difficult to reliably forecast).

- Lack of knowledge at the level of potential users. One of the greatest weaknesses of additive manufacturing technologies is the lack of knowledge, or very basic knowledge at the level of potential end users. Although usual for a new technology, a lack of demand due to limited knowledge can weaken the impetus to implement the technology at a global level.

- Lack of bundled and deployable equipment. Especially for on-site uses, there is currently no complete “package” of additive manufacturing equipment available to potential customers. Some of the potential uses of additive manufacturing depend precisely on the possibility of providing manufacturing capacity on the ground, and hence the absence of such facilities can be a significant constraint.

- Lack of systems for decision making. Systems have not yet been sufficiently developed to support decision making in the area of additive manufacturing, especially from an organizational or logistical point of view. Such systems could help evaluate each case for its potential to gain operational and/or economic advantages by the implementation of AM processes by reducing of supply times/ costs or by increasing critical operational capacities etc.

Strengths

- Manufacturing from 3D models. The ability to pass directly from a 3D file to an element or product is undoubtedly an innovation with the potential to modify greatly the way in which products are developed and manufactured, as well as to modify the way in which the products are supplied and delivered to the end users, even turning the latter into their own producers.

- Manufacturing of functional prototypes and short series. The current capabilities of additive manufacturing technologies (including the ability to manufacture in metallic materials and high-strength plastics) make them suitable at present for the production of fully functional prototypes, as well as for the production of short series of products, which benefit from the lack of need of added tools or investments to enable their manufacture.

- Technologies adapted to different uses. Although the existence of a wide range of different additive manufacturing technologies could be interpreted as a weakness (because it impedes a global understanding and knowledge of these technologies by potential users), it does gives rise to multiple options to implement the technology, depending on the planned uses.

- Decrease in the time and cost for developing new products. The ability to manufacture fully functional prototypes and models without the need to develop tools or to undertake additional investment makes it possible to move “from the drawing to the product” at reduced cost and in record time compared to traditional technologies. This not only implies an optimization of the product development processes, but also indirectly increases the number of design iterations and therefore the ability of a product to be improved between successive versions.

- Increased manufacturing and supply options. Additive manufacturing makes possible the off-site manufacture of products, bringing a completely new world of possibilities from the point of view of planning and logistics.

Threats

- Lack of practical experience. The lack of an extensive number of success stories that are publicly known/widely disseminated, adequately described, recognizable and sufficiently representative for the defence sector can undoubtedly act as an obstacle to the implementation of the technology.

- Lack of regulatory and standardization frameworks. Although currently under development, the lack of defined normative and standardization frameworks, as well as the lack of experience in implementing them, may generate some mistrust, in that potential users may require a framework that ensures quality and the reliability of the elements and products produced with these technologies.

- Lack of guides and guidance. Although the advantages of additive manufacturing are undeniable, it is also true that their use (especially the more ambitious applications) requires knowledge about the principles that guide the design and manufacture processes of each technology. Once again, the lack of technological guidance about the application acts as a limit to its growth.

- Lack of IPR framework. The digital nature of additive manufacturing technologies allows anyone with a 3D model and a suitable machine to produce one or more units of an element or product. In the same way, and in combination with digitalization technologies of real elements and products, it allows the reproduction of any element or product, even without having access to the original 3D files. Without a specific regulation or clear perception of associated intellectual and industrial property rights, there is a danger that the uncontrolled use of additive manufacturing technologies will lead to a systematic infringement of property rights.

- Lack of specialized staff. Due to its early stage of implementation, the number of professionals with competence in additive manufacturing technologies is still small and training programs or specific courses (industry-oriented) are few in number.

Opportunities

- Development of new and improved products. The possibility of manufacturing almost any geometry in a short time opens up a whole series of new possibilities when developing new products, which without the previous limitations can display characteristics impossible with traditional technologies. Additionally, the speed with which these technologies are able to implement product development processes and the customization options open the door for this technology to contribute to an environment in which different products can undergo considerable development.

- Logistic optimizations. Thanks to the technologies of additive manufacturing, it is possible to evolve from a traditional scenario of centralized production to one in which almost any site can become a production centre, thus offering a high potential for the optimization of logistics processes. The complementary development of decision-making systems to consider the possibilities of additive manufacturing can undoubtedly help to detect such optimizations.

- Creation of manufacturing capacities “in the field”. The opportunity to have a tool that allows the production of elements and products in the field is undoubtedly one of the main opportunities provided by additive manufacturing, with uses and applications that, although they have to be determined based on future experience, will be without doubt of high importance.

- End user as generator of technical solutions. The possibility of putting a production tool into the hands of an end user gives them the potential not only to improvise and define solutions to problems, but also to manufacture them. This will undoubtedly be an important tool in giving quick and accurate answers to the problems that may arise “in the field”.

- New possibilities of interaction with suppliers and collaborators. Additive manufacturing allows the production of an item or product to be moved to almost any part of the world. This will redefine the supplier-customer relationship, giving rise to situations in which the owner of a product can even hand over (under contractual conditions) the 3D model of a product to a customer, so that it is the customer himself who manufactures it.

13. Overcoming Existing Barriers

Section 11 illustrates the limitations that currently exist in relation to the development and implementation of additive manufacturing technologies. In relation to these, and based on trends in the current environment of additive manufacturing, it is possible to establish **general roadmaps that outline a scenario of development of additive manufacturing technologies, at all points where limitations have been reported**. For each of them a forecast is made of its plausible evolution in the short term (next 5 years), medium term (between 5 and 10 years), and long term (more than 10 years).

13.1. Technical Factors

13.1.1. Machine Capabilities

Factors	Short-term	Mid-term	Long- term
Machine capabilities	Increase in part size capabilities		
	Increase in speed		
		Significant improvements on resolution	
	Process control and monitoring improvements		

Figure 56: Machine capabilities roadmap (own creation)

- Increase in part size capabilities. As confirmation of the trends already detectable, currently available machines are progressively increasing their volumes of manufacture. Technologies based on the deposition of material are highly likely to experience a considerable increase of scale, integrating them into mechanical systems that allow movement in wide axes. However, in the case of other technologies, such as powder bed fusion, it is not expected that scale increases will be so pronounced, with their specifications, by definition, making this possibility more complicated. Very new technologies such as printing with metallic inks may not be affected by these limitations and may lead to scale increases greater than expected, but these are technologies that still have “much to prove” from a technical point of view.

- Increase in speed. The “layer by layer” manufacturing concept is a clear limitation for the speed increase of any AM technology since, regardless of other characteristics, the speed of manufacture is essentially a factor of the size of the part, the thickness of each layer and the precision and resolution required. However, today's machines are still new products and it is possible to foresee in the next few years an evolution that increases their speed, although they will always tend to be prejudiced in a direct comparison with traditional technologies regarding this subject.

- **Significant improvements on resolution**. The resolution of these technologies is a direct consequence of the principles of operation of each of them, so that even taking into account a foreseeable evolution, a significant leap in the ability of these technologies to reach precisions that are currently impossible is not predicted in the near future. Although current additive technologies will evolve greater capabilities such as speed and efficiency, the leap to quantitatively higher levels of accuracy can probably only occur when successive generations of additive manufacturing technologies emerge to replace current technologies, which will have by then reached their technological and productive “cap”.

- **Process control and monitoring improvements**. Given the difficulties that arise when a manufacturing process is not able to provide information during production (in order to prevent deviations), improvements that allow the monitoring of these processes is already being considered. One such development is the incorporation of infrared cameras in powder bed fusion technologies to evaluate if they are generating tensions and heats that could cause the manufacturing process to suddenly stop. It will be seen in the near future how these complementary means are naturally incorporated, either as standard or optional equipment especially in machines with more industrial characteristics.

13.1.2. Raw Materials

Factor	Short-term	Mid-term	Long- term
Raw materials	Increase in raw materials variety		
	Decrease in raw materials costs		
	Increase in raw materials production Capacity		

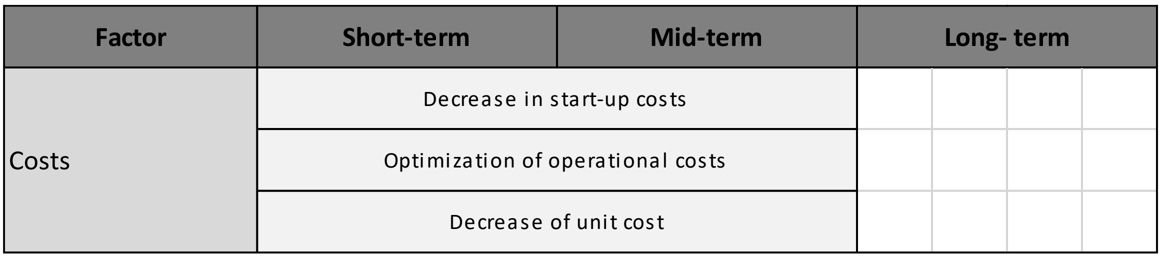
Figure 57: Raw materials roadmap (own creation)

- **Increase in variety of raw materials**. It is difficult to predict the extent to which the variety of materials available for additive manufacturing will become comparable to the range of materials available for traditional technologies, but what is certain is that there will be a continuous emergence of new materials which will increase the possibilities of these technologies. Currently, the driving force behind the development of new materials comes from early adopters, in fields such as medicine or the aeronautical sector; in the future, more sectors will become part of this “pressure” for the development of materials for additive manufacturing.

- **Decrease in raw material costs**. The progressive market penetration of AM manufacturing technologies will allow the growth of the market of material suppliers. This in turn will lead, when the market reaches a certain maturity, to price reductions up until the technology approaches or reaches its maximum point of insertion in the market.

- Increase in raw material production capacity. Associated with the above points, it can be predicted that the overall ability to produce materials for additive manufacturing technologies will grow and will not present an impediment to the use of the technology at more global levels.

13.1.3. Costs



Factor	Short-term	Mid-term	Long- term
Costs	Decrease in start-up costs		
	Optimization of operational costs		
	Decrease of unit cost		

Figure 58: Costs roadmap (own creation)

- Decrease in start-up costs. With the increase of AM technology markets, the increase in operational efficiency of existing technologies, and the emergence of new suppliers and new market niches, a future decrease in the cost of initial implementation of additive manufacturing technologies is to be expected. However, it should be borne in mind that, except for products classifiable as “desktop”, we are talking about industrial machinery which will always require a considerable investment.

- Optimization of operational costs. The operating costs of additive manufacturing technologies depend on the same factors as any other technologies: resource consumption (energy and raw materials), staff hours, and maintenance costs. Over the next few years, it can be expected to see improvements on the current “initial versions” of AM technology and accumulated experience will allow a more rational use the machines. This will undoubtedly result in a decrease of operational costs, although this reduction will stabilize as the technology matures, at which point only the emergence of a new generation of AM technologies will have the potential to continue to reduce costs.

- Decrease of unit cost. As already mentioned, without taking into account the volume of units to be produced, the unit cost using additive manufacturing technologies tends to be linear, and despite the progressive availability of more capable and efficient technologies that may result in a lower cost of each unit produced, this cannot change this fundamental feature of any layer-by-layer manufacturing technology. Although a progressive decrease in unit cost may be seen as the current AM technologies approach maturity, a significant change in linearity of cost is not predicted.

13.1.4. Large Scale Applications

Factor	Short-term	Mid-term	Long- term
Large Scale Apps.	Decrease of unit cost		
	Increase in production capacity of AM means		
	Increase in part size capabilities		
		Medium series	Large series

Figure 59: Large Scale Applications roadmap (own creation)

- **Decrease of unit cost**. Given that the unit cost is one of the main reasons that may prevent the use of additive manufacturing for the manufacture of high numbers of units, it is expected that in the coming years, the successive generations of equipment will increase their capacity (manufacturing volume) and speed, and there will be an optimization in the use of resources. Taking into account the characteristics of current AM technologies, the linearity of the unit cost will continue to apply, but there will be a greater certainty as to the number of units that represents the limit of technical and economic efficiency for each technology. In the long run, it is expected that new generations of AM technologies will be able to reach successively higher limits, but the characteristics of traditional technologies mean they will always be one step ahead when producing large numbers of units at a reduced cost.

- **Increase in production capacity of AM means**. The increase of the technical capacities of the existing technologies, as well as their progressive optimization and automation, will allow them to increase their productivity. The same restrictions to optimization that have been discussed previously still apply and, although it is not realistic to propose that they can reach the capacity of traditional technologies in the coming years, there will be a much greater certainty about the limits of economic feasibility for these technologies.

- **Medium series**. The capacity increases of the current additive manufacturing technologies will bring them to a point of maturity, which for certain applications will allow the production of products or elements in medium series quantities. This will also be supported by the progressive evolution of the global market towards the offer of customized elements and products, which will favour the use of AM technologies for which it is not necessary to carry out production changes and investments.

- **Large series**. Although the increase in the capacity and performance of existing additive manufacturing technologies will allow them to undertake the production of medium-sized series, those products or elements that must be manufactured in a very high number will continue to be almost completely economically disadvantageous. Successive generations of AM technology may be able to change substantially this, but by its very nature, no additive manufacturing process will be able to reach the capacity thresholds of a traditional manufacturing process. A classic example of this fact is the manufacture of plastic products by means of plastic moulding: what for the traditional process takes seconds and a few euro cents to form one piece, can take minutes and several euros for an additive manufacturing technology.

13.1.5. Quality

Factor	Short-term	Mid-term	Long- term
Quality	Improvement of mechanical behaviour of AM parts		
		Significant improvements on accuracy and reproducibility	

Figure 60: Quality roadmap (own creation)

- **Improvement of mechanical behaviour of AM parts**. The lack of certainty of the mechanical capabilities of elements manufactured using additive manufacturing technologies will be progressively solved, based on the proliferation of studies, standards and standardized post processing treatments. These will provide a framework for the accurate assessment of the advantages and limitations of each additive manufacturing technology, and clear information in this regard on the part of all the involved agents.

- **Significant improvements on accuracy and reproducibility**. The improvement and optimization of existing AM technologies in the coming years will increase their accuracy and reproducibility. However, since current technologies are based on principles of operation whose capabilities and limitations are known, it is likely that a leap to higher levels will require the emergence of new technologies, using different physical principles than current additive manufacturing technologies.

13.1.6. On Site AM Deployment

Factor	Short-term	Mid-term	Long- term
On site AM Deployment	Standard Infrastructures development		
	Standard deployment and operation processes		

Figure 61: On site AM deployment roadmap (own creation)

- **Standard infrastructure development**. The implementation of additive manufacturing in certain sectors and applications may require the existence of mobile infrastructures with a high capacity of deployment on demand. Therefore, it is expected that, in the coming years, “bundles” that contain everything necessary to be able to deploy some of the technologies will proliferate. Logically, those technologies with a lower need for pre- and post-processing operations will be the first to proliferate (e.g. FDM technologies), while those with a higher demand for such processes (e.g. additive manufacturing from particulate matter) will take more time to receive the same treatment.

- **Standard deployment and operation processes**. As rapid deployment facilities evolve, the procedures and systems necessary to ensure an effective and efficient performance (deployment, maintenance, quality, control, etc.) will develop concurrently.

13.2. Non-Technical Factors

13.2.1. Training

Factor	Short-term	Mid-term	Long- term
Training	AM Design and engineering skills development		
	AM Operators skills development		

Figure 62: Training roadmap (own creation)

- **AM design and engineering skills development**. The growth of the market for additive manufacturing technologies requires not only a technological evolution, but also the rapid growth of competencies and training materials in design and engineering adapted to additive manufacturing. Hence, in the short term, it is expected that there will be a significant increase in the content accessible in this area, as a way to favour the introduction of these technologies in the market.

- **AM operators' skills development**. In the same way that skills increase in the field of AM design and engineering is necessary, so is the proliferation and the consolidation of training schemes and materials in the field of the operation of AM machines, and a short-term development in this respect is also to be expected.

13.2.2. Standardization

Factor	Short-term	Mid-term	Long- term
Standardization	Development of AM design guidelines		
	Development of AM equipment standards		
	Development of AM products standards		
	Development of standard tests for AM products		

Figure 63: Standardization roadmap (own creation)

- **Development of AM design guidelines**. The novelty of AM technologies means that there are no “design guides” to assist with their effective and efficient use, which then becomes dependent on the experience of designers and machine operators. However, efforts are being made in this regard (see ISO/ASTM DIS 52910.2 on “Guidelines for additive manufacturing design”, ISO/SATM CD 52911-1 on “Additive manufacturing - Technical design guideline for powder bed fusion - Part 1: Laser- Based powder bed fusion of metals”, ISO/ASTM CD 52911-3 on “Additive manufacturing - Technical design guideline for powder bed fusion - Part 2: Laser-based powder bed fusion of polymers”) so in the short term, new standards will become available, and such tools will favour the designers’ approach to these technologies.

- **Development of AM equipment, products and AM test standards**. At both ISO and ASTM levels, joint efforts are underway for standardization in the field of additive manufacturing, with 7 published standards and 12 more under development, which together form a standardization scheme for additive manufacturing. The development of these first standards will be completed in the coming years, enabling the market to grow and develop.

13.2.3. Qualification and Certification

<table>
<tr><th>Factor</th><th>Short-term</th><th>Mid-term</th><th>Long- term</th></tr>
<tr><td rowspan="2">Qual. & Cert.</td><td colspan="2">Increase on Sectorial Experience on Qualification and Certification</td><td></td></tr>
<tr><td>Development of guidelines for Q&C</td><td></td><td></td></tr>
</table>

Figure 64: Qualification and Certification roadmap (own creation)

- **Increase on sectorial experience on qualification and certification**. Regardless of the emergence and evolution of general regulatory schemes, the use of additive manufacturing technologies will grow fundamentally through the accumulation of experience in the sectors themselves. This will give rise to the emergence and consolidation in the medium term of schemes adapted to qualification and certification.

- **Development of guidelines for Q&C**. From a general point of view, the proliferation and agreement of the first standards in the field of additive manufacturing will lead to a series of clear paths for the adoption of these technologies and therefore their integration through processes of qualification and certification.

13.2.4. IPR

<table>
<tr><th>Factor</th><th>Short-term</th><th>Mid-term</th><th>Long- term</th></tr>
<tr><td rowspan="2">IPR</td><td colspan="2">Development of FRAND terms for IPR usage</td><td></td></tr>
<tr><td colspan="3">Development for helping navigating on IPR complexity</td></tr>
</table>

Figure 65: IPR roadmap (own creation)

- **Development of FRAND terms for IPR usage**. The complexities of managing and using IPR in the additive manufacturing environment will have to be solved in the short and medium term, as the market will demand clarity of the rights, obligations, limitations and possibilities in this area. That is why the development of a convention regarding the fair use of IPR will be necessary, to enable the growth of additive manufacturing technologies to their maximum potential.

- **Development for helping navigating on IPR complexity**. The complexity associated with IPRs will not only require the development of terms of fair use of them, but also that any person or organization can know with some ease what these rights are, in order to prevent their violation. In this sense, and because this is a subject of great complexity, it is expected that these tools will become available, although it is not expected to be in the short or medium term.

13.2.5. Regulation

<table>
<tr><th>Factor</th><th>Short-term</th><th>Mid-term</th><th>Long- term</th></tr>
<tr><td rowspan="4">Regulatory</td><td>Development of AM products regulatory</td><td></td><td></td></tr>
<tr><td>Development of AM machinery regulatory</td><td></td><td></td></tr>
<tr><td>Development of AM raw materials regulatory</td><td></td><td></td></tr>
<tr><td></td><td>Development of AM sectorial regulatory</td><td></td></tr>
</table>

Figure 66: Regulatory roadmap (own creation)

- **Development of AM products, machinery, and raw materials regulatory**. In the near future, there must be certainty about the legislation applicable to the fundamental elements that enable the application of additive manufacturing technologies: products, machinery and raw materials. While specific legislative developments may not always be necessary (for example, in Europe, all AM machinery is expected to continue to have to conform to the CE mark scheme), it is to be expected that in the coming years, there will be clarification on how these elements fit into current regulatory frameworks, clarifying whether or not they are subject to them, and how.

- Development of AM sectorial regulatory. At a general level, it is expected that, rather than a specific development in the field of additive manufacturing, there will be a clarification of its place in the existing schemes. However, at sectoral levels, it is expected that there will be efforts towards self-regulation, so that those sectors in which these technologies will have a greater impact will tend to generate their own mandatory compliance frameworks.

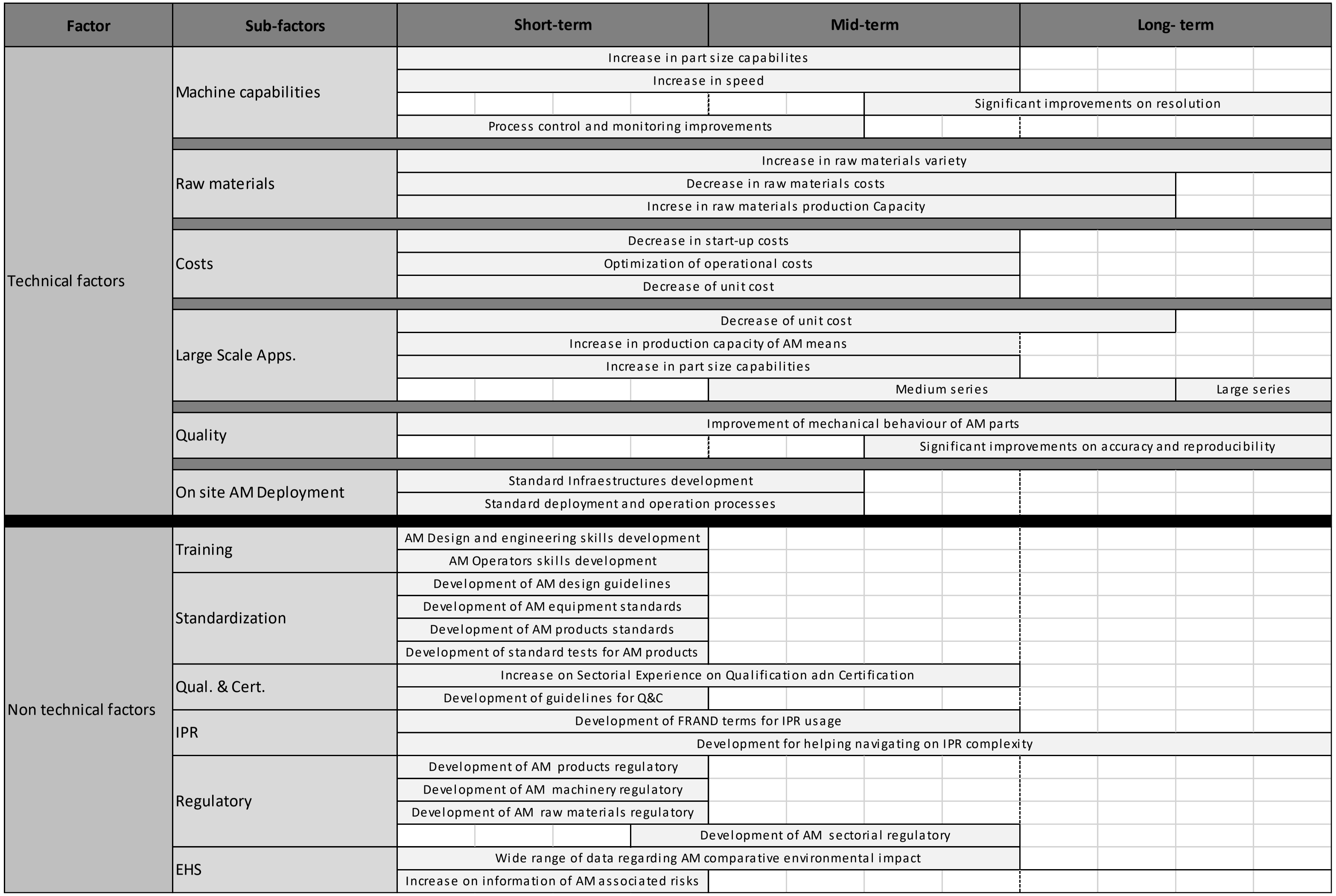
13.2.6. Environment, Health and Safety

Factor	Short-term	Mid-term	Long- term
EHS	Wide range of data regarding AM comparative environmental impact		
	Increase on information of AM associated risks		

Figure 67: Environment Health and Safety roadmap (own creation)

- Wide range of data regarding AM comparative environmental impact. In the short and medium term, with the proliferation of the use of this technology, information on the environmental impact of these technologies will increase, with data capable of comparing their behaviour with respect to traditional technologies.

- Increase on information on AM associated risks. At present, there is already sufficient use of this technology that the risks associated with its use are known by the current users. In the short term, use will continue to increase and the publication of information in this regard will proliferate.



Factor	Sub-factors	Short-term	Mid-term	Long- term
Technical factors	Machine capabilities	Increase in part size capabilites		
		Increase in speed		
			Significant improvements on resolution	
		Process control and monitoring improvements		
	Raw materials	Increase in raw materials variety		
		Decrease in raw materials costs		
		Increse in raw materials production Capacity		
	Costs	Decrease in start-up costs		
		Optimization of operational costs		
		Decrease of unit cost		
	Large Scale Apps.	Decrease of unit cost		
		Increase in production capacity of AM means		
		Increase in part size capabilities		
			Medium series	Large series
	Quality	Improvement of mechanical behaviour of AM parts		
			Significant improvements on accuracy and reproducibility	
	On site AM Deployment	Standard Infraestructures development		
		Standard deployment and operation processes		
Non technical factors	Training	AM Design and engineering skills development		
		AM Operators skills development		
	Standardization	Development of AM design guidelines		
		Development of AM equipment standards		
		Development of AM products standards		
		Development of standard tests for AM products		
	Qual. & Cert.	Increase on Sectorial Experience on Qualification adn Certification		
		Development of guidelines for Q&C		
	IPR	Development of FRAND terms for IPR usage		
		Development for helping navigating on IPR complexity		
	Regulatory	Development of AM products regulatory		
		Development of AM machinery regulatory		
		Development of AM raw materials regulatory		
		Development of AM sectorial regulatory		
	EHS	Wide range of data regarding AM comparative environmental impact		
		Increase on information of AM associated risks		

Figure 68: Global roadmap for surpassing AM current limitations (own creation)

14. A Brief Process for Implementing AM

This section intends to illustrate the main aspects involved in the consideration of additive manufacturing technologies, in reference to the value chains described in previous sections. Based on these value chains, **there are three situations in which the implementation of these technologies can be considered**:

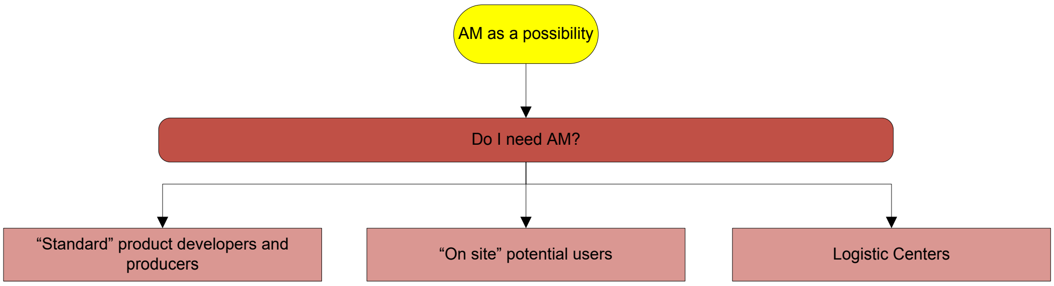


Figure 69: main situations for considering AM implementation (own creation)

- **Product development**. Currently, additive manufacturing is penetrating strongly as a tool for the development and revision of products, with capabilities ranging from the mere visual representation of design concepts, to the production of functional prototypes and short series of products. It is therefore a very clear scope of use for these technologies.

- **On site use**. The ability of additive manufacturing technologies to generate products and elements from a 3D file makes evident their use "in the field". This may include the manufacture of spare parts for maintenance work, and the improvisation and manufacture of non-existing or unavailable elements and accessories.

- **Logistics centres**. Although not necessarily direct users of the technology, logistics centres and managers should consider additive manufacturing as a key tool for stock removal, reduction of transport flows and increased self-sufficiency in the operating structure. In each case, managers must consider the advantages that a product manufacturable by means of additive manufacturing technologies may contribute, compared to previously existing alternatives.

Next, a general outline of the implementation of additive manufacturing technologies will be developed for each of these application cases, in order to illustrate in a general way the aspects to be taken into consideration.

14.1. Product Developers/Producers

From the point of view of a developer or a product manufacturer, the implementation of additive manufacturing technologies must take into account two fundamental issues:

- **How can I apply these technologies?**

  From the point of view of a product developer, there are different, complementary uses:

  - Design/mock-ups. Especially associated with the early stages of development of a product, the designer may model the initial design, illustrative of the design concept but without functional capacity. Some AM technologies (e.g. FDM machines) have a large range of relatively cheap desktop printers, which do not require great knowledge of adapted design and are simple to operate, making it possible to carry out these tasks cheaply and simply.

  - Prototyping/functional models. As the design process progresses, there is usually a need to bring the results of that process into practice and to generate prototypes to assess the suitability of the selected design concepts. The technologies needed to make this possible will be more advanced than in the previous case (because higher specification plastics or metals will be required) and therefore will be one or two orders of magnitude higher in cost and considerably more complex in respect of design and operation.

  - Pre-products/short series. When the design process is sufficiently mature, prototypes very close to a final product will be required. The technologies cost and level of knowledge demanded for this use can be considered very similar to those of the previous one.

  - End products (manufacturing). This stage of development is clearly different from previous one and, regardless of whether the designer is the manufacturer, between the end of the development of the product and its manufacture, there is a stage when the most suitable manufacturing technology must be assessed (especially from an economic point of view). Thus, it should not be assumed that a product developed with support of additive manufacturing technologies will eventually be produced with this technology since, as has been mentioned previously, for each case there will be a point at which additive manufacturing is not economically feasible and other options have to be considered.

- **Is additive manufacturing feasible as a production technology for a given product?**

  The answer to this question will be case-dependent. Regardless of the manufacturing technology, the transition from a prototype/pre-product to a product always requires a stage of “industrialization”, in which the most effective and efficient manufacturing process for a given product is sought. For each possible product, it is necessary to carry out a technical-economic analysis, capable of answering the following questions:

- What is the expected volume of production? As is well known, the unit cost of an element produced by additive manufacturing is not generally dependent on the number of units to be produced, so that for each product it can be estimated (taking into account all other issues) a production threshold value, beyond which production with this technology is no longer profitable.
- Is it a highly customizable product? If the product in question requires a certain level of adaptation to the needs of the end user and this leads to the generation of several sub-lines of production of these customizations, additive manufacturing technologies may be used, again depending on the number of units involved.
- What pre-processes and post-processes does it require? The most advanced additive manufacturing technologies (especially metallic ones) usually need a series of pre-treatment operations (e.g. recycling of materials) and post-treatment (removal of support materials, improvement of surface finishing, painting, thermostabilization, etc.), to give rise to the final product. These of course add to production times and costs.
- Does production produce products with stable quality? Any manufacturing process involves a certain variability, which results in a certain percentage of product outside the quality standard. It is necessary to consider whether the additive manufacturing process used can ensure that the required percentage of product is within specification.
- Is the process certifiable? In close association with the previous question, it is necessary to consider how to ensure the reliability of a manufacturing process based on additive manufacturing technologies.
- What competencies/knowledge does it require? The introduction of an additive manufacturing technology implies the need to have personnel and knowledge in the different stages involved in the manufacturing process.

The combined consideration of all these issues leads to the final translation of the responses into a cost per unit produced, a basic element from which to make a decision on the use of one or other manufacturing technologies.

As can be seen, **the integration of additive manufacturing technologies into all pre-manufacture product development processes is of obvious utility, although its consideration for serialized product manufacturing tasks must take into account multiple factors**. Hence, there will be many cases in which the additive manufacture cannot be considered as the only manufacturing technology because it is not feasible from a technical or economic point of view, giving rise to the following cases:

- Evaluation of alternative manufacturing processes.
- Assessment of the need for redesign to adapt the product to other technologies.
- Fragmentation of the product to manufacture certain essential elements by additive manufacture and the rest by more conventional methods.
- Manufacture of the main product with conventional technologies and manufacture of customizations through additive manufacturing.
- Specific short series (exclusive, illustrative, advertising) made with additive manufacturing.
- Lack of economic viability to produce the product.

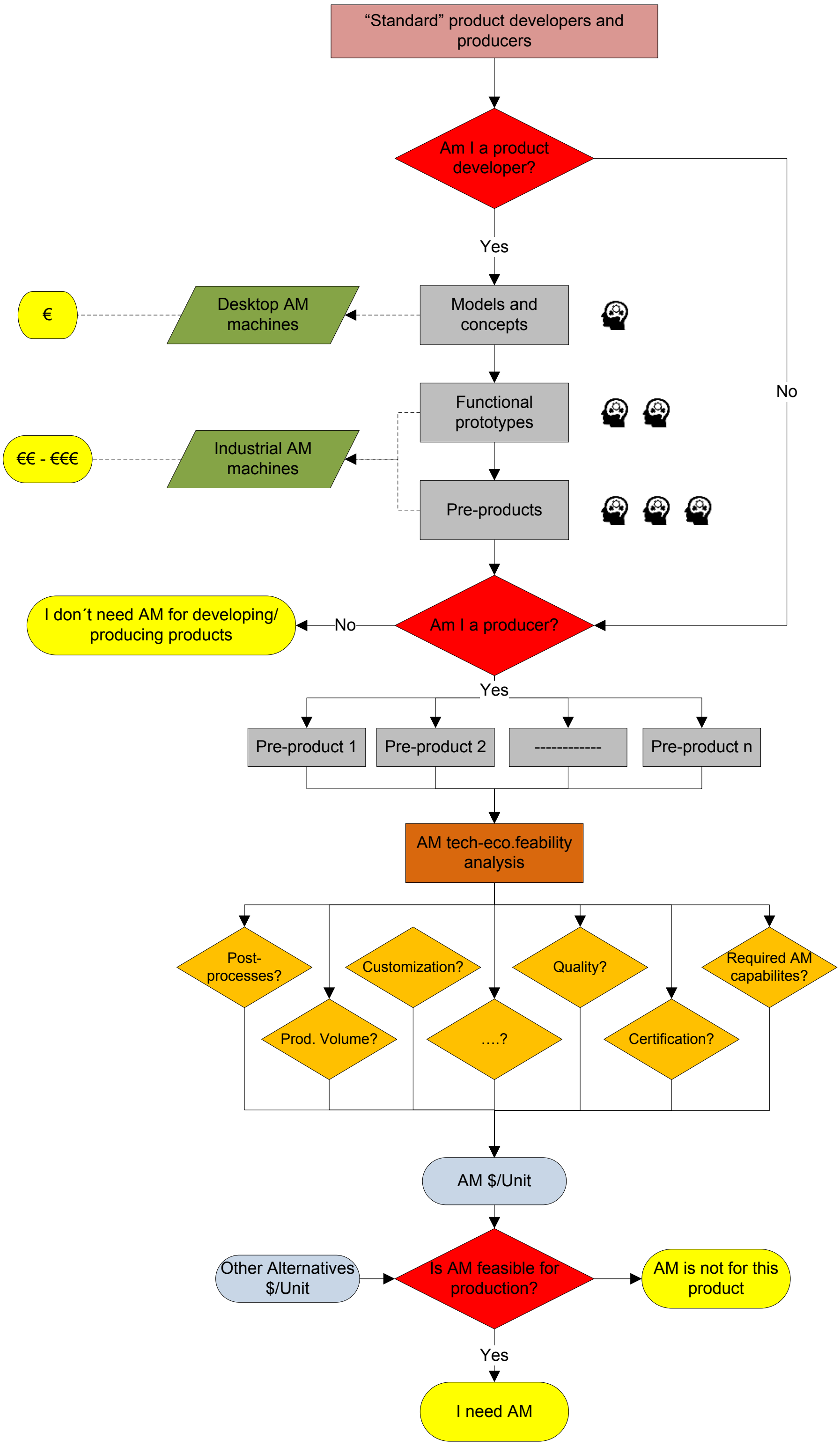


Figure 70: Implementation of AM on a product developer/producer scenario (own creation)

14.2. On Site Users

To evaluate the feasibility and the good sense of implementing an additive manufacturing technology as a field tool, there are a number of issues that need to be assessed:

- **Do I need to develop and/or manufacture parts/products on demand?**

  It may seem like an obvious question, but given that any incorporation of such technologies will require the mobilization of a range of resources, it is an important one to ask. In essence, there must be certainty that these technologies will fulfil a given (and planned) function and that for each use case its implementation is justified.

- **What are the on-site use cases?**

  (This question is necessary in order to be able to respond properly to the previous question).

  It is necessary to elaborate in detail the different on-site use cases that can be given for the technology. These can be categorized into two fundamental types:

  - Simple or non-critical elements/products, or single use elements. There will be in some cases the need to develop and/or manufacture simple elements, which because of their low demand or criticality can be manufactured on site, thereby eliminating processes that consume resources but add little value. In these cases, the most accessible technologies from the economic and technical points of view (desktop AM machines) will be able to cover a large part of the demand.

    This use case is represented in the manufacture of plastic elements, which when used as accessories, couplings, customizations or temporary spare parts can increase the operative capacity and solve small problems.

  - Complex and long-lasting elements. Other situations will require the on-site development and/or manufacture of elements of higher quality and durability, with a higher level of criticality. In these cases, additive manufacturing resources with ostensibly higher capacities will be required, resulting in higher costs and technical complexities.

    This use case can be seen in the manufacture of metal and plastic elements of high durability, with applications focused especially on the manufacture of durable spare parts, the manufacture of equipment or accessories of high criticality, and the generation of durable and high strength solutions in general.

Ideally, **the decision to implement these technologies in the field must start from the certainty that they will fulfil certain specific functions, rather than the belief that these functions can be generated by the capacity of improvisation in the field provided by these technologies**. Thus, it is very important to define the possible on-site use cases in conjunction with logistic operators, since it is they who can ultimately assess the technical, economic, and human feasibility of having this type of resources at an end user level.

Once the possible use cases are known and it is determined that the implementation of additive manufacturing technologies can be recommended, a complete economic-technical assessment must be carried out, capable of establishing in detail what are the resources and skills needed to enable deployment in the field. Aspects such as the following will have to be evaluated:

- Storage of raw material.
- AM technologies required.
- Post-processing means required.
- Reverse engineering means for cases in which original 3D models are not available.
- Machine operators, designers and engineers.
- Computer and communications supports to enable the transfer, storage and management and reuse of design and manufacturing processes.

It is important to bear in mind that one of the fundamental values of having these technologies as a tool of support in the field (in addition to the obvious value of manufacturing elements) **is the capacity to generate solutions that can later be reused and improved**. In this sense, each user on site can become a designer/engineer with the capacity to generate solutions to existing problems not only in their location, but in others. For this reason, the generation of structures for management and diffusion of this type of solutions becomes very important.

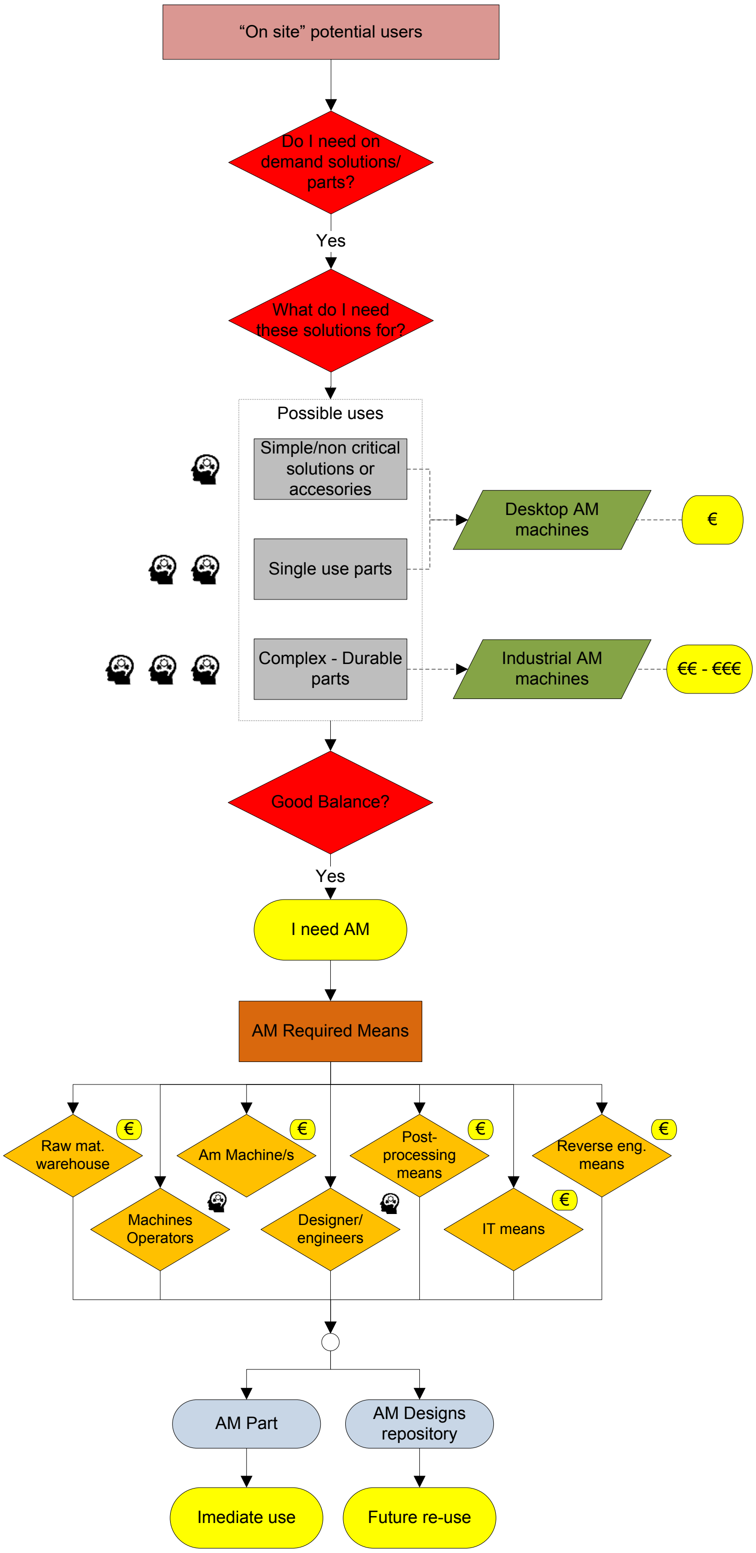


Figure 71: Implementation of AM on an on-site user's scenario (own creation)

14.3. Logistics Centres

Logistics is a field that can especially benefit from additive manufacturing technologies. The manufacture of an element or product using machinery that can be categorized as "light" gives rise to the possibility of relocation and deployment of the means of production to geographical points much more advantageous for the general logistics process, which in itself generates multiple optimizations in the provision and transportation of resources.

The fundamental question that arises in the field of logistics is "in which cases can the implementation of additive manufacturing positively affect logistics?" In general, it depends on two factors:

- Existence of tactical and operational advantages. In some cases, the fundamental feature of additive manufacturing will be its ability to provide elements or products in a considerably shorter period of time, either because the traditional centralized production is replaced by production at intermediate points, or even by production on site. In the most favourable cases, provision processes that can take several days from the communication of the need can be fulfilled in a few hours (for elements manufacturable in on-site facilities).

- Economic savings. Although the final cost of a product is dependent on its cost of production, certain products are greatly impacted in terms of cost by the management and transportation associated with delivery to the end user. Thus, in some cases, products can become economically more advantageous if additive manufacture greatly reduces their cost of transport and management.

So although there is no general answer to the question posed, there is no doubt that the assessment of the previous points may depend on the consideration that additive manufacturing technologies can be actively taken into account. Of course, there are other issues involved in such a decision, such as:

- **Who will produce the product?**

  Will the final producer be the same as the original producer or different? If different, does the final producer have rights to manufacture that product? Is the end user to be the final producer? In that case, is there an agreement with the original supplier? These questions are framed within the scope of IPR management and have to be taken into account to ensure that the various situations are contemplated and that the rights of any legitimate owner are not infringed.

- If I am going to expand my resources by means of investing in additive manufacturing that enables production to take place in centres closer to the end points of use, **have I contemplated the resources and costs that this will require?** What is the overall strategy in this regard, will I try to provide end users with means or will I create manufacturing and supply structures at points close to end users?

As can be seen, the consideration of additive manufacturing from the point of view of logistics is perhaps one of the most complex assessments since it demands not only the conscious consideration by the logistics managers of the points mentioned above, but also requires the development of decision support systems capable of facilitating the identification and comparison of new logistical alternatives.

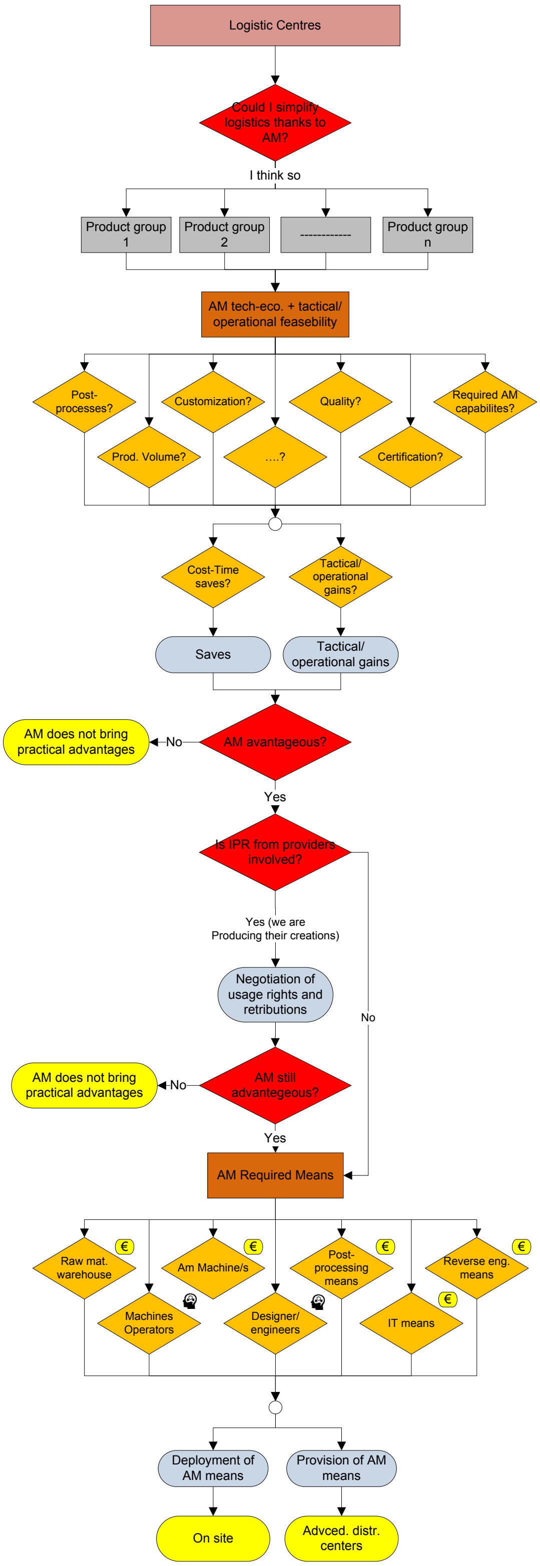


Figure 72: Implementation of AM on a logistics scenario (own creation)

14.3.1. Systems and Software for Supporting Decisions based on AM Technologies in the Context of Defence

When assessing the implementation of a new technology in the field of defence, it should be noted that its applicability is not only determined by its technical characteristics, but also by the operational benefits and especially the improvement and optimization in the times and processing costs. In other words, every technology has to prove not only its effectiveness but also its efficiency; this fact also applies to additive manufacturing, however disruptive their capabilities in the technological field are.

The development and existence of analytic systems and tools to support the decision-making process around different manufacturing alternatives (estimates of possible supply lines, times and costs of different processes, etc.) is a problem of great complexity, especially in areas associated with the planning and management of defence resources. The difficulty inherent in the (essentially mathematical) modelling of a new technological process is compounded by the current existence of a wide variety of differentiated AM technologies which in practice require the development of as many models as technologies.

At the present time, these systems (ideally software) have not yet been sufficiently developed to allow a logistics operator to evaluate the various alternatives for the provision of a certain element. There are many elements to take into account and to integrate into a system, such as the structure and characterization of suppliers, definition of supply flows, quality control, etc. However, it is not difficult to envisage a future in which, through input by a user of a particular element/product/part, software is able to analyse all possible manufacturing and provision alternatives and to show the user those most advantageous from different points of view.

It is noteworthy that although these tools have not yet been developed to a level of commercial exploitation, the first significant efforts are already being made to define analytical systems capable of incorporating AM technologies as an element for decision making in the processes of defence provision. One example is a recent work called “Modelling Applications of Additive Manufacturing in Defence Support Services[93]”, in which a complete mathematical development capable of integrating diverse technologies of additive manufacturing (Selective Laser Melting, Wire & Arc Additive manufacturing and Fused Deposition Modelling) has been implemented into software, able to compare different processes and facilitate decision making for selected cases.

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[93] *Alessandro Busachi. (2017). PhD “Modelling Applications of Additive manufacturing in Defence Support Services”.*

Current Practices (INPUTS)

CP-SysCo-1

Procurement Delay Time (PDT) 50 Hrs

Administrative Delay Time (ADT) 500 Hrs

Mean Time Between Failures (MTBF) 100000 Hrs

UP Time 100000

DOWN Time 565.86111

Next Generation Practices (INPUTS)

NG-SysCo-2.2

WAAM Cycle Time 7.3586011 Hrs

Administrative Delay Time (ADT) 500 Hrs

Mean Time Between Failures (MTBF) 100000 Hrs

UP Time 100000

DOWN Time 965.40405

Travel Times
Lo1 - 1.25 - Hrs
Lo21 - 1.25 - Hrs
Lo31 - 11.11111111111
Lo41 - 1.25 - Hrs
Lo5 - 1 - Hrs

Logistic Cost
Lo1 - 0.0002526941657
Lo21 - 0.000252694165
Lo31 - 5.326396630744

Availability 0.994 %

Travel Times
Lo33 - 454.545454545455
Lo42 - 2.5 - Hrs
Lo5 - 1 - Hrs

Logistic Cost
Lo33 - 0.856389986824769
Lo42 - 0.000505388331475
Lo5 - 0.0958751393534002

Availability 0.9904382 %

Logistic Delay Time (LDT) 15.861 Hrs

Logistic Cost 5.423 £/Kg

Logistic Delay Time (LDT) 458.045 Hrs

Logistic Cost 0.953 £/Kg

Alessandro Busachi CEng MIMechE

Figure 73: AM-Decision Support System (image courtesy of Alessandro Busachi, Cranfield University)

14.3.2. A Specific Look at Benefits of AM for Customer Support Services

The business of making, storing and shipping spare parts has long been a source of time-consuming and costly difficulties for their suppliers as well as for customers. Moreover, maintaining inventories of infrequently ordered parts is so expensive that suppliers often simply stop offering them; that in turn forces customers to store large inventories of parts or to turn to third-party manufacturers.

However, the advent of additive manufacturing technology is about to change everything. This additive manufacturing technology, long used in the prototyping of new products, will enable suppliers to make and send parts on an on-demand basis, and do so locally, close to where the parts are needed. Alternatively, companies can opt to print their own parts, bypassing the suppliers entirely.

Exploiting additive manufacturing opportunities for 'Customers Support Services' in the framework of Security and Defence is a fairly new concept. The main benefits in 'Defence Support Services' are as follows:

- Production on an "on-demand" basis. One benefit that additive manufacture offers is the ability to manufacture parts on-demand. This will eliminate the challenges that the volatile demand of spare parts brings to the business, and this opportunity will improve availability and allow flexibility compared with traditional manufacturing methods. Having the necessary parts when and where they are needed can have a significant impact on an operation's efficiency.

  Thanks to an autonomous manufacturing system based on additive manufacturing technology, the customer's personnel can have access to it any time during the mission and can print components continuously. Waiting time will be no more than the cycle time of the additive manufacturing machine, post processes, qualification, and assembly.

- **Immediate repairs**. Point-of-use manufacturing: the ability to produce spare parts in the field. Some additive manufacture techniques (such as metal deposition) facilitate the repair of essential parts on site to support a mission.

- **Improvement in Manufacturing Lead Times**. Producing spare parts through additive manufacturing methods can shorten lead times.

  The improvement in lead times is also made possible by the reduction in production interruption caused by assembling multiple parts. With 3D printing, companies can consolidate assemblies into single parts, drastically reducing the number of manufacturing operations and tooling costs.

- **Reduction of inventory**. Additive manufacture facilitates on-demand manufacturing of spare parts. The technology also makes it possible to have spare parts produced near the point where they are needed or even on-site; the delivery of goods is no longer a restriction. This results in a shortening of the supply chain since shipping and platform inventory is not necessary. The need for excess inventory or stocks will become obsolete, providing more space or reducing storage requirements.

  Maintaining an inventory or stocks of spare parts is not free. It is costly to maintain warehouse storage. Some parts are expensive, and suppliers/customers only need to keep a couple of spares on hand to avoid machine downtime.

- **Simplification of the supply chain**. Local production by additive manufacturing methods in comparison to centralized production can allow supply chain complexity to be reduced to merely the supply of raw materials such as powder and wire. It can result in a more sustainable after-sales service supply chain.

- **Replacement discontinued parts**. If maintained properly, assets in a manufacturing plant can operate for many years. But inevitably a machine will become outdated and spare parts may be difficult to find or too expensive to order. The life of an older asset can be extended by outsourcing the 3D printing of discontinued, high-value parts.

- **Hedge against disruptions**. Additive manufacture can provide a low cost and reliable back-up solution when disruptions occur. Additive manufacture enables mid-market manufacturers to temporarily produce some components in-house. This can be of great help when suppliers have short-term supply problems such as broken machines or shipping delays.

- **Overcoming obsolescence**. For parts which the original manufacturer has stopped production, additive manufacturing methods could be a suitable alternative manufacturing method.

- **Reduced transportation cost**. As previously commented, one of the benefits of additive manufacture is the reduction in the length of the supply chain by enabling customers to station local manufacturing centres on site. Consequently, this benefit will reduce transportation cost of global logistics network.

- Lower total cost of ownership. Additive manufacture reduces cost of ownership. With the potential of additive manufacture to affect a company's supply chain, factoring in the costs related not only to the acquisition of a product but also those involving its transportation and storage, it follows that it will also have an effect on a product's Total Cost of Ownership.

  The ability to produce complex low-volume parts cost-effectively, make parts on an order basis without compromising lead times, reduce logistics costs, and even the ability to prolong a piece of equipment's lifetime are just some of the ways additive manufacturing can contribute to lowering Total Cost of Ownership.

- Improved sustainability. Traditional global sourcing generates high emissions resulting from high volume physical movement of materials and goods. Products made by additive manufacture will have a smaller environmental footprint due to sustainable local production and the reduced physical movement of materials and goods.

- No economies of scale. Production with additive manufacturing methods does not need to achieve economies of scale in order to minimise cost per part. The manufacturing can always start with just one part without exceeding minimum variable part costs.

15. Final Conclusions

Under the umbrella of the concepts of "additive manufacturing" or "3D printing" there is nowadays a considerable number of differentiated technologies, which, although sharing the concept of "layer by layer" manufacturing, differ in technical capacities and potential applications. In this sense, **today, there is no "Swiss Army AM machine" for all purposes**, as the specific applications sought (material, mechanical requirements, precision, etc.) are those which determine the 3D manufacturing technologies to be applied.

While this may be an entry barrier when assessing the implementation of these technologies in a defence environment, the flexibility and diverse applications that this range of technologies provides is **able to bring a high added value to each and every one of the aspects related to the development, manufacture and provision and management of products and equipment**:

- Development and improvement of products. The **possibility of developing prototypes and first functional units in reduced times and without the need to incur in tooling costs** is the main reason why these technologies are already used by numerous suppliers in the field of defence, the aerospace sector being one of the most important in integrating these technologies in their current product generation and revision processes. On the other hand, the availability of AM technology and service suppliers is certainly considerable at all scales, so the development of potential applications at this level is, so to speak, simply a matter of mobilizing adequate resources.

- Manufacture of products. In this area, it is necessary to establish a differentiation: **although the future may bring a considerable evolution of AM technologies, its characteristics make large-scale production expensive in relation to traditional technologies.** This is especially applicable in the production of plastic products by moulding technologies, in which the speed of manufacture of each unit and the consequent low cost is not surpassable by any other technology. Thus, one has to differentiate between the manufacture of small series, and the manufacture of medium to large ones.

    - *Small production series (tens or a few hundred units)*: additive manufacturing renders investment in tools unnecessary, so the production of reduced series can especially benefit from it, giving rise to products in a more agile and economic way. An example in this area would be the manufacture of a multitude of components for the aeronautical sector (components of aircraft, missiles, etc.). Where the number of final units is low, it is economically advantageous to implement additive manufacturing. For the same reasons, all customizable products are also especially receptive to benefiting from these technologies.

    - *Medium-large production series (thousands to tens/hundreds of thousands of units):* although the current additive manufacturing technologies are still far from being optimized, their nature makes them moderate or high consumers of energy, resources, and time, and their use for large volumes of manufacture is never advantageous with respect to traditional technologies. However, it is expected that the capacities of the current technologies will be optimized, allowing their use at this level to cover progressively larger volumes, but realistically very large volumes will tend not to be feasible from an economic point of view for AM.

In any case, for these type of products, the additive manufacture will be able to give a considerable boost in design speed and cost optimization at the design and development stage, so it is foreseeable that, although not part of the manufacturing process itself, additive manufacture will influence prior stages of the conception of the product.

- Field applications. Although the **applications of additive manufacturing in operational areas are already broad**, it is impossible to imagine all those that will arise in the future, when these technologies have reached their maturity and when standardized mobile infrastructures of AM equipment exist, providing the capacity for these technologies to be deployed anywhere in the world. **The applications of these technologies in the operational area are especially oriented towards the manufacture of spare parts, the development, and manufacture of improvised solutions, the customization of equipment, and the rationalization of stocks due to the capacity to produce elements on site.**

  Experience of using these technologies in operational environments is still lacking, but a variety of factors is expected to make the application in the field of additive manufacturing technologies one of the main bastions in the field of defence: the expected proliferation of mobile infrastructures capable of bringing these technologies to where they are needed, the deepening of existing experiences of deployment and the progressive evolution of these technologies towards their full capacities and optimization.

- Support and maintenance operations. Undoubtedly, **the planning and management of support and maintenance operations will be substantially affected by additive manufacturing.** From the point of view of the provision and maintenance of legacy equipment (for which spare parts are no longer supplied by the original producer), the **autonomy to manufacture elements that are no longer on the market** will prolong the useful life of equipment that, although not in the technological vanguard, can continue to play a role. For equipment still under official support, the **foreseeable autonomy to manufacture elements can lead to significant changes in contracts and systems of provisioning, storage, and maintenance.** In any case, the ability to transfer the production of elements from the original producer to the final customer makes it likely that technological change will be the basis for a change in logistic and contractual levels between the Ministries of Defence and their suppliers.

- Logistic processes. Additive manufacturing is not only valued through assessment of the technologies themselves and their direct applications, but also through assessment of their impact on the processes that lead to the provision of resources. In this sense, additive manufacturing introduces a series of very significant novelties with respect to traditional paradigms, possibly the most significant being the **possibility of offshoring production, based on manufacturing infrastructures much "lighter" and less resource intensive than traditional ones.** This enables **various, new alternatives for providing resources, from the use of suppliers closer to the end user, to the manufacture at the point of use when the necessary technological means are provided.** Whatever the alternatives that these technologies offer, it can be considered that their impact at this level may be at least as important as their impact from the perspective of their technical applications, since they can completely modify the processes and lines of supply, as well as supplier relationships.

It should also be noted that at present, **there are still a number of limitations to be addressed** in order for these technologies to reach their maximum application:

- In the technological field, although the technologies of additive manufacturing already have very estimable capacities, **they are still immature,** although they will evolve further in the next few years: new and more capable machines, new materials, cost optimization, etc. Nor is the current absence of standard AM equipment/facilities capable of bringing these technologies anywhere in the world in a systematic and reliable manner, a negligible limitation.

  However, **these limitations are not expected to persist for long**: the evolution of the market will lead these technologies to reach their maximum technical development, while providing AM equipment and infrastructure adapted to each market need.

- **Non-technological aspects are undoubtedly those that can be considered of greatest relevance**, since in the medium and long term they are the ones that can undoubtedly establish restrictions or accelerate the implementation of these technologies. Thus, the development of standards for quality certification and equipment accreditation, materials, quality testing, etc. will be important, not only from the point of view of ensuring the quality of a particular product, but also from the point of view of covering potentially delocalized manufacturing processes, as discussed above.

  Other limitations come from the lack of experience and adapted training in this area, uncertainties relating to doubts about ownership and the IPR rights of the manufacture, and the use of parts/products that may not be manufactured by its original producer.

  Overcoming these limitations is complex because it requires coordination and agreement between different groups and stakeholders at a global level, but **important working groups and projects have already been established.** Therefore, these limitations, although of some consideration for a reliable use of additive manufacturing technologies, will be overcome as long as the different market players can agree on common frameworks for global understanding and application of technology.

As a final word, this document has tried to present to the reader a perspective on the additive manufacturing and the technological bases, uses, applications, advantages and limitations of these technologies. **From an objective point of view, these technologies present capabilities that are already proving their capacity in industries and in demanding environments, although there are still limitations to be overcome** in both technological and non-technological areas that act as a retardant to its implementation. **Experience of these technologies in the field of defence will increase and the complementary evolution of technological and non-technological factors will increase the level of knowledge and confidence in them in the coming years.** This will lead to the implementation of changes in operational and logistical areas, creating manufacturing capacities even at the point of final use, modifying the decision-making systems for the provision of resources, and with them, the relationship with the providers. It is for all these reasons that **additive manufacturing is considered to be one of the main triggers of change and evolution in the field of defence in the 21st century.**

Annex 1. Abbreviations

Abbreviation	Term
3D	Three Dimensional
AM	Additive Manufacturing
BJ	Binder Jetting
CDLP	Continuous Digital Light Processing
DLP	Digital Light Processing
DMLS	Direct Metal Laser Sintering
DOD	Drop on Demand
EBM	Electro Beam Melting
FDM	Fused Deposition Modelling
IPR	Intellectual Property Rights
LOM	Laminated Object Manufacturing
MJ	Material Jetting
MJF	Multi-Jet Fusion
NPJ	Nano-Particle Jetting
RTO	Research and Technology Organization
S&D	Security and Defence
SLA	Stereolithography
SLM	Selective Laser Melting
SLS	Selective Laser Sintering
UV	Ultra Violet

Annex 2. List of Figures

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