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Additive Manufacturing Technology – Review and Challenges

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Resumo

A manufatura aditiva é uma tecnologia de fabricação de produtos finais camada por camada. É diferente dos processos convencionais, como estampagem / fundição. Trata-se de um sistema computacional, utilizando projetos em *Computer Added Design* que utiliza impressão 3D para a junção de diferentes materiais até a forma final do produto, por meio de calor e outro processo, até a aplicação final. Os materiais utilizados são pós micro / nanométricos de cerâmica, metal e polímero ou uma mistura deles. Foi em meados da década de 80 do século 20 que se iniciou o desenvolvimento desta tecnologia. A Manufatura Aditiva tem grande importância para as indústrias, pois dispensa o ferramental de estamparia / forjamento e fundição de modelos / moldes, pois o bem é fabricado em sua geometria final. Os desafios são o custo de produção e a qualidade da peça produzida, que deve ter desempenho igual ou superior ao fabricado pelos métodos convencionais. A produção de custos também requer desenvolvimentos. Este artigo apresenta a história dessa tecnologia ao longo do tempo, com as tendências que norteiam sua evolução.

Palavras-chave: Tecnologia de Manufatura Aditiva, aditivos, Materiais e Revisão

Abstract

Additive manufacturing is a technology of manufacturing final products through layer by layer. It is different from conventional processes such as stamping/ casting. It's involves a computer system, using projects in Computer Aided Design that uses 3D printing to join of different materials to final shape product, through heat and other process, because the final application. The materials used are micro/nanometric powders of ceramic, metallic and polymeric or a mixture of them. It was in the middle of the 80's of the century XX that began the developments of this technology. Additive Manufacturing has great importance for industries, since it eliminates the stamping/forging tooling and casting models/molds because the good is manufactured in its final geometry. The challenges are cost production and quality of the produced piece, that must have performance equal or better than manufactured by conventional methods. Cost production also requires developments. This article presents the history of this technology over time, with the trends that guide its evolution.

Keywords: Additive Manufacturing Technology, Additives, Materials e Review

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1. Introduction

Many researchers present a definition to Additive Manufacturing - AM (Azam et al. 2018; Bikas, Stavropoulos, and Chryssolouris 2016; Brandão et al. 2017; Costabile et al. 2017; Everton et al. 2016; Ford and Despeisse 2016; Hegab 2016; Jiménez et al. 2019; Klocke et al. 2017; Körner 2016; Liu and Shin 2019; Mani et al. 2017; Stavropoulos and Foteinopoulos 2018; Tofail et al. 2018; Zadi-Maad, Rohib, and Irawan 2018; Zhang et al. 2018) some are standards (Azam et al. 2018; Bikas, Stavropoulos, and Chryssolouris 2016; Brandão et al. 2017; Costabile et al. 2017; Everton et al. 2016; Ford and Despeisse 2016; Jiménez et al. 2019; Liu and Shin 2019; Mani et al. 2017; Stavropoulos and Foteinopoulos 2018) and others not (Hegab 2016; Klocke et al. 2017; Körner 2016; Tofail et al. 2018; Zadi-Maad, Rohib, and Irawan 2018; Zhang et al. 2018). Of those who take the norm as the primary source of reference, only two authors (Brandão et al. 2017; Jiménez et al. 2019) cite the current standard and that has been active since 2015. This fact does not detract from the research of any of them, however, it is a point of attention when referring to norms and standards, and it is always necessary to adopt the current and active.

Therefore, the definition of Additive Manufacturing is given by the standard current and active ISO ASTM 52900-15 (ISO/ASTM International 2015) as "process of joining materials to make parts from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing and formative manufacturing methodologies".

1.1 Literature review method

There is many works published on AM, however, in this review we will align the works focused on the cost of production, quality of products by AM, the processes and the raw materials. Researchers such as (Bikas, Stavropoulos, and Chryssolouris 2016) present a large number of articles on AM to be examined it is possible to solve this problem, e.g., separating them by:

- Definition of the Keywords (Fera et al. 2016; Bikas, Stavropoulos, and Chryssolouris 2016);
- Collection of papers from the main international scientific papers' database (Bikas, Stavropoulos, and Chryssolouris 2016; Fera et al. 2016);
- Analysis of the papers' characteristics by relevance (Bikas, Stavropoulos, and Chryssolouris 2016; Fera et al. 2016);
- Selection of the most interesting theme defined by the keyword (Bikas, Stavropoulos, and Chryssolouris 2016) and
- Eventual knowledge lack of literatures (Bikas, Stavropoulos, and Chryssolouris 2016; Fera et al. 2016).

We also add:

- The time period of analysis, for example, the last 4 years, including the current year.
- Focus on the main subject of the paper and
- Have references available for free.

1.1.1 Main Subject of Reviews

Based on the criteria established in the literature review method adopted, there have been, in the last four years (2016 to 2019), publications on additive manufacturing reviews (Elahinia et al. 2016; Lehmhus et al. 2018; Li, Shang, and Wang 2017; Azam et al. 2018; Bikas, Stavropoulos, and Chryssolouris 2016; Costabile et al. 2017; Everton et al. 2016; Hegab 2016; Körner 2016; Liu and Shin 2019; Mani et al. 2017; Stavropoulos and Foteinopoulos 2018; Zadi-Maad, Rohib, and Irawan 2018; Zhang et al. 2018; Fera et al. 2016) which studied, for the most part (Murr 2018; Azam et al. 2018; Bikas, Stavropoulos, and Chryssolouris 2016; Costabile et al. 2017; Everton et al. 2016; Hegab 2016; Klocke et al. 2017; Körner 2016; Liu and Shin 2019; Zadi-Maad, Rohib, and Irawan 2018; Zhang et al. 2018; Elahinia et al. 2016; Lehmhus et al. 2018; Li, Shang, and Wang 2017), on the existing processes and materials, on the particularities of each one, its benefits and applications (Table 1).

Table 1 – Main subject studied by AM Reviews Papers.

Main Subject	Year of Publication	Reference
Metals	2018	(Azam et al. 2018)
Methods and Modeling	2016	(Bikas, Stavropoulos, and Chryssolouris 2016)
Cost Models	2016	(Costabile et al. 2017)
Metals	2016	(Everton et al. 2016)
Composite Materials and Potential Alloys	2016	(Hegab 2016)
Metallic Components by EBM	2016	(Körner 2016)
Ti6Al4V Alloy	2019	(Liu and Shin 2019)
Metal Powder	2017	(Mani et al. 2017)
Modeling	2018	(Stavropoulos and Foteinopoulos 2018)
Steels	2017	(Zadi-Maad, Rohib, and Irawan 2018)
Titanium Alloys by EBM	2018	(Zhang et al. 2018)
Tolerances, Mechanical Resistance and Production Costs	2016	(Fera et al. 2016)
NiTi Alloy	2016	(Elahinia et al. 2016)
Smart Materials	2017	(Li, Shang, and Wang 2017)
Metallographic by Metal and Alloys	2018	(Murr 2018)

However, few cite, even if specifically on trends (Gardan 2019; Hegab 2016; Lehmhus et al. 2018) and what challenges (Brandão et al. 2017; Ford and Despeisse 2016; Tofail et al. 2018) for this technology to become more competitive. This paper discusses the history of this recent technology (about 33 years), along with the trends and challenges that guide its evolution.

2. Brief History

Some researchers (Costabile et al. 2017; Everton et al. 2016; Jiménez et al. 2019; Fera et al. 2016; Gardan 2019) deal with the history of AM, but very briefly, there are controversies (Costabile et al. 2017; Fera et al. 2016), but only Wholers Report (Collins 2014), also cited by some researchers (Everton et al. 2016; Gardan 2019), present a more detailed sequence, which we use as a primary reference and is summarized in Table 2.

AM is still in constant evolution, but we have not yet obtained, at moment, more relevant open, free source data, and consolidated by Wholers Report (Collins 2014).

3. Materials

Several researchers (Ford and Despeisse 2016; Hegab 2016; Zadi-Maad, Rohib, and Irawan 2018; Lehmhus et al. 2018) present the classes of materials most commons in Additive Manufacturing: polymers, metal, ceramics and composites. One researcher (Lehmhus et al. 2018) also cite about novel steel grades and advanced aluminum alloys, while another author (Jiménez et al. 2019) cite about polymers, but for space applications.

Table 2 – Wholers Report presenting a summary of the History main facts (adapted) (Collins 2014).

Year	Summary of History Main Facts
1980	Hideo Kodama of the Nagoya Municipal Industrial Research Institute, Japan, was among the first to invent the single-beam laser curing approach.
1982	Alan Herbert of 3M Graphic Technologies Sector Laboratory published a paper "Solid Object Generation in the Journal of Applied Photographic Engineering".
07/1984	Jean-Claude Andre, from French National Center for Scientific Research, France, and colleagues working for the French Cilas Alcatel Industrial Laser Company, filed a patent titled "Apparatus for Fabricating a Model of an Industrial Part, involving a single-beam laser approach".
08/1984	Charles Hull, co-founder and chief technical officer of 3D Systems, United States of America (U.S.A.), applied for a U.S.A. patent titled "Apparatus for Production of Three-Dimensional Objects by Stereolithography".
1986	Hull's patent describes a process of photo-hardening a series of cross sections using a computer-controlled beam of light. Also, Yehoram Uziel, then of Operatech (Israel) had invented a basic machine resembling stereolithography.
1987/1988	3D shipped its first beta units to customer sites in the U.S.A., followed by production and systems. These were the first commercial additive-manufacturing system installations in the world.
1991	Uziel, that was in 3D Systems, left to form Soligen, Inc., U.S.A., and he licensed MIT's ink jet printing technique for exclusive use in the metal-casting industry in its Direct Shell Production Casting (DSPC), a process that created ceramic investment casting shells (molds) by adhering thin layers of ceramic powder material using droplets of liquid binder.
1991	Three AM technologies were commercialized, fused deposition modeling (FDM), solid ground curing (SGC), and laminated object manufacturing (LOM). FDM extrudes thermoplastic in filament form to produce parts layer by layer. SGC used a UV-sensitive liquid polymer, solidifying full layers in one pass by flooding UV light through masks created with electrostatic toner on a glass plate. LOM bonded and cut sheet material using a digitally guided laser.
1992	Selective laser sintering (SLS) from DTM (a part of 3D Systems) and the Soliform stereolithography system from Teijin Seiki became available using heat from a laser, SLS fuses powder materials.
1997	AeroMet was founded as a subsidiary of MTS Systems Corp and developed a process called laser additive manufacturing (LAM) that used a high-power laser and powdered titanium alloys.
1998	Optomec commercialized its laser-engineered net shaping (LENS) metal powder system based on technology developed at Sandia National Labs.
1999	Fockele & Schwarze of Germany introduced its steel powder-based selective laser-melting (SLM) system, developed in cooperation with the Fraunhofer Institute for Laser Technology.
2006	Stratasys signed an agreement with Arcam to be the exclusive distributor in North America for electron beam melting (EBM) systems.
2010	Microjet Technology of Taiwan developments Irepa Laser formed EasyCLAD Systems to market its laser metal deposition (LMD) equipment using a powder fed through a nozzle similar to LENS. The equipment has the capability of multi-axis and multi-material deposition.

(Hegab 2016) describes that the additive manufacturing (AM) technology, started with plastic prototypes using various AM Process, such as Fusion Deposition Modeling (FDM), Stereolithography (SLA) and other processes. After more research and development, AM can be used with other materials, include metals, ceramics, and composites. The (Hegab 2016) consider that polymers and metals are as commercially available materials for AM processes, but, ceramics and composites are under research and development. He studied composite materials such as nanocrystalline titanium carbide (TiC)-reinforced with Inconel 718 matrix, and potential alloys. Others like (Azam et al. 2018; Brandão et al. 2017; Liu and Shin 2019; Lehmhus et al. 2018) cite metal feedstocks such as Ti6Al4V alloy. It is important to note that, according to ISO ASTM 52900-15 (ISO/ASTM International 2015) “feedstock is a bulk raw material supplied to the Additive Manufacturing building process”.

Researchers (Azam et al. 2018) used data from several literature to compose a table of mechanical properties for the Ti6Al4V alloy. They comment that one process had mechanical properties better than the other (EBM bether than SLM), but these results are all equivalent when compared with the minimum values specified by ASTM F136-08, which was not presented in their paper. Of the data they used, only Cast material does not meet the Yield Strength (YS, MPa) and Ultimate Tensile Strength (UTS, MPa) standard, but only Wrought and EBM meet all the requirements of the standard, including Elongation (%) for all references (Azam et al. 2018).

Authors as like (Körner 2016) cites metal and alloys, (Zadi-Maad, Rohib, and Irawan 2018) present steel fabricaion and Ti alloy and Ni-Base alloys, and (Elahinia et al. 2016) present a NiTi alloy. (Lehmhus et al. 2018) present composite, TiAl6V4, pure Fe, pure Al and advanced aluminum alloys (AlSi10Mg, AlSi12). And (Gardan 2019) cites smart materials and Dilberoglu et al. (Dilberoglu et al. 2017) cite metals, composite, smart materials and special materials such as concrete, textile, etc.

Table 3 – Overview of process AM by material class, adapted (LEHMHUS et al., 2018).

Process Class	Process	Polymer	Metal	Ceramic	Composite
Binder Jetting (BJ)	3D Printing (3DP)	X	X	X	X
Direct Energy Deposition (DED)	Laser Engineered Net Shaping (LENS)	-	X	X	X
	Direct Light Fabrication (DLF)	-	X	-	-
	Direct Metal Deposition (DMD)	-	X	-	-
Material Extrusion (ME)	Fused Deposition Modeling (FDM)	X	X	X	-
	Multiplayer Jet Solidification (MJS)	-	X	-	-
	Robocasting	-	-	X	-
	Freeze-form Extrusion Fabrication (FEF)	-	-	X	-
Material Jetting (MJ)	Multijet/Polyjet Modeling (MJM/PJM)	X	-	-	-
	Direct Printing (DP)	X	X	X	-
Powder Bet Fusion (PBF)	Laser Beam Melting (LBM)	-	X	-	X
	Selective Laser Sintering (SLS)	X	X	X	X
	Direct Metal Sintering (DMLS)	-	X	-	X
	Electron Beam AM (EBAM)	-	X	-	-
Sheet Lamination (SM)	Laminated Object Manufacture (LOM)	X	X	X	-
	Plate Diffusion Brazing (PDB)	-	X	-	-
Vat Photopolym.	Stereolithography	X	X	X	X

4. Process

According to (Azam et al. 2018; Ford and Despeisse 2016; Körner 2016; Lehmhus et al. 2018) comment that for each material there is a specific process of AM.

However (Lehmhus et al. 2018) reveal that all AM process has by now been adapted to several material classes. Table 3 (adapted) provides an overview of process by material class and these data should be read with care because new combinations or process are constantly emerging (Lehmhus et al. 2018).

On the other hand (Azam et al. 2018) showed that metal additive manufacturing consists of many different technologies (see Figure 1), and it can be divided in "direct" where the metal powder completely melts and solidifies to form the final part, good or component and "no direct" where a binder is used to join the particles of metal powder together and post processing is necessary to meet the expected requirements.

ADDITIVE MANUFACTURING OF METALS

1.

NO DIRECT

Selective Laser Sintering (SLS)	**Stereolithography (SLA)**	**Fused Deposition Modelling (FDM)**	**Laminated Object Manufacturing (LOM)**	**3 D Printing (3DP)**

DIRECT

Selective Laser Melting (SLM)	**Laser Metal Deposition (LMD)**	**Electron Bean Melting (EBM)**

Figure 1 – Classification of Metal AM Processes, adapted (Azam et al. 2018).

From these processes presented in Figure 1, the great majority of the researchers approach in their revision texts the SLM (Azam et al. 2018; Bikas, Stavropoulos, and Chryssolouris 2016; Brandão et al. 2017; Everton et al. 2016; Ford and Despeisse 2016; Hegab 2016; Körner 2016; Liu and Shin 2019; Stavropoulos and Foteinopoulos 2018; Zadi-Maad, Rohib, and Irawan 2018; Zhang et al. 2018; Elahinia et al. 2016; Murr 2018; Gardan 2019), EBM (Azam et al. 2018; Bikas, Stavropoulos, and Chryssolouris 2016; Everton et al. 2016; Ford and Despeisse 2016; Hegab 2016; Körner 2016; Liu and Shin 2019; Stavropoulos and Foteinopoulos 2018; Zadi-Maad, Rohib, and Irawan 2018; Zhang et al. 2018; Lehmhus et al. 2018; Murr 2018; Gardan 2019) e o LMD (Azam et al. 2018; Bikas, Stavropoulos, and Chryssolouris 2016; Hegab 2016; Stavropoulos and Foteinopoulos 2018) / DED (Liu and Shin 2019; Elahinia et al. 2016; Lehmhus et al. 2018; Gardan 2019), which will be detailed next. We also cover texts in the review of AM processes LBM (Azam et al. 2018; Lehmhus et al. 2018), SLS (Bikas, Stavropoulos, and Chryssolouris 2016; Lehmhus et al. 2018), LAM (Klocke et al. 2017) e PDM (Lehmhus et al. 2018).

4.1 Selective Laser Melting (SLM)

SLM is one of the industry's leading additive manufacturing technologies. It is precise and fast compared to other AM Technologies (Azam et al. 2018). SLM using Argon as shielding gas (Körner 2016). See Figure 2 (Azam et al. 2018).

4.2 Electron Beam Melting (EBM)

EBM is another additive manufacturing technology which forms 3D parts by full melting of powder particles. The key difference between laser based additive manufacturing technologies and EBM is the heat source (Azam et al. 2018). EBM uses an electron beam instead of laser, which requires that the procedure for EBM is carried out under vacuum conditions (Azam et al. 2018; Körner 2016; Zadi-Maad, Rohib, and Irawan 2018; Zhang et al. 2018) to prevent dissipation of the electron beam. See Figure 3 (Azam et al. 2018).

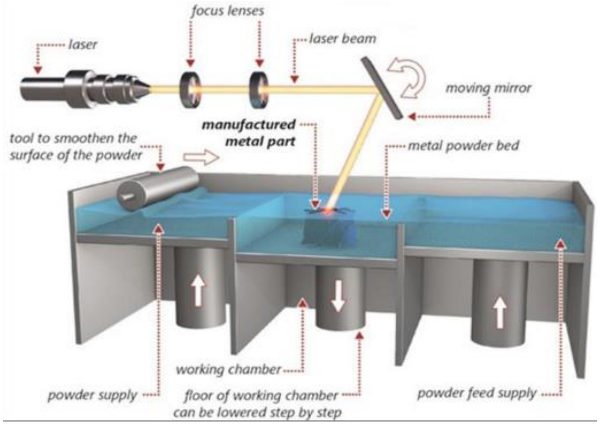

Figure 2 – SLM process, adapted (AZAM et al., 2018).

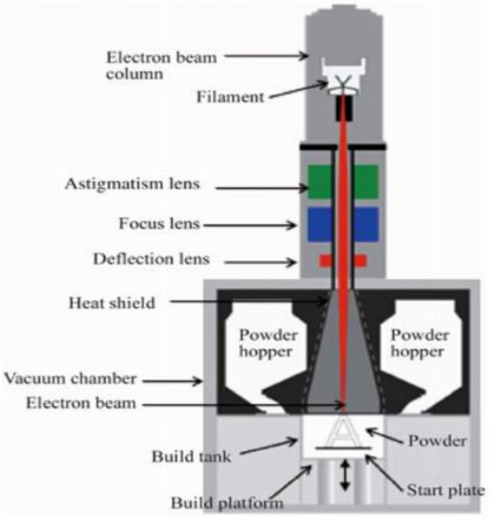

Figure 3 – EBM process, adapted (AZAM et al., 2018).

4.3 Laser Metal Deposition (LMD)

LMD also called as direct energy deposition (DED) and laser cladding, is a powder based additive manufacturing process, which is used to build 3D parts, repair metal components deemed non-repairable by conventional methods or add features to existing parts. The process is very simple, and it begins with a 3D model like other AM technologies. Shown in Figure 4 (Azam et al. 2018).

(Körner 2016) presents that SLM can be used for metals, polymers and ceramics, while como EBM works under vacuum conditions, with high velocities and a high beam power, is restricted to metallic components, because source eletric conductivity is required. While (Lehmhus et al. 2018) show LBM mechanical properties data of many materials, but haven't standard specifations and (Liu and Shin 2019) cite Ti6Al4V fabricated by DED, SLM and EBM. They made a table of mechanical properties of Ti6Al4V by DED, SLM, EBM, Forged and Cast using several references from the literature and the standard specifations (ASTM F136).

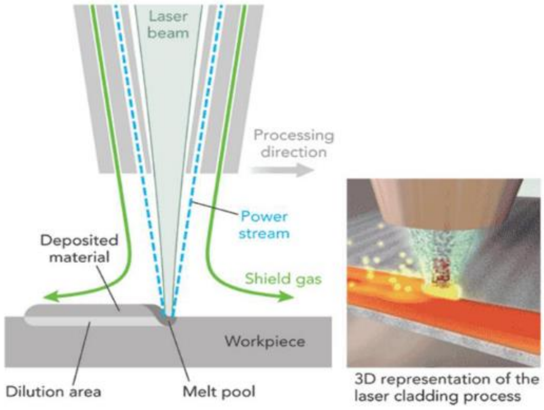

Figure 4 – LMD process, adapted (AZAM et al., 2018).

Research such as (Zadi-Maad, Rohib, and Irawan 2018) show that EBM can provide higher scan rate up to 10^4 mm/s while LBM that only 1,200 mm/s. For EBM there is few studies for steel fabrication, but is popular for Ti Alloy and Ni-Base Alloys (Zadi-Maad, Rohib, and Irawan 2018).

5. Application

The researchers' review papers (Bikas, Stavropoulos, and Chryssolouris 2016; Hegab 2016; Jiménez et al. 2019; Liu and Shin 2019; Gardan 2019) present some AM applications. (Hegab 2016) presents applications for automotive, biomedical, aerospace. Aerospace applications haven't been limited by using only metals, as ceramic parts are used especially ultra-high temperature ceramics which can withstand more 2,273 K. Examples of aerospace ceramic parts are hypersonic flight systems and rocket propulsion systems which have more complex geometries using SLS process.

In the research of (Liu and Shin 2019) show biomedical and air duct made of Ti6Al4V fabricated by EBM and SLM, respectively. The work of (Gardan 2019) presents applications aeronautics, architecture, automotive industries, art, dentistry, fashion, food, jewellry, medicine, pharmaceuticals, robotics and toys. Shown in the Figure 5 follow, the percentage of the industrial sectors using AM (Bikas, Stavropoulos, and Chryssolouris 2016; Jiménez et al. 2019).

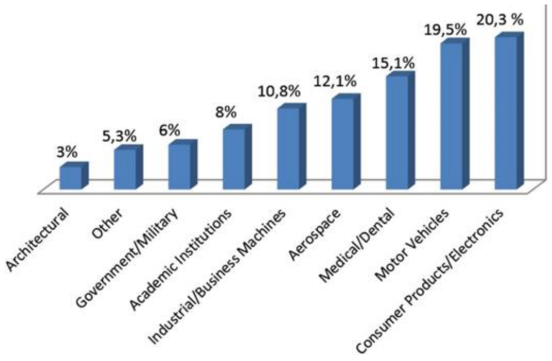

Figure 5 – Percentage of the industrial sectors using AM (Bikas, Stavropoulos, and Chryssolouris 2016; Jiménez et al. 2019)

The works of (Jiménez et al. 2019) summarize some of the possibilities of AM applications (Figure 6).

6. Advantages and disadvantages, trends, and opportunities/challenges

Advantages are, in some way, associated with trends and disadvantages to opportunities for improvement and / or challenges to be overcome.

6.1 Advantages and Disadvantages

(Bikas, Stavropoulos, and Chryssolouris 2016; Costabile et al. 2017; Hegab 2016; Jiménez et al. 2019; Körner 2016; Tofail et al. 2018; Zadi-Maad, Rohib, and Irawan 2018; Lehmhus et al. 2018) present the AM advantages:

- More flexible development (Costabile et al. 2017; Körner 2016; Tofail et al. 2018);
- Freedom of design/complexity geometry (Costabile et al. 2017; Hegab 2016; Jiménez et al. 2019; Körner 2016; Zadi-Maad, Rohib, and Irawan 2018; Lehmhus et al. 2018);
- Less assembly (Costabile et al. 2017; Lehmhus et al. 2018);
- No production tool (Costabile et al. 2017; Jiménez et al. 2019);
- Production small quantities/economic low volume production (Hegab 2016; Jiménez et al. 2019; Körner 2016; Zadi-Maad, Rohib, and Irawan 2018);
- Reduction time to launch a good in the market (Costabile et al. 2017; Tofail et al. 2018);
- Environmental sustainability / reduce waste (Bikas, Stavropoulos, and Chryssolouris 2016; Hegab 2016; Tofail et al. 2018; Zadi-Maad, Rohib, and Irawan 2018) and
- Weight reduction/reduce cost (Körner 2016; Zadi-Maad, Rohib, and Irawan 2018).

The AM disadvantages (Costabile et al. 2017; Jiménez et al. 2019) are showed by:

(a) (Costabile et al. 2017) as:

- High costs of machine and feedstocks and
- Rework is often necessary.

And (b) (Jiménez et al. 2019) as:

- The finish of complex surfaces can be extremely rough;
- Long production times;
- Materials with limited mechanical and thermal properties which restrict performance under stress and
- Higher tolerances than with other manufacturing methods such as those based on material removal.

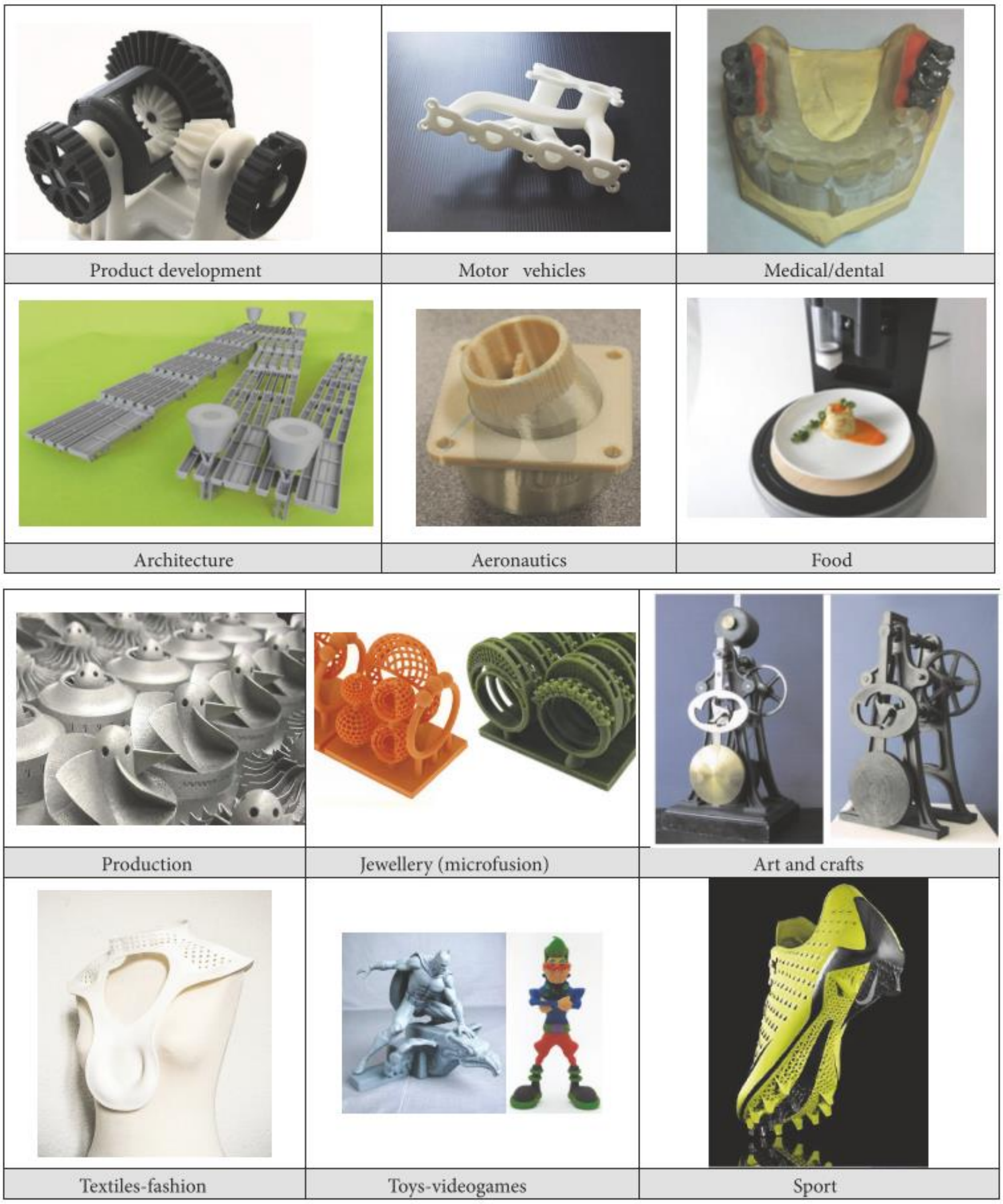

Figure 6 – AM applications, adapted (Jiménez et al. 2019).

6.2 Trends, Opportunities and Challenges

Within this perspective (Hegab 2016; Jiménez et al. 2019; Körner 2016; Lehmhus et al. 2018) agree that AM is a revolutionary industrial process to goods' or components' production.

6.2.1 Trends

The researchers cited initially (Hegab 2016; Lehmhus et al. 2018; Gardan 2019) in their review papers, add other (Bikas, Stavropoulos, and Chryssolouris 2016; Brandão et al. 2017;

Dilberoglu et al. 2017) who also cite trends.

(Hegab 2016) presents trends for the future:

- More potential users will lead to low or medium cost AM systems.

- Increase of materials and process through increasing the speed of processing.

- Capability of processing multiple materials within the same AM system.

In the articles of (Lehmhus et al. 2018) present future trends in AM:

- Advanced Alloys: where the growing diversity of materials processed by means of AM techniques are considerable advances have been made regarding alloy development AM processes, such as novel steel grades, and advanced aluminium alloys with enhanced properties.

- Multi-Material Solutions: through the possibility to change a part’s internal structure has fuelled massive interest in AM as the major tool for realization of tailored materials developed using computational materials science techniques, optimizing properties both the micro- to the macroscopic scale.

Howerver (Gardan 2019) presents that trends in smart material:

- Biomedical: Bio AM or 3D bioprinting shows significant promise for creating complex tissue and organ mimics to solve transplant needs and to provide platforms for drug testing and tissue morphogenesis can be fabricated, yielding advanced porous thermoplastic polymer scaffolds, layered porous hydrogel constructs, as well as reinforced cell-laden hydrogel structures.

- Textile: To design a textile product that can adapt to heat or moisture to improve comfort and to develop new functionalities.

- Aerospace: NASA has used AM to fabricate some rocket parts, and their tests show that AM can save time and reduce costs by 60% or more.

(Bikas, Stavropoulos, and Chryssolouris 2016) show that AM is a technology rapidly expanding on a number of industrial sectors. In terms of materials processed, plastics are currently leading the AM market, but the metal AM market is also growing and in the last few years, there is a significant trend towards metal AM for the production of structural components, mainly in areas, such as aerospace and motorsport applications, that built from metal.

Meanwhile (Brandão et al. 2017) discusses that in the aerospace area there is a trend for future missions is that many more components are envisioned to be manufactured using AM, with production of these goods or parts in orbit. AM is a key in the technology revolution and provides manufacturing opportunities in a wide range in terms of material (metallic polymers), size (nanoscala for large parts) and functionality (auto-auxiliary for a large heat transfer) (Dilberoglu et al. 2017). And (Dilberoglu et al. 2017) also cite that another future direction about AM is the sustainability issue, in which AM may play a significant role in diminishing waste resources and reducing energy consumption by employing just-in-time production. Moreover, the AM may expectedly have an impact on the society where the role of employee in the industry is to be redefined such that they perform jobs about management/design/analysis rather than being labor force and the platforms like do-it-yourself and maker can involve, integrate users. In the future, the manufacturing business will be distributed to many separate locations like small workplaces or homes. In other words, the current barrier of mass production on location will be overcome with personal and customized fabrication (Dilberoglu et al. 2017).

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6.2.2 Opportunities and Challenges

In addition to the researchers (Brandão et al. 2017; Ford and Despeisse 2016; Tofail et al. 2018) cited before (see item 1.1.1), whose their review papers treat about opportunities / challenges, others researchers (Klocke et al. 2017; Lehmhus et al. 2018)) present this information too. Researcher (Brandão et al. 2017) emphasize that dominating Space (outside the Earth) is a great opportunity and challenge for AM regarding cost savings and performance increase. (Ford and Despeisse 2016) cite what seems like a brainstorming of various ideas, because a big amount of data, that a more detailed discussion of each item, for example, certifying new components, certifying materials, validating material properties, and others.

Researchers (Tofail et al. 2018) present that the challenge is transfer AM into obtaining objects that are functional. It is necessary much work to study the challenges related the materials and metrology to achieve this functionality in a predictive and reproductive ways (Tofail et al. 2018). (Klocke et al. 2017) show that for Laser Additive Manufacturing (LAM) there are opportunities and challenges (Table 4).

Table 4 – LAM opportunities and challenges (Klocke et al. 2017).

OPPORTUNITIES	CHALLENGES
Simple product development	Restricted variety of materials
Unique design flexibility	Unusitable for large scale
Manufacturing customization	Undefined process standards
Applications in new industries	Confidentiality issues
Green manufaturing	Ethical concerns (e.g., guns)

Researchers (Lehmhus et al. 2018) propose that a critical challenge in manufacturing of metallic materials via AM tecnology is of whether AM parts can compete, in terms of mechanical properties, with their counterparts made from conventional manufacturing processes like casting and forging.

7. Discussion

Always in the light of the cost-benefit ratio, you can evaluate potential opportunities and challenges based on the references used and main topics (Materials, Process and Applications) in this paper to:

7.1 Materials

The materials used in the AM technology can be polymer, metal, ceramic and composites, with metals, metal alloys and ceramics, usually in powders in micro and nanometric sizes agglutinated or not in a polymer.

The opportunities and or challenges are:

- Currently, there is more use of AM for polymeric and metallic materials Even so, not all metals and alloys and their feedstocks have been developed or researched, which opens up a range for new demands and future goods.

- For metallic materials it is necessary to ensure that the same part produced by AM technology presents performance equal to or better to those manufactured by conventional methods such as forging. Cost and large-scale production also require developments in order to become as competitive as conventional processes such as stamping and casting. The shape of the additives, whether powders or powders wrapped in polymers, composite wires or other modes also requires research too.

- There are few references associated with ceramic materials, probably due to the high costs of their fusion. However, it is a possibility of future developments, opportunities for improvement and challenges to be achieved.

7.2 Processes

The AM technology is of great importance for goods and components' modern manufacturing because it eliminates the need for tooling such as stamping or forging and casting models and molds, since the product or component is already manufactured in its final geometry with computational precision. The SLM, EBM and LMD "direct" processes were more explicit because they are more cited in the references used in this paper, but it is clear that all other processes ("direct" or "no direct") also have their particularities, since for each material, as commented in item 4, there is a specific process.

The opportunities and or challenges are:

- Equipment in which AM processes, binder removal (when applied), sintering and possible subsequent heat treatments are all done in the same chamber or in separate locations, but in series and automated, still need to be developed.

- As mentioned previously, Advantages are associated with trends and disadvantages to opportunities for improvement and / or challenges to be overcome. For example, an advantage today of "Freedom of design / complexity geometry" may generate a trend in the marketplace for designers and manufacturers of parts, components, products to prefer AM to conventional processes such as casting. A disadvantage that refers to "High costs of machine and feedstocks" can generate research and development of AM equipment and the manufacture of cheaper feedstocks, which is an opportunity for improvement and a challenge, a goal to be achieved or overcome.

- Manufacture of large parts or components (such as a propeller of Panamax class ship propeller or a commercial airplane turbine), it will be a possibility to be evaluated and the AM machine chamber must be big also to contain such a component, and there is a need to develop an equipment that guarantees precision, quality and speed of production.

- Very small parts, micro or nanometric size also need to develop equipment capable of guaranteeing functionality and durability of these. The manufacturing of ever smaller components with micro or nano precision can open another frontier in several areas such as a medical robot or micro satellites for various uses and with the guarantee of lower energy consumption, reduction of the use of feedstocks, reduction or disposal of waste, cost reduction. For this to occur the laser diameter also needs to be decreased and accurately.

- Having an equipment with several lasers or electrons beam that can manufacture several and or differents components simultaneously and, if necessary, subsequent processes that are done in the same chamber or in sequence, serially and in an automated way, can solve the problem, the disadvantage of large-scale manufacturing.

7.3 Applications

Developed materials, processes, dimensions and costs the applicability of this technology is total, i.e., in all areas, from aerospace, war, automotive to everyday products like a spoon, a mug or a pencil. In the case of fabrication in Space, which is already happening today, there is no need to take several pieces for Space, only feedstocks are transported, as well as AM equipment and others such as extruders, ovens, etc., since the which has been produced may after some time be recycled and transformed into a new component or part, and continuously.

The opportunities and or challenges are:

- Satellites can also be made in Space or on Earth, miniaturized through AM technology and taken to Earth orbit.

- Use in biomedical applications in which the implant is not made of a metallic or polymeric material, but for example of a material as similar as possible to the human bone or skin and with all the characteristics and properties of the original can be a great challenge not only for AM technology as well as for ethics and morals.

- Another question of ethics and morals. With the possible popularization of this technology and commercialization for civil purposes, ethical aspects should be raised, and software cannot be allowed to release the execution of war goods such as knives, weapons or something of bio-construction, except for research or eminent risk of harm the health of the human being.

8. Conclusion

- First, the use a Literature Review Method is always important to guide, focus the research and the elaboration of a paper.

- There are no general revisions of AM, due to the large number of processes and materials, always being about specific subjects, and few researchers mention the History, advantages, disadvantages, trends, opportunities and challenges.

- All classes of materials known as polymers, metal, ceramics and composites can be used for manufacturing or repair of parts and components by AM technology, with specific developments of both materials and equipment.

- After consolidation of polymeric and metallic materials, the opportunities and challenges for ceramic and composite materials can be evaluated, which can occur together.

- Ceramic materials are being used in AM, but specific reviews have not yet been observed in the studied period, probably due to the previous aspects, such as the need for equipment that operates at more than 2,273 K.

- Ceramic materials are being used in the AM, but have not been observed in the period studied (2016 to 2019) for elaboration this paper, specific revisions regarding, probably in function of existing functional aspects, industrial secrets, the need for equipment that operate at temperatures above 2,273 K, among others.

- The popularization of AM, in order to have equipments for civil use may only occur in decades, but in any case must be attentive to ethical aspects as programming and software associated with AM technology never allow weapons, guns to be made in parts or complete or biological use.

- Finally, the AM technology is revolutionary and can change the actual industry, and human behaviour scenario to better.

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Divulgação

Este artigo é inédito e não está sendo considerado para qualquer outra publicação. O(s) autor(es) e revisores não relataram qualquer conflito de interesse durante a sua avaliação. Logo, a revista *Scientia Amazonia* detém os direitos autorais, tem a aprovação e a permissão dos autores para divulgação, deste artigo, por meio eletrônico.

References

Azam, Farooq I, Ahmad Majdi Abdul Rani, Khurram Altaf, T.V.V.L.N Rao, and Haizum Aimi Zaharin. 2018. “An In-Depth Review on Direct Additive Manufacturing of Metals.” *IOP Conference Series: Materials Science and Engineering* 328 (March):

012005. https://doi.org/10.1088/1757-899X/328/1/012005.

Bikas, H., P. Stavropoulos, and G. Chryssolouris. 2016. "Additive Manufacturing Methods and Modelling Approaches: A Critical Review." *The International Journal of Advanced Manufacturing Technology* 83 (1–4): 389–405. https://doi.org/10.1007/s00170-015-7576-2.

Brandão, Ana, Romain Gerard, Johannes Gumpinger, Stefano Beretta, Advenit Makaya, Laurent Pambaguian, and Tommaso Ghidini. 2017. "Challenges in Additive Manufacturing of Space Parts: Powder Feedstock Cross-Contamination and Its Impact on End Products." *Materials* 10 (5): 522. https://doi.org/10.3390/ma10050522.

Collins, Fort (Wohlers TT). 2014. "Wohlers Report 2014: History of Additive Manufacturing."

Costabile, G., M. Fera, F. Fruggiero, A. Lambiase, and D. Pham. 2017. "Cost Models of Additive Manufacturing: A Literature Review." *International Journal of Industrial Engineering Computations*, 263–83. https://doi.org/10.5267/j.ijiec.2016.9.001.

Dilberoglu, Ugur M., Bahar Gharehpapagh, Ulas Yaman, and Melik Dolen. 2017. "The Role of Additive Manufacturing in the Era of Industry 4.0." *Procedia Manufacturing* 11: 545–54. https://doi.org/10.1016/j.promfg.2017.07.148.

Elahinia, Mohammad, Narges Shayesteh Moghaddam, Mohsen Taheri Andani, Amirhesam Amerinatanzi, Beth A. Bimber, and Reginald F. Hamilton. 2016. "Fabrication of NiTi through Additive Manufacturing: A Review." *Progress in Materials Science* 83 (October): 630–63. https://doi.org/10.1016/j.pmatsci.2016.08.001.

Everton, Sarah K., Matthias Hirsch, Petros Stravroulakis, Richard K. Leach, and Adam T. Clare. 2016. "Review of In-Situ Process Monitoring and in-Situ Metrology for Metal Additive Manufacturing." *Materials & Design* 95 (April): 431–45. https://doi.org/10.1016/j.matdes.2016.01.099.

Fera, M., F. Fruggiero, A. Lambiase, and R. Macchiaroli. 2016. "State of the Art of Additive Manufacturing: Review for Tolerances, Mechanical Resistance and Production Costs." Edited by Duc Pham. *Cogent Engineering* 3 (1). https://doi.org/10.1080/23311916.2016.1261503.

Ford, Simon, and Mélanie Despeisse. 2016. "Additive Manufacturing and Sustainability: An Exploratory Study of the Advantages and Challenges." *Journal of Cleaner Production* 137 (November): 1573–87. https://doi.org/10.1016/j.jclepro.2016.04.150.

Gardan, Julien. 2019. "Smart Materials in Additive Manufacturing: State of the Art and Trends." *Virtual and Physical Prototyping* 14 (1): 1–18. https://doi.org/10.1080/17452759.2018.1518016.

Hegab, Hussien A. 2016. "Design for Additive Manufacturing of Composite Materials and Potential Alloys: A Review." *Manufacturing Review* 3 (July): 11. https://doi.org/10.1051/mfreview/2016010.

ISO/ASTM International. 2015. *ISO/ASTM 52900: Additive Manufacturing-General Principles - Terminology*. Geneva, Switzerland.

Jiménez, Mariano, Luis Romero, Iris A. Domínguez, María del Mar Espinosa, and Manuel Domínguez. 2019. "Additive Manufacturing Technologies: An Overview about 3D Printing Methods and Future Prospects." *Complexity* 2019 (February): 1–30. https://doi.org/10.1155/2019/9656938.

Klocke, Fritz, Kristian Arntz, Mahesh Teli, Kai Winands, Maximilian Wegener, and Stella Oliari. 2017. "State-of-the-Art Laser Additive Manufacturing for Hot-Work Tool Steels." *Procedia CIRP* 63: 58–63. https://doi.org/10.1016/j.procir.2017.03.073.

Körner, C. 2016. "Additive Manufacturing of Metallic Components by Selective Electron Beam Melting — a Review." *International Materials Reviews* 61 (5): 361–77. https://doi.org/10.1080/09506608.2016.1176289.

Lehmhus, Dirk, Matthias Busse, Axel von Hehl, and Eric Jägle. 2018. "State of the Art and Emerging Trends in Additive Manufacturing: From Multi-Material Processes to 3D Printed Electronics." In *MATEC Web of Conferences*, edited by S. Pantelakis and S. Koubias, 188:03013. https://doi.org/10.1051/matecconf/201818803013.

Li, Xin, Jianzhong Shang, and Zhuo Wang. 2017. "Intelligent Materials: A Review of Applications in 4D Printing." *Assembly Automation* 37 (2): 170–85. https://doi.org/10.1108/AA-11-2015-093.

Liu, S., and Y.C. Shin. 2019. "Additive Manufacturing of Ti6Al4V Alloy: A Review." *Materials and Design* 164. https://doi.org/10.1016/j.matdes.2018.107552.

Mani, M., B.M. Lane, M.A. Donmez, S.C. Feng, and S.P. Moylan. 2017. "A Review on Measurement Science Needs for Real-Time Control of Additive Manufacturing Metal Powder Bed Fusion Processes." *International Journal of Production Research* 55 (5): 1400–1418. https://doi.org/10.1080/00207543.2016.1223378.

Murr, L. E. 2018. "A Metallographic Review of 3D Printing/Additive Manufacturing of Metal and Alloy Products and Components." *Metallography, Microstructure, and Analysis* 7 (2): 103–32. https://doi.org/10.1007/s13632-018-0433-6.

Stavropoulos, P., and P. Foteinopoulos. 2018.

"Modelling of Additive Manufacturing Processes: A Review and Classification." *Manufacturing Review* 5. https://doi.org/10.1051/mfreview/2017014.

Tofail, Syed A M, Elias P Koumoulos, Amit Bandyopadhyay, Susmita Bose, Lisa O'Donoghue, and Costas Charitidis. 2018. "Additive Manufacturing: Scientific and Technological Challenges, Market Uptake and Opportunities." *Materials Today* 21 (1): 22–37. https://doi.org/https://doi.org/10.1016/j.mattod.2017.07.001.

Zadi-Maad, A, R Rohib, and A Irawan. 2018. "Additive Manufacturing for Steels: A Review." In *IOP Conference Series: Materials Science and Engineering*, 285:012028. https://doi.org/10.1088/1757-899X/285/1/012028.

Zhang, Lai-Chang, Yujing Liu, Shujun Li, and Yulin Hao. 2018. "Additive Manufacturing of Titanium Alloys by Electron Beam Melting: A Review." *Advanced Engineering Materials* 20 (5): 1700842. https://doi.org/10.1002/adem.201700842.