Long-term technological and industrial plan

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1. Executive summary

SAM (Sector Skills Strategy in Additive Manufacturing) project, aims to deliver together with all partners and stakeholders a shared vision and collaborative skill solutions capable to foster and support the growth, innovation and competitiveness in the Additive Manufacturing (AM) sector.

Work package 1 is composed of five deliverables (see Figure 1) that look individually into specific fields, thus supporting the definition of the European AM skills strategy. The European AM skills strategy is based on three pillars: firstly, global and societal challenges, secondly technology development and thirdly professional profiles (skills).

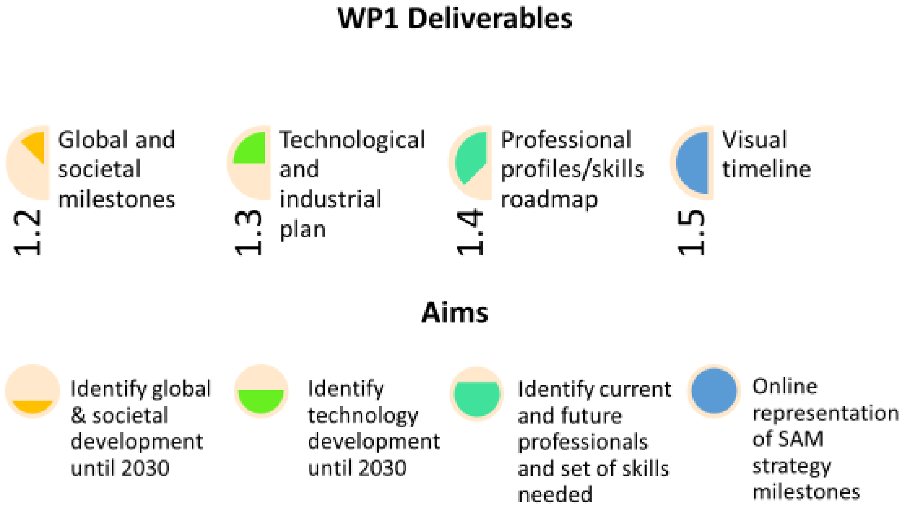

Figure 1 - WP1 Deliverables overview

The deliverable D1.3 corresponds to a Technological Long-Term Industrial Plan, which aims at defining and collect major technological developments expected to happen in the next 10 years, until 2030. These technological developments together with Global and Societal challenges and transformations (D1.2) and Current professional Profiles/skills Roadmap (D1.4) are critical to ensure that future skills needed in AM are identified in due time, thus guaranteeing that a skilful workforce is ready when industry requires it.

Finally, the results from these three WP1 deliverables will be represented graphically as a visual timeline in the AM Observatory (WP4) as relevant Technological Trends to consider until 2030.

To ensure a European and industrial perspective on the long-term technological and industrial plan, SAM project has analysed a set of 84 initiatives - encompassing networks, platforms and research programs at international, European, national and regional level. The aim is to clearly understand which areas/topics are common and how new offerings can be promoted to allow employees, students and society in general to progress coherently with the technological evolution.

SAM is engaged and will continue to engage with a range of initiatives, either AM specific or related (for example ”advanced technologies”, Industry 4.0 and Digitisation) to ensure that the priorities identified in those initiatives are analysed and, if needed, addressed in the project. The aim of involving relevant organisations representing the AM sector, is to avoid a duplication of efforts in addressing AM skills needs, which is creating confusion in industry on “which training” to do.

The analysis and comparison of technological roadmaps in the AM field helped to identify a total of 38 technological trends that promise challenges at short-term (2020-2021) and long-term (2022-2030) linked to materials, process and manufacturing, post-processing, ICT and quality.

Identified technological trends and related initiatives included in this long-term technological map will be included in the online observatory to track them and to analyse their potential effect and contribution to decrease the skills gaps and shortages in the AM sector. By doing so synchronizing the technology evolution with required human skills to avoid any delay or obstacle which might hinder successful and on time industrialization will be achieved.

As part of the AM Observatory rules and operational procedures (D4.1), the methodology to update trends, engage stakeholders, will gather new inputs from the AM global markets and other sources will be stablished and defined. According to these rules, the responsibility to keep the technological trends updated lies with the European AM Industrial Council. By default, reporting on industrial trends will be done every two years.

2. Introduction

SAM addresses the common vision and actions to support the growth, innovation and competitiveness of the AM sector.

The “Long-term Technological and Industrial Plan” is the second deliverable of WP1, which together with the “Global and Societal Milestones Report” (D1.2) feeds the remaining work package deliverables, i.e. D 1.4 (professional profiles/skills roadmap) and D1.5 (visual timeline).

The present deliverable D 1.3 is a critical input for the definition of the European AM skills strategy. In fact, the identification of short and long-term technological trends is essential to discover gap drivers and to set objectives and supporting actions in due time to avoid shortage or lack of skilled professionals required to support innovation and industrial implementation of AM.

In addition, D1.3 contributes to feed the AM skills “Forecast Methodology” (WP2), the “Methodology for Design and Review Professional Profiles and Skills” (WP3) and the “AM Observatory” (WP4). The technological trends identified in the present deliverable will be kept updated, as they are supposed to be integrated in the AM Observatory (see Figure 2).

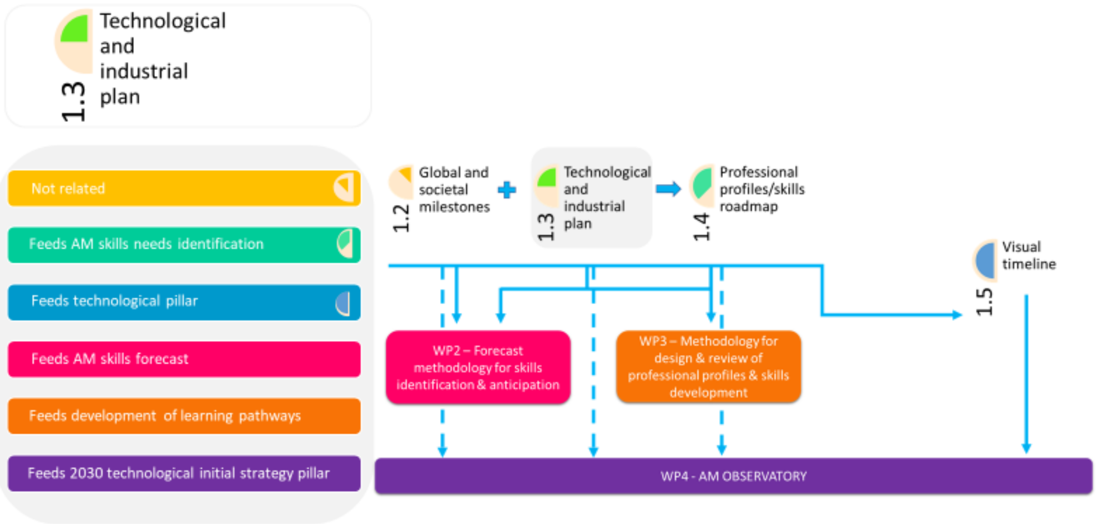

Figure 2 - Interaction flow between D1.3 and remaining project outcomes

A top-down approach based on global and societal challenges, technological trends and skills requirements matching with professional profiles was used to define the European AM skills strategy from 2019 to 2030, where the following objectives defined in SAM play a crucial role:

- Global and societal change analysis with milestones and related skills definition. (D1.2)
- Major technical developments analysis (D1.3)
- Current and Future Professional Profiles (skills) identification (D1.4),
- Continuous improvement and development process that will allow maintaining the skills strategy updated

The present long-term report deals with the technological and industrial transformations/ evolution from 2019 to 2030, thus addressing all transformations that can directly and indirectly impact on the AM skills.

The technological plan will be represented graphically as a timeline of the relevant trends/

transformations expected to happen until 2030 and which are related to the skills that will be required.

AM technologies are evolving at a much faster pace than the development of the skills to use them. That is why the industry demand for a skilled workforce has to be fulfilled by identifying real needs using a strategic approach and ensuring a methodology which guarantees continuous knowledge updates. In order to keep up with technological changes, an active approach able to anticipate current and future needs is selected.

The focus of the report will concentrate on analysing and identifying expected technological breakthroughs until 2030 which can be assigned to the following 3 segments:

1. Materials
2. Process/Manufacturing
3. Post Processing

The three segments have been chosen by the SAM partners due to a previous division done by ISO and ASTM according to currently available standardization documents (see Figure 3.) The partners in SAM believe that all main areas in AM that will be important in terms of technological trends (including sustainability, lifecycle and quality) can be assigned to the three segments and will be covered in more detail in section 6 of the present document.

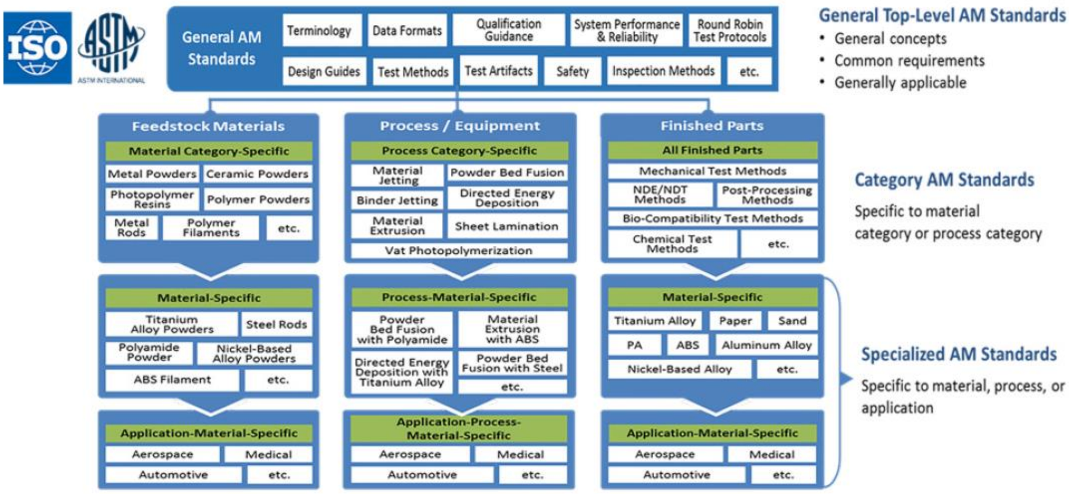

Figure 3 - Top level AM Standards defined by ISO and ASTM

In addition, a set of initiatives, encompassing networks, platforms and research programmes have also to be updated to promote new offerings and to allow employees, students and society in general to progress together with technological evolution.

3. Methodology

The methodology applied to the development of the long-term plan is the result of an extensive desk research and mapping of technological literature, roadmaps, policies and initiatives. Since many of the SAM partners are members of national and international platforms, associations and clusters, a close inspection of trends, needs and challenges in the field of AM was carried out.

The following methodology has been carried out by the SAM partners during the first year of the project (2019). The results can be seen in chapter 5 and 6 and in the annex.

The methodology used in the current deliverable is composed by three main steps, namely:

1. Analysis of existing national, regional and European level initiatives and policies in AM.
2. Identification and analysis of main up-to-date roadmaps.
3. Collection and analysis of technical literature and demands in the following segments in AM

    - Materials
    - Process and manufacturing
    - Post Processing
    - Other relevant areas

Analysis of technical trends in segment overlapping “AM Product Quality” and “Information Communication Technology (ICT)”. A “top-down” approach was used for mapping and updating all relevant initiatives, thus considering policies, platforms, clusters, frameworks and associations addressing AM and related areas (e.g. “Advanced Technologies”, Industry 4.0 and Digitisation) at international, European, national and regional levels.

Additionally, the most relevant worldwide technological roadmaps in AM have been analysed and compared to identify promising technological challenges. From that, a list of technological trends was developed which should determine the evolution of these technologies. A spotlight has been put on trends which have direct influence on skills development to be coherent with the SAM project approach.

4. Initiatives in Additive Manufacturing

As mentioned before, SAM partners and associated partners are members of regional, national and European initiatives belonging to education, research and industry. As such, the mapping of relevant activities reflects the engagement and networking encompassed in AM specific and related initiatives. Furthermore, wider skills promotion initiatives such as educational/training courses have also been included even though they are mainly addressed in deliverable *1.4 Professional Profile/Set of Skills Roadmap.*

The mapping and analysis of initiatives is presented in Section 8 (Annex), covering 84 initiatives, ranging from policies, platforms, frameworks, clusters and associations linked to AM and related areas. Mapping of the initiatives was done to allow the identification of priorities and areas that were identified in order to critically understand how SAM can complement and relate to those initiatives.

SAM will engage with the identified initiatives in the following ways: promote the use of AM technology, raise awareness or boost skills development. The relational used for the mapping of initiatives, first the European and then the national, is linked to the way SAM intends to implement the education and training system.

In fact, SAM is using a joint European approach to identify the necessary skills. Based on the required skills a Qualification system in AM can be developed and implemented which will be supported by a network of training centres across Europe to allow access for industry to the necessary skills. The focus is to involve relevant organisations representing the sector at national level, and responsible for each type of initiative, in order to avoid the duplication of efforts in developing solutions to address AM skills gaps and shortages. Moreover, an analysis of initiatives at international level was performed to compare the approaches in terms of policies, platforms and research outside Europe to check if they are aligned with European initiatives.

Worldwide, eight programs supporting research and innovation in AM technologies were identified and analysed by SAM. At international level, meetings to promote SAM's sector skills strategy and Observatory are planned with *America Makes* (USA) and *National Additive Manufacturing Cluster* (Singapore). More details about these international initiatives can be found in section 8.1 Non-European (National) Initiatives.

At European level, a total of 21 European initiatives were mapped mostly addressing policies, platforms and associations. Project partners are already engaged and will continue working with key initiatives addressing AM technology and skills in line with industrial needs, such as the *AM Platform, ISO TC261, World Manufacturing forum, EFFRA and ESCO.* More details about these international initiatives can be found in section 8.2 Transnational Initiatives.

Then, 47 national and seven regional initiatives which might accelerate the national and regional roll out were analysed. SAM has given priority to initiatives taking place in partners countries (France, Spain, Italy, UK, Germany, Portugal, Belgium and Greece), since these clusters, programmes, networks and platforms can contribute for boosting implementation of training and skills development in AM. More details about these international initiatives can be found in section 8.3 National Initiatives.

The analysis and engagement with initiatives, including regional, national and European networking will be kept throughout AM Observatory and is expected to grow depending on the number of training centers and levels of development of AM technology in each country.

5. AM technological trend evolution to 2030

The goal of this section is to assemble, collect and describe future AM technology trends of the following three segments:

- Materials
- Process and manufacturing
- Post processing

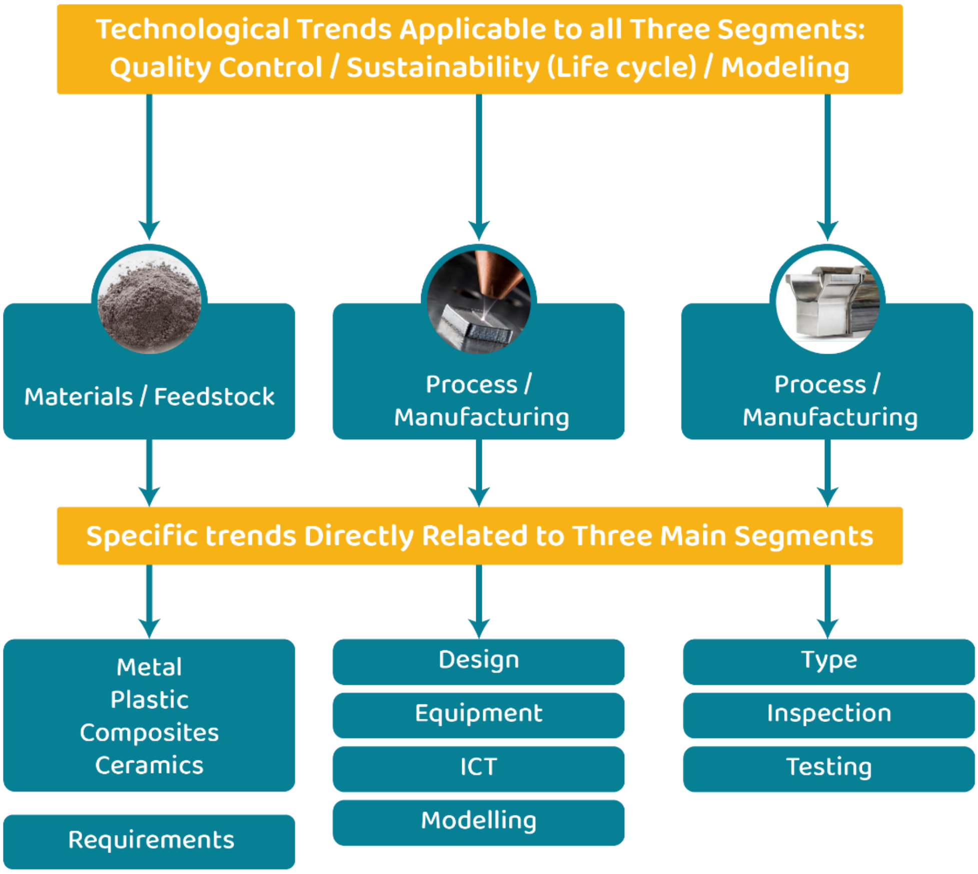

Figure 4: Steps of AM value chain in FOFAM and AM-MOTION roadmaps[1]

As can be seen from Figure 4, the three main segments can be further divided into different subsections. With regards to an AM process chain and linking this to necessities and skills in AM for professional roles, all major areas have been covered.

From the image it can be seen that aspects such as sustainability (life cycle), quality and modelling have also been included. These areas will most certainly, in line with environmental trends, play a role until 2030. In fact, they have been considered as a "Global and Societal Challenge" in D 1.2. However, in terms of technological trends, these aspects are not considered to be stand-alone but can connected to all three segments. The authors expect sustainability, quality and lifecycle to be a by-product of the optimization and efficiency efforts of the three main segments. Moreover, as AM is a rather young technology the main focus for advances in the technology will likely lie in the optimization of the base requirements (processes, equipment and materials) rather than focusing on environmental optimization.

AM skills will be constantly updated with regards to these areas and therefore provide an insight into

[1] https://www.am-motion.eu/images/D5.3_rev_July2018-rev9.pdf

the future to match skills with current and future demand of professionals.
The following sources of information have been employed to complete this roadmap: technical literature, technological roadmaps, sectorial roadmaps, etc.

5.1. Technological Roadmaps

Although it was identified that AM has been included in a wide range of broader roadmaps such as smart manufacturing, digital manufacturing and Industry 4.0, it was decided to focus on roadmaps and applications specifically aiming at AM technologies and its applications. Thus, analysing technological trends, opportunities and barriers only in AM.
Several different initiatives which refer to associations such as the AM platform, VDMA and others but also national and regional strategies (American, Flemish or UK) as well as projects (AM-Motion, SAMT) and private initiatives such as Lloyds Register are briefly discussed below.

5.1.1. AM motion

AM Motion was a European project[2] which aimed to contribute to the rapid market uptake of AM technologies across Europe.
End of 2018, AM motion developed a roadmap[3] based on the challenges and opportunities and recommending future actions for the AM development and successful market uptake in the following seven target sectors:

- Health
- Aerospace
- Automotive
- Consumer goods and Electronics
- Industrial equipment and Tooling
- Construction
- Energy

The Roadmap identified key challenges and opportunities for a successful market uptake of AM products for every sector. It aimed to create a joint vision to boost the European leadership in AM and defined actions to fill existing gaps between current status and the target vision.

5.1.2. America Makes

America Makes[4] is the national leading partner in additive manufacturing (AM) and 3D printing (3DP) technology research, development and innovation in the United States of America
America Makes developed an AM technology roadmap to identify measurable and significant challenges that, once met, can bring technical and knowledge advancements across the industry.

The result of the roadmap can be divided into five technical focus areas:

- Design
- Process
- Material
- Value Chain
- The Additive Manufacturing Genome

Each focus area of the roadmap is aimed at driving technological advancements to enable a faster, more efficient and competitive AM sector.

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[2] https://www.am-motion.eu/
[3] https://www.am-motion.eu/am-motion-roadmap.html
[4] https://www.americamakes.us/our_work/technology-roadmap/

5.1.3. SAMT SUDOE

SAMT SUDOE is a collaboration between partners from Spain, Portugal and France. The project was funded by the Interreg Programme[5] focusing on AM technologies and advanced materials to boost advanced production systems, nanotechnology and materials in industrial sectors present in SUDOE space such as plastic processors and mould industries.
The project developed a roadmap[6] with the aim to motivate the increase in the use of AM technologies and "Advanced Materials" in the SUDOE regions and to facilitate the approach of Moulds and Plastics Industry and R&D entities. The roadmap identifies new markets, innovation and research opportunities to stimulate the uptake of AM technologies.

5.1.4. VDMA roadmaps[7]

VDMA Additive Manufacturing Association is based in Germany and developed at the end of 2018 detailed roadmaps for different AM technologies. Their vision is a quality-controlled, automated AM process chain which will pave the road for a cost-efficient series production of ready-to-use components.

5.1.5. Lloyds Register Foundation

The Lloyd's Register Foundation is a UK charity established in 2012 which aims to protect the safety of life and property, and to advance transport and engineering education and research.[8]
The foundation has published a roadmap on additive manufacturing, which identifies four key challenges that, once developed, can lead to a safe adoption of the technology:

- Qualification of technology
- Confidence in the supply chain
- A competent and qualified workforce
- Safety enhancements (enabled by additive manufacturing / 3D printing)

Three of the challenges focus upon reducing the risk of premature or unexpected failure of the parts and one challenge seeks opportunities on how AM technology can deliberately be used to improve overall safety of an asset.[9]

5.1.6. Additive Manufacturing UK National Strategy 2018-2025

This roadmap has been prepared by the UK Additive Manufacturing Steering Group, a research group of business, research and leadership in AM. To complement the group of key stakeholders, leading industries made also important contributions.
The program brings together
all key UK stakeholders and provides critical mass to focus efforts and build national competency in the use of AM. With this a similar approach has been taken such as other national programs in USA, Korea, Japan, Canada and Singapore. It also looks for strong and relevant research and innovation activities to sustain future competitiveness by the implementation and adoption of AM technologies.
The roadmap analyses different technological barriers in terms of design, materials and processes, inspection, test and standards, IPR and data management, skills and education, supply chain development and implementation and provides recommendations to overcome them.

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[5] https://www.samtsudoe.com/fr/
[6] https://www.samtsudoe.com/fr/roadmap/
[7] https://www.vdma.org/en/v2viewer/-/v2article/render/27025768
[8] https://www.lrfoundation.org.uk/en/
[9] https://www.lrfoundation.org.uk/en/publications/additive-manufacturing-roadmap/

5.1.7. STREAM-roadmap

In 2009, the "Strategic Initiative Materials (SIM)" which is a virtual research center was initiated by the flemish materials industry and universities. The mission of SIMis to strengthen the scientific materials base and to build technology platforms in relevant areas with sufficient critical mass.
Within SIM, several research programs have been defined on specific topics. The STREAM program deals with (materials for) AM.[10]
Within the STREAM program, a roadmap is kept up-to-date concerning the evolution of the materials research in the world but with a focus on the Flanders region. The program is mainly focusing on polymers and metals but ceramics and composites have also been included (to a lesser extent). Furthermore, the program groups a number of specific research projects.

6.1.8 Summary on Technological Roadmaps

Opportunities, challenges and trends in AM have been covered by all of the roadmaps that have been examined. It was found that roadmaps were developed mostly in national initiatives or regional cooperations (further information about initiatives can be found in Annex 8). The trends can be assigned to AM processes, standardisation, certification, ICT, skills and education, financing, intellectual property, safety, communication, applications and sectors. In Table 1 an overview of the different major topics covered in each roadmap is given. All roadmaps covered standard topics but approach and focus vary across the nations or initiatives. In terms of the European Union, a unified approach could not be found with regards to skills development. This is probably due to the reason that knowledge in AM technology is a competitive aspect for many countries. A lack of appropriate skills in design, processes, materials, quality and testing, might prevent a proper adoption of the technology and even more, hinder the development and validation of new products in some countries.

Table 1 - Comparison of different topics covered by examined technological roadmaps

Roadmap	**Topics**					
	Materials	**Processes**	**Post-processing**	**ICT (AI, cyber security)**	**Quality**	**Skills**
AM- Motion	X	X	X		X	X
America Makes	X	X	X	X	X	X
SAMT SUDOE project	X	X				X
VDMA	X	X		X	X	X
Lloyds Register – Roadmap	X	X			X	X
AM UK National Strategy	X	X		X	X	X
STREAM roadmap	X	X				

5.2. Materials

In order to understand the current and future developments concerning materials in AM, it is

[10] https://www.sim-flanders.be/research-program/stream

necessary to look at the past. During the 35 years history of Additive Manufacturing, material research and development have been turbulent. The early stereo-lithography parts were extremely brittle and could practically only be used as visualisation tools or prototypes. Today, functional and even structural parts can be 3D-printed in materials that come very close to conventional manufacturing materials.
Like in conventional manufacturing technologies, the materials are categorised. There are essentially four categories:

- **Polymers:** They are the oldest AM-material group and are by far the most used and wide-spread of all AM-materials. This is the case measured in produced numbers, produced volume and in generated turnover (over 95%). The growth rates are still quite high (see Figure 5, the figure includes the overall AM-market and is not about polymer AM alone. However, as will become clear further on, polymer AM covers more than 95% of the market) and this is mainly due to technological advances opening up new (specific) markets.
- **Metals**: Compared to polymers, metals are not yet so extensively used in AM. The graphs in Figure 5 show the worldwide turnover (l) and the growth ® of the AM-market as a whole. The graphs in Figure 6 do the same for metal AM only. In absolute numbers, the metal market is not even 3% of the total AM-market. However, when looking at the growth numbers, metal AM is clearly in the lead, especially for steel, aluminium, titanium, nickel and copper alloys. This is a clear indication that metal AM is still in an early phase and consequently has a very high growth potential (also for the coming years). Precious metals (gold, silver) are also currently used in jewellery applications and they have their niche market.

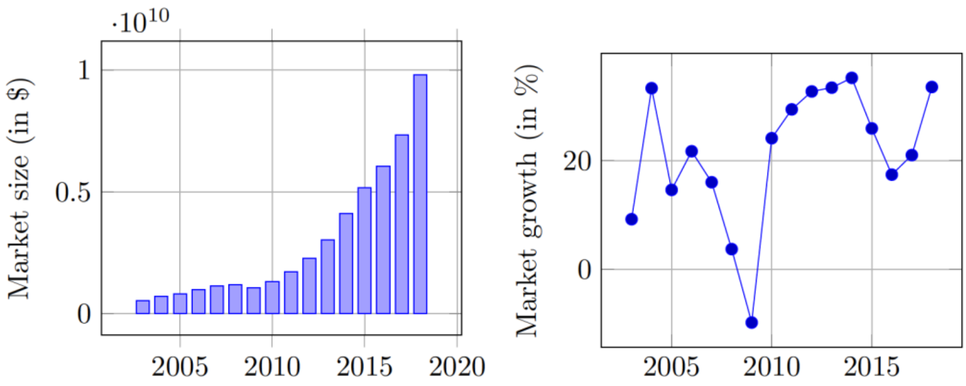


Figure 5: AM-market evolution until 2018 (Source: Wohlers report)

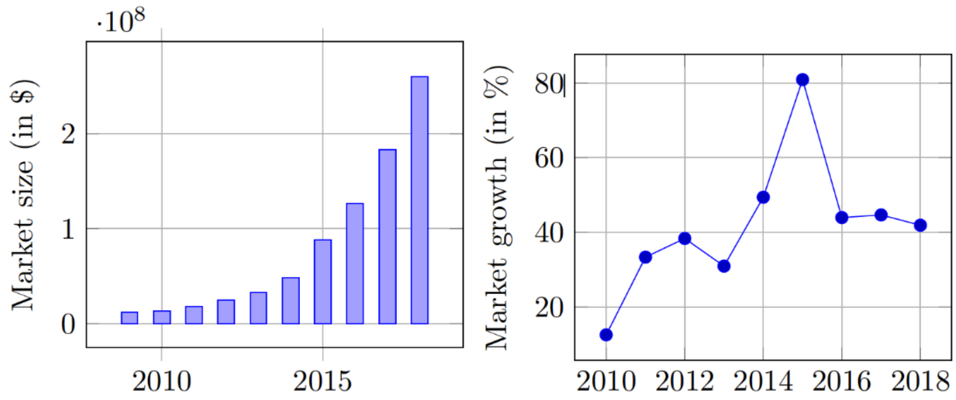


Figure 6: Metal AM-market evolution until 2018 (Source: Wohlers report)

- **Ceramics**: Figure 7 shows expected ceramics AM material revenues until 2029[11]. Despite at this moment they are still only used in niche markets, 450 million US dollar sales in ceramic

[11]https://www.globenewswire.com/news-release/2019/09/05/1911538/0/en/New-SmarTech-Analysis-Report-Sees-Ceramic-Additive-Manufacturing-Materials-Sales-at-450-Million-and-an-Overall-3-8-Billion-Ceramics-AM-Market-in-2029.html

AM materials are expected by 2029. This market growth will be based on the more extensive application of silica-based (sand)/cement, alumina based and zirconia based raw materials.

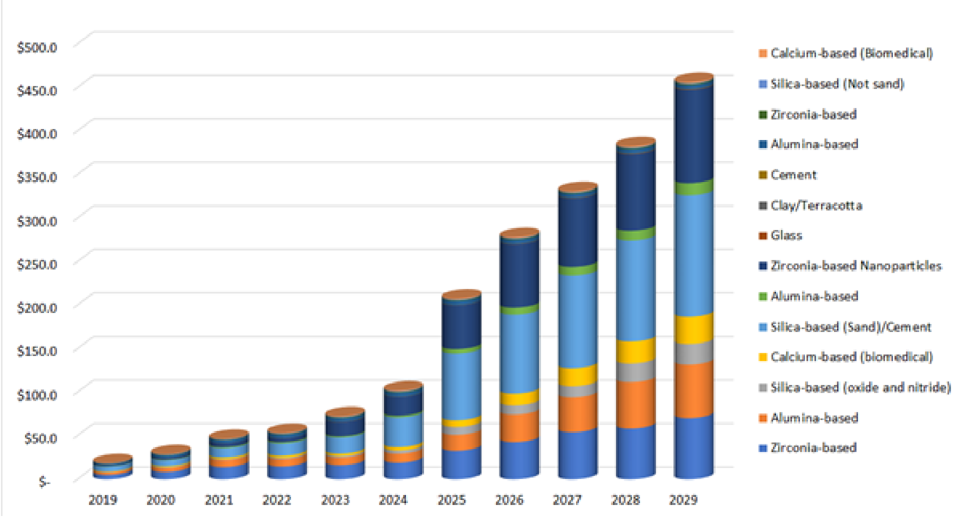
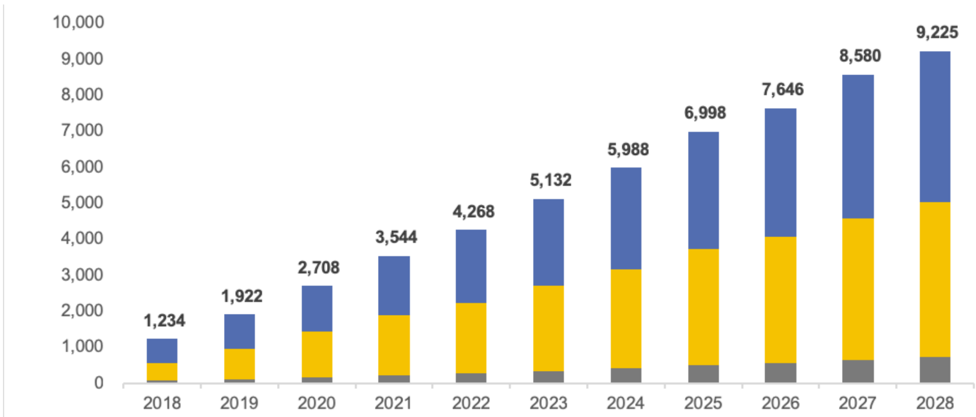


Figure 7: Ceramics AM materials revenues until 2029 (Source: SmarTech Publishing)

- **Composites**: The AM processes for composites are still in a very early development phase. Current composite AM material market (around 100 million US$) is expected to multiply by 7 until 2028[12] (see Figures 8 and 9). Whereas short term market applications will be mainly focused on chopped fibre composites, including both large format extrusions and powder bed fusion applications, medium term developments will also include continuous fibre composites.



	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Total	1,234	1,922	2,708	3,544	4,268	5,132	5,988	6,998	7,646	8,580	9,225
Parts	678	958	1,272	1,644	2,017	2,427	2,821	3,251	3,578	3,985	4,179
Hardware	466	837	1,265	1,675	1,964	2,357	2,741	3,247	3,486	3,939	4,314
Materials	90	127	171	225	287	348	426	500	582	657	733

Figure 8: Composite AM market forecast until 2028, including materials market (Source: SmarTech Publishing)

[12] https://www.3dprintingmedia.network/composites-additive-manufacturing-market-2028/

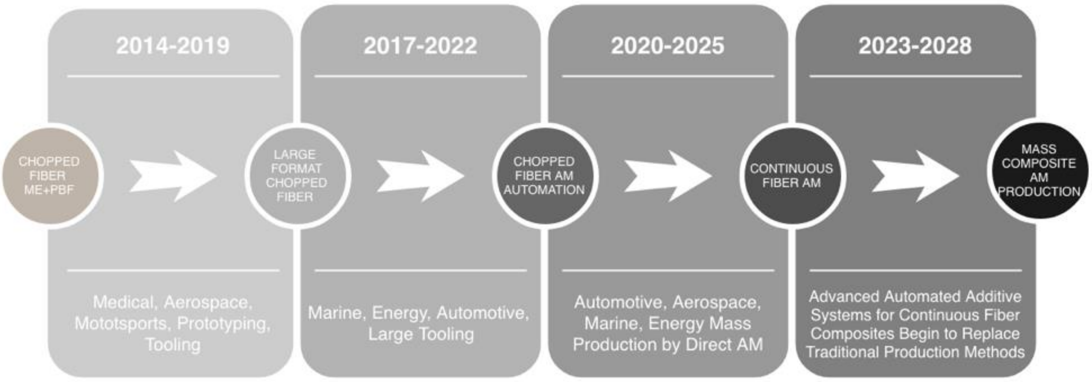


Figure 9: A timeline for adoption of composite AM (Source: SmarTech Publishing)

There are more categories of materials currently opening up for AM but these are very marginal (according to current market-value). Examples of these are: food, pharmacology and (living) cells. Currently, 3D bioprinting research focuses on drug discovery and toxicity applications (*in vitro*), or tissue and organ modelling (*in vivo*).However, the **bioprinting (#M8)** of complex internal organs, such as hearts, kidneys, and livers, is still far away and will not turn into reality before 2030[13].

Apart from the very early years of AM, new research and technological advances in AM have been application and market driven. This is a trend that will most likely continue the coming years. An exception to this is the research on **4D-printing (#M9)** with the so-called smart materials.
The research and developments in materials that impact the performance and life cycle of AM parts goes beyond the printed materials themselves. Obviously, the final material properties of the printed parts depend on many more aspects. Furthermore, concerning materials, the following should be taken into consideration:

- the raw material synthesis and manufacturing
- the handling and pre-processing of raw materials
- the effect of the AM process itself (see 3.3)
- post-treatment (see 3.4)
- impregnating and/or coating (see 3.4)
- recycling
- circular economy, i.e., the production of high added-value products from recycled or bio-based raw materials

These last topics should be independent of the material group although it will be hard to recycle ceramics or composite materials after they have been fully processed. Nevertheless, the reduction of the CO2 footprint of the new products, including their production and lifetime, will be a critical aspect that will progressively affect to decision criteria and compete with current prevailing economic criteria.
The logical evolution for the future is therefore best characterised within the following trends in AM research:

- The implementation of existing AM materials to **new applications and products (#M1).**
- The **development of new AM materials (#2)**, including metals (high strength aluminium alloys, steels, magnetic alloys and intermetallic and composites.
- The use of **materials used in conventional applications** (welding, metal injection moulding, investment casting) as raw **AM materials (#M3)** (wires, pellets, sand, wax…).
- **Thermo-mechanical modelling (#4)** of AM processes (plastic and metal):
    - There is limited insight in the fundamental physics of plastic AM processes, for instance thermal history in Plastic Powder Bed printing of plastics has an effect on mechanical properties. The aim of this topic is to optimize the printing process by

[13] https://www.biogelx.com/key-questions-of-3d-printed-organ-market/

increasing the fundamental insight in process. Research on the actual AM process highly encouraged in this topic.
  - Inherent variations in AM processes of plastics limit its use in application areas where strict quality assurance is needed.
  - Research has to unveil the key physical phenomena on different levels: micro (laser-material interaction), meso (layer level) and macro (part level).
- **Raw-material handling and logistics** of (plastic) AM at industrial level
- AM of fatigue-demanding applications
- **Life cycle analysis (LCA) and circular economy (#M5)** for Additive Manufacturing
- **Quality assurance, traceability,** first article inspection, NPI-processes
- Development of **fit-for-purpose materials (#M6).**
- Combination of different materials in the same structure **(multi-material parts) (#M7).**

A summary of the AM processes that can be used, main applications and status for different materials are shown in Table 2. Please note that references for the most pioneering or relevant publications have been given rather than the newest publications.

Table 2- Material, AM process, Application, Status

Material	AM Process	Application	Status	References
ABS [Acryonitrile Butadiene Styrene]	Amorphous, Material extrusion	Automotive, Biomedical, Electronics	Commercial	[13]
Acrylics	Thermoset, Vat polymerization, Material jetting		Commercial	[13]
Acrylates	Thermoset, Vat polymerization, Material jetting		Commercial	[13]
Acrylamide monomer	FDM, Inkjet	Robotics		[18]
Alginate	Material extrusion, Vat polymerization, Cell printing	Biomedical (Tissue engineering, Organ-on-a-chip applications)	R&D	[16] [25]
Aluminium alloys	Powder bed fusion, Binder jetting, Sheet lamination, Directed energy deposition, LBM	Mechanical structures, Mechanical structures, heat exchangers	Commercial	[35] [13]
Bio-glass	Selective Laser Sintering/ Melting	Biomedical (dental application, orthopedic implants)	Commercial	[19] [37]
Biopolymer (PLA, PCL, PLLA)	Electrohydrodynamic (EHD) printing	Biomedical (tissue engineering)	R&D	[14] [16]
Carbon black	Material extrusion	Conductor, Sensor	Commercial	[30] [16]
Carbon filled	Semi-Crystalline, Powder bed fusion		Commercial	[13]
Calcium phosphate	3D printing	Biomedical (bone, dental application)	Commercial	[13] [15]
Cement	Powder bed fusion, Binder jetting, Material extrusion	Construction	Commercial	[39]
Chocolate	Semi-Crystalline, Material extrusion		Commercial	[13] [22]
Co–Cr alloys	Powder bed fusion, Binder jetting, Directed energy deposition	Biomedical (surgical instrument)	Commercial	[32] [37]

Copolymers	FDM, MJM, DLP, Inkjet, SLA	Biomedical (Tissue engineering)	R&D	[18] [36]
Decellularized extra cellular matrix – dECM	Material extrusion, Vat polymerization, Cell printing	Biomedical (Tissue engineering, Organ-on-a-chip applications)	R&D	[16] [33]
Epoxies	Thermoset, Vat polymerization, Material jetting		Commercial	[13]
Gallium	Material extrusion	Conductor, Electronics	Commercial	[16] [23]
Glass filled	Semi-Crystalline, Powder bed fusion		Commercial	[13] [37]
Glucose	FDM, Inkjet	Robotics	commercial	[18]
Gold	Powder bed fusion	Jewellery	Commercial	[38] [44]
Hydroxyapatite		Biomedical (dental application, implant coating material)	Commercial	[34] [37]
Indium	Material extrusion	Conductor, Electronics	Commercial	[16] [23]
Lithium	Material extrusion	Microbatteries, Biomedical	Commercial	[16] [17]
Metal filled	Semi-Crystalline, Powder bed fusion		Commercial	[13] [28]
Methacrylate gelatin (GelMa)	Material extrusion, Vat polymerization, Cell printing	Biomedical (Tissue engineering, Organ-on-a-chip applications)	R&D	[16] [26]
Nanoclay	FDM, Inkjet	Robotics		[16] [20]
Neat	Semi-Crystalline, Powder bed fusion		Commercial	[13] [31]
NFC	FDM, Inkjet	Robotics	Commercial	[16] [18]
Nickel alloys	Powder bed fusion, Binder jetting, Directed energy deposition		Commercial	[21] [39]
NiTi	SLA	Biomedical (catheters, stents), Aerospace, Defense	Commercial	[18] [38]
Paper	Sheet lamination		Commercial	[28] [37]
PC/ABS Blend	Amorphous, Material extrusion		Commercial	[13] [28] [37]
Piezoelectric	FDM, MJM, DLP, Inkjet	Automotive, Biomedical, Robotics, Actuators, Sensors, Touch screen	Commercial	[18] [43]
PLA	FDM, MJM, DLP, Inkjet	Biomedical (Tissue engineering, Organs replacement), Robotics, Textile, Electronics	Commercial	[18] [37] [42]
Polyetherimide (PEI)	Amorphous, Material extrusion		Commercial	[13]
Polyetheretherkeytone (PEEK)	Semi-Crystalline, Material extrusion, Powder bed fusion	Biomedical (dental application, knee joint bearing surface, hip joint bearing surface, soft issues, articular cartilage)	Commercial	[13] [37]
Polycarbonate	Amorphous, Material extrusion, FDM, SLS		Commercial	[28] [37]
Polyamide	Semi-Crystalline, Powder bed fusion, FDM (FFF), SLS		Commercial	[27] [40]

Polymer bound	Amorphous, Semi-Crystalline, Material extrusion	Automotive, Aerospace, Biomedical	Commercial	[13]
Polypropylene	Semi-Crystalline, Powder bed fusion		Commercial	[18] [29]
Polystyrene	Amorphous, Powder bed fusion		Commercial	[13] [40]
Polyester (“Flex”)	Powder bed fusion		Commercial	[13]
Sand	Powder bed fusion, Binder jetting, Material extrusion		Commercial	[18]
Stainless steel	Powder bed fusion, Binder jetting, Sheet lamination, Directed energy deposition	Biomedical (surgical tools, dental application, knee joint, hip joint)	Commercial	[18]
Silver	Powder bed fusion	Jewellery	Commercial	[44] [24]
Thermoplastic polyurethane	Material extrusion, Powder bed fusion, FDM, Material jetting, Binder jetting, Sheet lamination, Vat polymerization, Powder bed fusion,		Commercial	[13] [40]
Ti and Ti alloys	Powder bed fusion, Binder jetting, Sheet lamination, Directed energy deposition, LBM	Biomedical (bone fixation, artificial valve, stent, dental application, knee joint, hip joint, spinal implant)	Commercial	[27]
Tool steel	Powder bed fusion, Binder jetting, Directed energy deposition	Tooling	Commercial	[13]
Viscoelastic ink	FDM, Inkjet	Robotics	Commercial	[18]
Zinc-silver	Material extrusion	Microbatteries	Commercial	[16]
Zirconia	Laser Engineered Net Shaping (LENS)	Biomedical (dental application, porous implants)		[37]

The relationship between the materials, the AM process and the sector of application is a key aspect to take into consideration for the establishment of the European AM skills strategy.

For the foresight on skills gaps and anticipation (WP2), during and after SAM project, the emerging of new materials to be applied in AM and/or new applications of the existing materials should be explored on a consistent basis in order update or develop new learning pathways for the skills development of AM Professionals.

Knowledge about materials, and in particular in regards to materials application based on specific sector requirements, will be a key aspect in terms of causes of skills gaps to be addressed in the development of SAM methodology for design and review of professional profiles and skills (WP3).

5.3. Process/Manufacturing

ISO / ASTM52900 – 15 “Additive manufacturing – General principles – Terminology” standard defines the seven additive manufacturing process categories: binder jetting (BJT), directed energy deposition (DED), material extrusion (MEX), material jetting (MJT), powder bed fusion (PBF), sheet lamination (SHL) and vat photopolymerization (VPP). All existing AM technologies are classified into these seven categories irrespectively of the material, layer wise deposition system and part consolidation technology. For the different processes’ categories, a summary of the AM Commercial techniques and their manufacturers is shown in table 3.

Table 3 - Commercial AM techniques and their manufacturers (extracted from [45[i]])

Process Category 1: Binder jetting (BJT)

Process	Feedstock	Manufacturer	References
Binder Jetting *Joined with bonding agent*	Metal	Digital Metal, 3DEO, hp, General Electric, Desktop Metal, ExOne	[45]
Binder Jetting *Joined with bonding agent*	Gypsum, Sand	3DSystems, voxeljet	[46]
Phenol-Direct-Binding (PDB)	Ceramics	voxeljet	[47]
ColorJet Printing/ZPrinting	Ceramics	3DSystems	[47]
3DP Binder Jetting	Ceramics	ExOne	[47]
CerPrint	Ceramics	WZR	[47]
Bound Metal Deposition	metal powder held together by wax and polymer binder	Desktop Metal	[48]

Process Category 2: Direct energy deposition (DED)

Process	Feedstock	Manufacturer	References
Laser Engineering Net Shape (LENS) *Fused with laser*	Metal	OPTOMEC	[45] [46]
Electron Beam Additive Manufacturing (EBAM) *Fused with electron beam*	Metal	SCIAKY Inc	[46]
Laser Metal Depositon (LMD)	Metal	Trumpf, DMG Mori	
Wire Feed Laser/Electron Beam Energy Deposition	Metal wire	РОСЭЛ, ADDITEC, Chervona Hvilya, AML3D, WAYLAND ADDITIVE etc.	[45]
Wire Arc/Plasma Arc Energy Deposition	Metal wire	e.g. NORSK TITANIUM, ИААМ, SBI, Mazak	[45]
Laser metal deposition	Metal	BEAM (France)	[45]

Process Category 3: Material extrusion (MEX)

Process	Feedstock	Manufacturer	References
Fused Deposition Modeling (FDM)	Plastic	Stratays, Ultimaker, MakerBot, zortrax, PRUSA Research, printrbot, UP-3D, CandyFab, Fab@Home, Solidscape, Polyflex	[45] [46]
Fused Deposition Modeling (FDM)	Composite	Markforged	[46]

Metal Pellet Fused Deposition Modeling	Metal Pellets	AIM3D, pollen	[45]
Liquid Deposition Modeling (LDM)	Ceramics	WASP	[45]
Fused Feedstock Depositioning (FFD)	Ceramics	3D-Figo	[45]
3D Bioplotter	Ceramics	EnvisionTec	[47]

Process Category 4: Material jetting (MJT)

Process	Feedstock	Manufacturer	References
Material Jetting (MJ) *Cured with UV light*	Plastic	Stratasys, 3DSYSTEMS	[46]
NanoParticle Jetting (NPJ) *Cured with heat*	Metal	XJET, Nanogrande	[46] [45]
NanoParticle Jetting (NJP)	Ceramics	XJET	[47]
Drow on Demand (DOD)	Wax	SOLIDSCAPE	[46]
Liquid Metal Printing	Metal Wire	Xerox	[45]
Micro Dispensing	Ceramics	nScrypt	[47]

Process Category 5: Powder bed fusion (PBF)

Process	Feedstock	Manufacturer	References
Selective laser melting (SLM), Directed metal laser sintering (DMLS) Laser Metal Fusion *Fused with laser*	Metal	MICROFABRICA, DMG Mori (former REALIZER), SLM Solutions, Wuhan Binhu Mechanical & Electrical Co., Ltd., Insstek eos, 3DSystems, SLM, CONCEPTLASER, Additive Industries, Trumpf	[45] [46] [49]
Selective laser sintering (SLS), selective heat sintering *Fused with laser*	Metal	3DSYSTEMS, Farsoon Technologies, Blueprinter (Denmark), eos, MC Machinary Systems, Wuhan Binhu Mechanical & Electrical Co., Ltd., headmade materials	[45] [46]
Electron beam melting (EBM) *Fused with electron beam*	Metal	Arcam AB	[45] [46]
Selective Laser Sintering *Fused with laser*	Plastic	eos, 3DSystems, SINTERIT, Sintratec	[45] [46]
Multi Jet Fusion (MJF) *Fused with agent and energy*	Plastic	hp	[45] [46]
Metal powder bed fusion	Metal	RENISHAW	[45]

Laser Beam Powder Bed Fusion (LB-PBF)	Metal	e.g. OPENADDITIVE, Laser Melting Innovations, adira, 3D-Mectronic, AmPro Innovations	[45]
Electro Beam Powder Bed Fusion	Metal	Wipro 3D, Wayland Additive, Arcam EBM, freemelt, Mitsubishi Electric etc.	[45]
Powder Feed Laser Energy	Metal	e.g. Prisma Additive, IBAMRMIA, DM3D, OPTOMEC	[45]
Coldspray	Metal	TITOMIC, 3D-Hybrid-Solutions Inc, Hermle AG, IMPACT. SPEE3D, Plasma	[45]
Mold Slurry Deposition	Metal	Tritone	[45]
Powder Metallurgy Jetting	Metal	Stratasys	[45]
Metal Lithography	Metal	ADMATEC, incus	[45]
Multi Jet Fusion (MJF)	Ceramics	hp	[47]
Direct Laser Microfusion (DLM)	Ceramics	OsseoMatrix	[47]

Process Category 6: Sheet lamination (SHL)

Process	Feedstock	Manufacturer	References
Laminated Object Manufacturing (LOM)	Paper/Composite	Cubic Technologies, Mcor, envisiontec, IMPOSSIBLE OBJECTS	[45] [46]
Ultrasonic Welding	Metal sheets	Fabrisonic	[45]

Process Category 7: Vat photopolymerization (VPP)

Process	Feedstock	Manufacturer	References
Stereolithography (SLA), lithography-based Ceramic manufacturing *Cured with laser*	Plastic	3DSYSTEMS, CMET Inc., Somos, Lithoz, Prodways, Wuhan Binhu Mechanical & Electrical Co., Ltd., Formlabs, DWS	[45] [46]
Digital Light Processing (DLP) *Cured with projector*	Plastic	B9Creations, envisiontec	[46]
Continuous Digital Light Processing (CDLP) *Cured with LED & oxygen*	Plastic	Carbon, envisiontec	[46]
Fast Ceramics Production (FCP)	Ceramics	3DCeram	[47]
ADMAFLEX	Ceramics	ADMAPRINT	[47]
Lithography-based Ceramics Manufacturing (LCM)	Ceramics	LITHOZ	[47]
MOVINGLight	Ceramics	PRODWAYS	[47]
Large Area Maskless Photopolymerization (LAMP)	Ceramics	DDM Systems	[47]

Innovative AM concepts, variants, machines and systems are currently constantly released to the market. Coherent with this development are technological breakthroughs and innovations. However,

up until now, all of the new processes have been catalogued into one of the worldwide accepted categories. Since the underpinning principles of each category are distinctive and well-known, the understanding of possibilities and new developments is easy to be understood.
As stated above, this segment is not only limited to the main process related trends, but also main tendencies in terms of design and simulation software, ICT and equipment are included.

5.3.1. Design and manufacturing software

For the last three to five years, an enormous progress of AM within the field of digitalization has been seen. Yet, there are still important obstacles to be overcome in order to produce products in a fully automated way. Hence, many critical decisions and operations have to be made or carried out by humans. Conceiving a product for AM, starting from conceptual design to the final part validation is a multi-step process in which a wide variety of commercial software has to be employed. The underlying challenge here is the issue of **software interoperability and the challenge of moving the design into all-in-one file format (#PR1)**. Hence, software interoperability is a major aspect in the AM process chain and has therefore been classified as a short-term technological trend that will be approached within the next two years.

A typical workflow in design for AM (DfAM) begins with a conceptual design in CAD software and going from conceptual to detailed design could involve topology optimization as well as integrated simulation tools able to predict part integrity and performance, considering stress, thermal, fatigue, vibration, and other multi-physics performance parameters.
When it comes of topology optimization, it´s role is to identify an optimal shape, based on boundary conditions and constraints with the goal of maximizing the performance of the system. The first result from the software is a mere representation, not a definitive geometry ready for manufacturing, which means that an engineer take part to manually reconstruct the geometric shape with several iterations and cost due works, becoming a potential bottleneck in the workflow.
One step forward is the preparation of the final digital geometry into a printable configuration which involves several additional steps. The digital geometry has to be converted to STL, AMF, 3MF, or another mesh file format for build preparation, positioning, scale, and orientation—as well as special structure generation for lattices, foams, and metamaterials. Contour and layers must then be generated to enable the necessary part slicing required by a 3D printer. Process parameters to infill these contours must then be assigned. Additionally, depending on the specific AM machine and material parameters such as beam power, deposition? speeds, hatching distance or other parameters have to be considered because final results can vary.
These complexities are being overcome by **recent software advances that provide a more agile DfAM development framework (#PR2)**, based on a single model of data platform able to replace multiple and fragmented streams of engineering knowledge. This single platform, theoretically, removes barriers and connects design and manufacturing in a way that enables DfAM in an all-in-one solution. 3Dexperience platform from Dassault System is one example, being able to generate a workflow from designing to printing within the platform for Renishaw SLM machines. Other examples are 3DXpert, Siemens NX, Link3D or MSC Apex Generative Design software.

5.3.2. AM modelling

Another important step for successful development of AM parts is modelling and simulation. This is usually required to enhance the performance of high added value applications and to achieve the highest benefits from AM. Simulation entails the **development of multiscale and multiphysics models (#PR3)** for simulating heat transfer, stress, distortion, interaction between feed stock and heat and also predicting the microstructure and mechanical properties of AM parts. These are relevant issues especially in metal AM processes (PBF, DED). For these technologies, many software developers are currently working in improved simulation tools with the aim of enabling:

- **Powder scale models** to simulate how gas is entrapped on the melt pool and to quantify the **porosity and the roughness** (see Figure 10)

- **Part-scale models to predict distortions** during manufacturing and after releasing the part from the plate using FE methods
- **Simulate microstructure** using kinetic Monte Carlo (see Figure 11)
- Simulate 3D multi-layer grain microstructure
- Prediction of phase transformation using phase fractions, cooling rates, temperatures and kinetics
- Prediction of **mechanical properties** by Gaussian methods metamodels

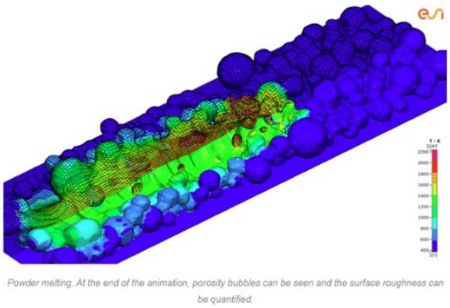


Figure 10. ESI Group´s example of powder scale model

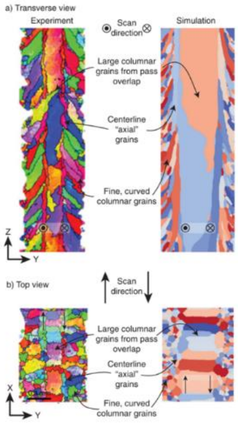


Figure 11. Comparison between experimental EBSD (left) and (right) simulated images.

5.3.3. More compact, modular and cheaper plastic AM machines

The three most common plastic AM printing technologies are material extrusion (MEX) or fused deposition modelling (FEM), stereolithography (SLA) and selective laser sintering (SLS). Until 2010 the access to these technologies was limited to large enterprises due to the high machine cost, complexity and patent royalties. However, in the last years these technologies have become widely available to due to the development of more capable, compact and affordable system**,** the expiration of original patents and the development of new specialized AM machine suppliers. This has led to development of **new kind of desktop and benchtop AM machines (#PR4)** and to the expansion of these technologies for professional engineering, prototyping and production applications. It is estimated that by 2017 more than 1 million desktop 3D printers had been sold worldwide[50].

5.3.4. Metal AM machine innovation trends

Metal 3D printing machines have been evolved from simple machines since 1980s to really complex and industrial equipment today when digitalization is the protagonist but cannot be ignore other aspects as productivity, repeatability, traceability, etc. That is, many AM machine manufacturers are working in **faster hardware (#PR5), new process automation concepts (#PR6), hybrid machines (#PR7)**, **advanced monitoring solutions (#PR10)** or **simplification of material handling and recycling** as well as integration with subsequent post processing steps.

A big push for higher overall speed, better surface finish, traceability and quality assessment is on development a best of breed metal AM machines are already incorporating these solutions. To meet these demands, manufacturers are building machines with **multiple lasers (#PR5)** and properly layer height to shorten build time and help bring overall cost down for the AM part. Moreover, they are integrating **advanced monitoring and data acquisition system (#PR10)** to ensure part traceability and quality.

Several PBF machine manufacturers (Renishaw, SLM Solutions, Trumpf) include up to 4 static lasers to improve processing speed. On the other hand, Fraunhofer ILT has recently developed 5 spot laser array in a single head, which increases the scalability by enhancing the speed. In addition, the chamber size is not limited by the optical system (see Figure 12). Aurora Labs, Multi-layer Concurrent Printing (MCP™) technology, for example, increase productivity by melting multiple powder layers simultaneously with multilaser powder bed machine instead of printing layer by layer

PBF machine manufacturers are leading also improvements in the following lines in terms of **capacity, accuracy, productivity (speed) and ergonomics** such as:

- Larger build area
- **Printing different materials (#PR8)**
- Supersize machine dimensions to include productivity-enhancing modular set up (removable build chamber with offline setup, powder preparation facility, post-print booth) and get new parts printing in the machine without any delay.
- Automatic recirculating powder handling.
- Self-cleaning filter units.
- Improved Control System & Software.
- Recycling external system.
- Automated loading system.

Finally, for powder bed, new machine designs are also looking for better safety conditions for workers, separating the operator from physical interactions with the metal powder feedstock.

Figure 12. Comparison between conventional laser on SLM and multispot concept [50]

5.3.5. Automation of the manufacturing process

Despite being a fully digital process, currently labour costs significantly contribute to the overall AM manufacturing costs. Technicians must load raw materials, set-up AM machines, remove parts from printers and perform special post-processing tasks. These include brushing, solvent-washing, heat treatment, support removal, polishing or coating processes (see section 3.4). **Workflow automation and technology improvements (#PR6)** will bring important savings of labour costs. These improvements will be achieved both at machine level (soluble supports, integrated cleaning and post-curing stations, automated powder recycling…) and at distributed manufacturing cell level. Manufacturing cells will be composed by **connected modular printers operated by robots (#PR12)** hat will reduce and substitute many current operator tasks.

- **Powder transport systems for PBF**

Similar to other conventional manufacturing processes, powder based additive manufacturing need to become a fully industrial process, **minimizing the manual operations (#PR6)**. In this sense, PBF machine manufacturers are developing innovative powdered feeding system, able to control powder storage of every machine and for the whole system, recirculate the powder leftovers and recover remnant powder from building chamber after parts manufacturing (see Figure 13).
These solutions are rapidly becoming market available not also from machine manufacturers but also from new independent companies able to make their systems compatible with several brands.

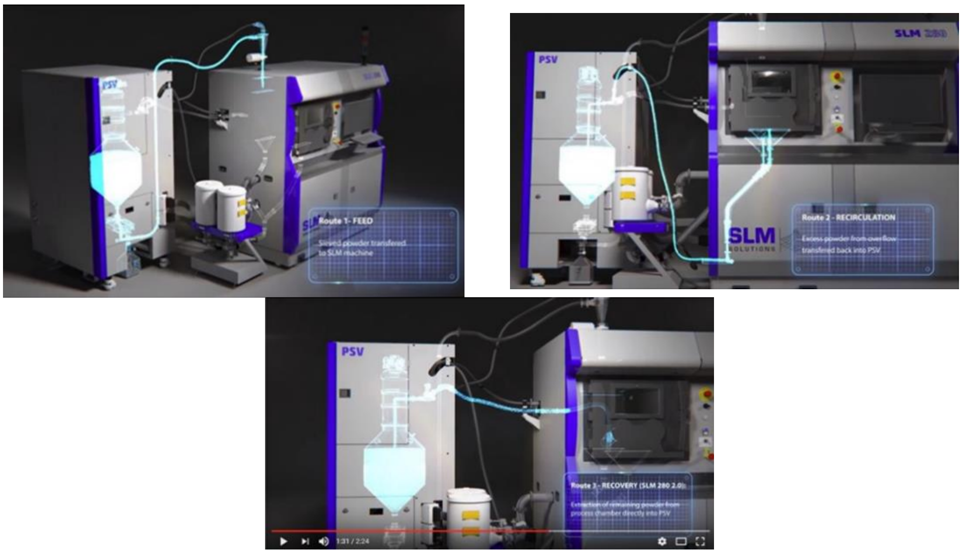


Figure 13. Powder circulation through SLM machine system: (1) feed with virgin powder, (2) recirculate excess powder from overflow after manufacturing and (3) recover remnant powder from build chamber [51]

- **Line factories**

Bringing additive and subtractive manufacturing into the similar production workflow is becoming a technological trend in metal AM. Different companies and machine manufacturers are thinking on future Additive Manufacturing factory concepts which are based on **fully automated, connected and integrated systems (#PR6).** That is the case of MetalFAb1 (Additive Industries) solution´s which includes modules for manufacturing, heat treatment, cutting parts from plate, machining and levelling support plates and a storage module, being all process automated (see Figures 14 to 16).
On the other hand, line factories with all machines connected with a common pipe for powder transportation, exchanging building chambers and **self-guided mobbing industrial robots (#PR13)** to transport parts and powder from one module to another (e.g. from building module for heat treatment) (see Figure 11) have been conceived and will be introduced within the next years for large series production.

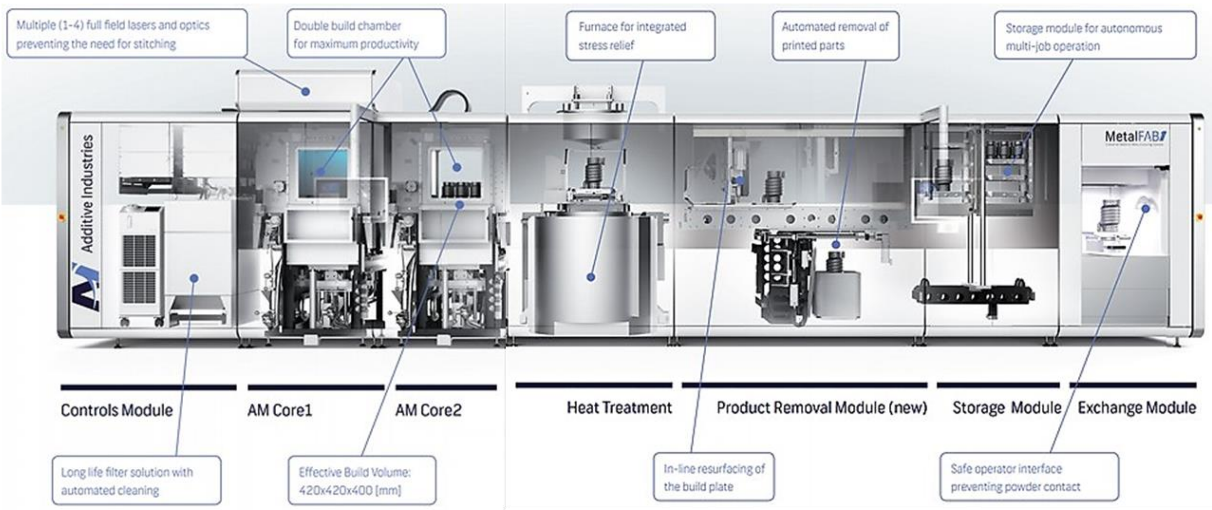


Figure 14. MetalFab1 system (Additive Industries) [52]

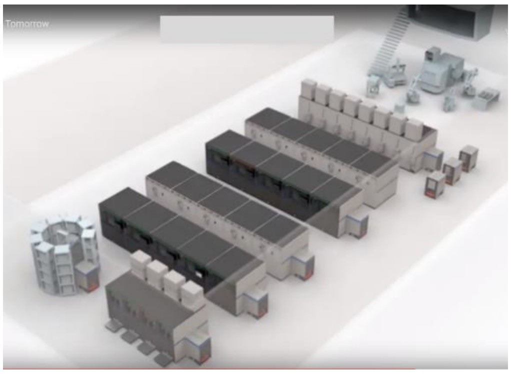


Figure 15. M Line factory with all machined connected an areas for post-processing (GE Additive) [53]

Figure 16. Automated powder transport (feed, extraction and recycling) from SLM Solutions

5.3.6. Process control, quality control and monitoring

AM part quality is highly dependent on the machine performance, material batch, process parameters, etc. Currently, there is a lack of adequate AM control and monitoring methods and standards. Furthermore, there is no uniform way of implementing scanning strategies among different AM machine suppliers. Therefore, the selection of scanning strategy is not always possible and the resulting microstructures, distortion, external quality can be different in different machines. Thus, machine manufacturers and software developers are working on:

- Implementation of **advanced sensors and data acquisition** system to monitor process **(#PR10)**
- Development of **advanced data analysis solutions to predict part quality** and detect defects on-line based on **Artificial Intelligence (#PR11)**
- Development of advanced **close-loop controls (#PR12)** to automatically adapt process parameters.

5.3.7. Hybrid process to high-volume production by integration with conventional manufacturing

Hybrid additive manufacturing (hybrid-AM) joins different additive and subtractive processes and enables **multilateral (#PR8)** and **multifunctional AM parts (#PR9)** (Figure 17).
This brings AM paradigm into a new dimension. New capabilities are afforded by hybrid-AM creating **new design rules for materials and new machine concepts**. Hybrid-AM processes are defined as the inclusion of AM within the framework of one or more secondary processes.
Nowadays, for example, LUMEX Avance-60 machine (Matsuura) combines laser sintering and CNC milling and LASERTEC 4300 3D hybrid (DMG MORI) combines DED and turning/milling (Figure 18).
Main goal of hybrid-AM processes is to improve part quality and part performance rather than improve processing. Hybrid-AM processes are part of a cyclic process chain which includes both

additive manufacturing and conventional manufacturing processes (turning, milling, peening, metrology,…)- The interest in hybrid-AM will increase considerably within the next years and will be accompanied by machine capabilities improvements.

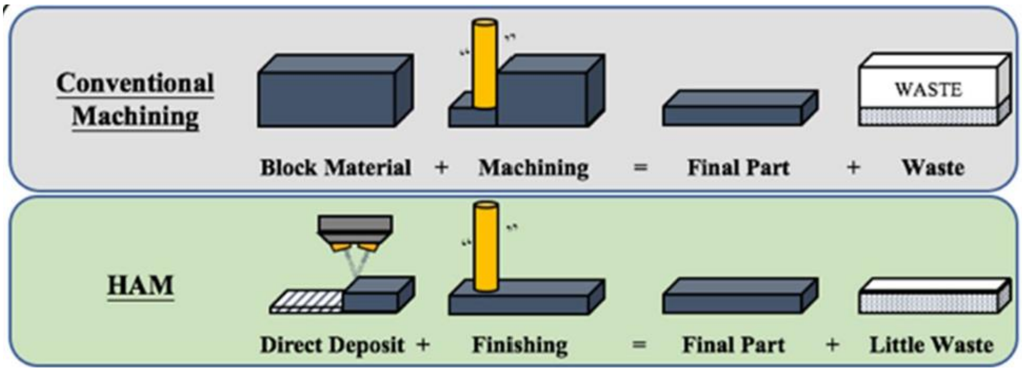


Figure 17. Comparison between conventional machining and hybrid process

Figure 18. DMG MORI´s hybrid process images

5.3.8. 4D-printing

Time is the variable which makes the difference between 4D and 3D printing, the big breakthrough about 4D Printing over 3D Printing technology is its ability to change shape over time.
4D Printing technology uses advanced materials that behave in a different way after adding water, light or heat making a 3D printed object to come "alive" changing its shape and behaviour over time. The base of the technology is a **"smart material"**, that can be either a hydrogel or a shape memory polymer. Thanks to their thermomechanical properties and other inherent properties, smart materials are given the attributes of shape changing making the difference from the common 3D printing materials.
This technology opens a new window of opportunities with applications as:

- Self-repair systems for different sectors
- Self-assembly furniture
- Medical industry
- Aerospace labs
- Reshaping transports in case of an accident
- Reducing environmental impact through diminishing volume of packaging

Though full of promise, this technology still has questions to solve such as the behaviour of these materials over time. 4D printing applications will be developed in the coming years but it is not fully clear if the impact will be relevant before 2030 year.

5.3.9. Market update of new technologies

Finally, it must be highlighted that current **balance between AM technologies will surely change** in the following years and this will lead to **market uptake of new AM technologies and downfall of**

existing ones (#PR14). An example is the additive manufacturing of small size metal parts. Being this application segment currently mastered by PBF technologies, it is very likely that other technologies which are currently in a lower technology readiness level (TRL) like BJT, MEX or MTJ, will get more mature and grow taking part of the current market of PFB technology, especially in applications with lowest mechanical performance requirements. Figure 19 shows a comparison of the characteristics of the main metal AM technologies.

Figure 19. Comparison of main metal AM technologies [54]

5.4. Post-processing

Post-processing has a considerable cost effect over the cost-per-part in AM manufacturing, it could represent up to 60% of the total cost depending on the AM manufacturing process. Supports removal and other **post-processing treatments are cost and time-consuming** and the necessity for post-processing to improve functionality or aesthetics is something demanded by the majority of parts in order to fulfil the dimensional and mechanical requirements.

Thus, when it comes to checking the viability of AM for serial production, this is a main task to take into account.

The post-processing puzzle needs to be faced up with as an ecosystem approach, joining the path from product conception through to final product. The problem is that for an industry that is called as disruptive, manufacturers are still post-processing parts the same way they did 100 years ago and it is this that is slowing the whole process chain down for production applications of AM.

On the other hand, challenges with post-processing are also applicable to small companies with potentially fewer resources. The data shows that the percentage of participants experiencing two or more different kinds of challenges is equal regardless of company size. As a matter of fact, 70% of companies in the categories of 25 employees or less and 500 employees or more have two or more post-processing related challenges. The primary difficulties experienced include issues of throughput, high quality parts, scrap rates, and use of human resources.

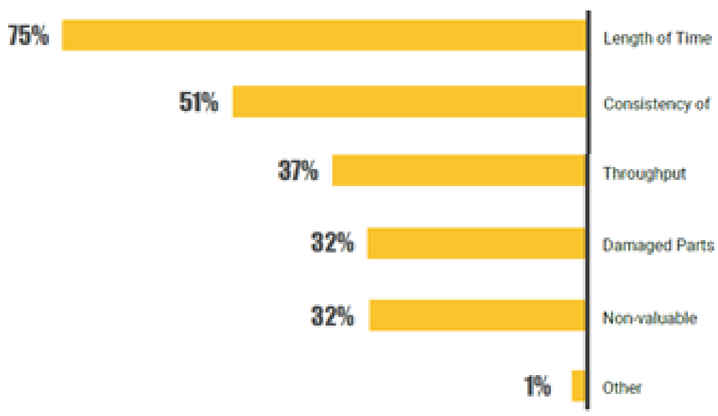


Figure 20. What are your current Post Processing challenges?. Source: Annual Additive Post-Printing Survey: Trends Report 2019. Post-Process

Over 80% of respondents are using two or more different AM technologies in their businesses. When a greater number of print technologies are employed, an increased occurrence of different post-processing challenges is observed.

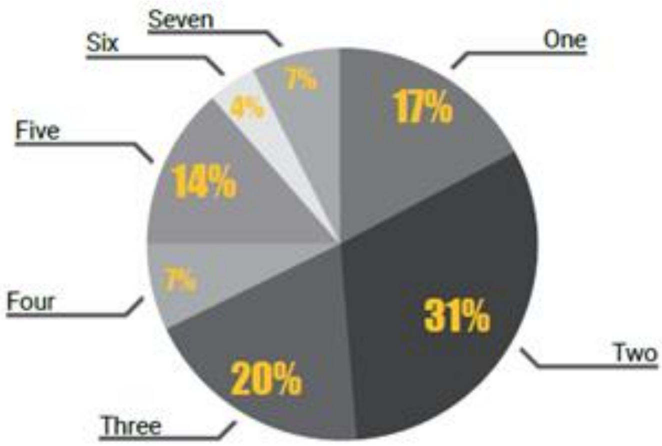


Figure 21. How many print technologies are you using?. Source: Annual Additive Post-Printing Survey: Trends Report 2019. Post-Process

Additionally, with different technologies and materials with different post-print process requirements, users can expect this complexity to grow further as new types of print options are launched to the market regularly.

The two most often employed AM post-processes (Figure 22), **support removal and surface finishing**, are performed by over 50% (3 or more challenges using one technology 38%; using multiple print technologies 51%).

For those who are performing a support removal step, the majority are spending more than half of their time just on that one operation. Additionally, 75% of those performing support removal are then also undertaking a surface finishing step.

The third most popular post-processing operation, **resin removal** commonly used for Vat Photopolymerization print technologies, also requires a surface finish step 80% of the time.

Figure 22. Top Post-processing. Source: Annual Additive Post-Printing Survey: Trends Report 2019. Post-Process

Currently, most AM processes require post-processing after part building to prepare the part for its intended form, fit and/or function. Depending upon the AM technique, the reason for post-processing varies. These include:

- **Support material removal (#PP1)**
- **Surface texture improvements (#PP5)**
- Dimensional accuracy improvements
- Aesthetic improvements
- Preparation for use as a pattern
- Property enhancements using non-thermal techniques
- Property enhancements using thermal techniques

The skill with which various AM practitioners perform post-processing is one of the most distinguishing characteristics between competing service providers and manufacturing companies. Companies which can efficiently and accurately post-process parts to a customer's expectations can often charge a premium for their services; whereas, companies which compete primarily on price may sacrifice post-processing quality in order to reduce costs.

Really the main trend in post-processing is not specifically in this process, but in **design**, try to **minimize from the beginning the needs of this post treatment (#PP9)**. Moreover, the demand is for fully **automated, safe, sustainable, and digitally connected** post-processing solutions.

Three solutions within the post-processing segment offer systems that promise to automate the post-processing stage. Additive Manufacturing Technologies' PostPro3D offers 'automated surface finishing technology' said to rival injection moulding finishing. Similarly, **Post-process Technologies** offers automated surface finishing and support removal solutions, while DyeManison provides high-volume finishing systems.

Some innovative solution in the post-processing area of AM parts are:

5.4.1. FDM. Support Removal with Volumetric Velocity Dispersion

The recommended process involves mixing a caustic chemical solution and finding a conventional circulation or ultrasonic tank to pair it with. Basic submersion, relying heavily on a chemical rate of removal (cRoR) is one method to tackle the soluble support removal problem. A conventional tank may work for blocks and basic geometries, but for complex designs and features it is clear that there is an opportunity to improve upon its shortcomings. Post-process Technologies (PPT) has developed an alternative technology for soluble support removal: Volumetric Velocity Dispersion (VVD). This software-driven technology uses a series of high volume and flow jet streams spraying bidirectionally, coupled with perpendicular linear motion for mechanically assisted support removal. The Volumetric Velocity Dispersion technology surpasses a conventional tank by deploying a different form of mechanical energy that has shown to speed up FDM support removal cycle times up to 70% or greater. This is accomplished while reducing risk of warpage and cracking and speeding up dry times.

5.4.2. PolyJet. SVC and chemical solutions

The most common PolyJet support materials are SUP705 and SUP706, often referenced as '705' and '706', respectively. Either type can be used in combination with the majority of print material offerings. 705 is not considered soluble. Common industry practice is water-blasting. This consists of a cabinet with a viewing window where a hose producing a high-pressure jet stream is accessed via arm ports, designed for an individual to 'blast off' the support material one part at a time. Additional hand tools akin to dental picks and bristle brushes are often found not too far from the water-blasting system. To improve upon this process, 706 was developed as a softer, **water-soluble material** that can be **soaked for easier removal (#PP1).** This made it better suited for delicate designs and created the potential for batch processing.

Post-Process' Submersed Vortex Cavitation (SVC DEMI) technology combines these three core elements of a comprehensive solution - software, hardware, and chemistry. The native software platform, AUTOMAT3D, manages the chemical and mechanical en-ergy within the system to minimize operator attendance time. This is done through real-time sensor data that tracks key process parameters such as temperature, tank level, system pressure, ultrasonics output, and pump flow.

Hardware considerations including advanced filtration and a vortex pumping scheme help extend detergent life and support cycle time efficiency and consistency.
The test proves that using the DEMI solution:

- The operator time would be reduced by 86%.
- The total throughput would be increased by 30%

5.4.3. SLS/MJF

Powder bed technology eliminates the need for support structure design and removal. However, it is not without its post-print challenges. After brushing away the initial bulk powder (see Figure 23), a thin layer remains adhered, leaving the part caked with unusable powder.

Figure 23: Example of an SLS part after the majority of bulk powder is removed

This creates a new problem where basic submersible support removal systems, re-lying heavily on chemical reactions or ultrasonic, are rendered useless. The powder removal aspect of post-processing powder parts typically involves a high pressure and flow system combined with an abrasive component. There are some clear drawbacks to this approach. The first limitation of bead blasting is simply being labour intensive. This process requires someone to stick their hands through clunky rubber gloves and peer through a limited window while they try to 'hose off' the part with high-pressure grit. As part geometries become more complex, and potentially more fragile, handling and blasting parts this way can lead to wide inconsistencies or even breakage. Beyond being labour intensive, the dry nature of bead blasting struggles to fully remove powder from fine cavities. This is quite the roadblock for many users wishing to print functional assemblies.
Another approach considered to address the removal of this pesky layer of powder is a vibratory system. The idea here is to aggressively shake and scrape off this final powder layer. However, this process runs into the same issues as bead blasting; you will not be able to remove the powder from smaller crevices. This uncontrolled ap-proach, especially when using traditional vibratory equipment, also runs a high risk of damaging parts, or at minimum wearing down fine features before the powder layer is fully removed. This approach is also limited when trying to remove the partially sin-tered hybrid layer because it cannot reach small crevices for a uniform surface finish.
The bottom line is that these approaches are not practical if you want to fully leverage the powder bed printer capabilities.
An ideal solution would free up operator time and provide repeatable results on multiple parts simultaneously, without damaging them. To tackle those needs, Post-process Technologies developed the Hybrid DECI Duo. Powered by Post-process' AUTOMAT3D™ software, this intelligent, patent-pending system leverages Thermal Atomized Fusillade (TAF) technology. Two perpendicular, single-axis jet streams comprised of compressed air, proprietary detergent, and suspended solids provide targeted blast sequences while utilizing 360° part rotation for maximum surface exposure.

5.4.4. SLA

Materials used in SLA are photosensitive thermoset polymers that start in a liquid form. The top surface of the vat is where a part is solidified by selectively curing the resin layer-by-layer using an ultraviolet (UV) laser beam. It is worth noting that SLA shares many characteristics with Digital Light Processing (DLP) and Continuous Liquid Interface Produc-tion (CLIP), two additional vat photopolymerization 3D printing technologies. For simplicity, the three technologies can be treated as equals, especially from a post-printing perspective. Being that the SLA process involves only a single material at a time, with the final parts being submerged in a wet resin, there are some additional challenges when it comes to preparing the part for its final application.

The first challenge is the **removal of uncured resin (#PP6).** This is a process that traditionally re-quires the use of repetitive harsh chemical baths. These baths are tedious, hazardous, and can be lengthy and inconsistent. In addition, a part manufactured using SLA technology often requires support structures to be printed to brace certain geometries during printing. Because the material is the same throughout the build, the unwanted support material cannot be iso-lated and removed through the means of chemistry alone. Thus, hand tools such as razor blades and sandpaper are traditionally used to separate the supports from the model and smooth the remnants, or nubs, of the support structures. Up to this point, the industry has adapted a number of chemicals for resin removal and managed their inherent drawbacks. Some of these chemicals include acetone, IPA (iso-propyl alcohol) and TPM (tripropylene glycol methyl ether). Acetone removes resin, can smooth part surfaces, and is very inexpensive. However, acetone has a low resin capaci-ty and is highly flammable. Similarly, IPA removes resin and it is inexpensive, but IPA is dangerous to work with as it is very volatile. Two significant volatility measurements are vapour pressure and flash point. IPA has a high vapour pressure, which is a measure of a liquid's propensity to evaporate, and it has a low flash point, 53.1°F (11.7°C), which is the minimum temperature at which a liquid gives off vapour in sufficient concentration to form an ignitable mixture with air. Conversely, TPM has a higher resin capacity as compared to IPA from a sol-vent performance standpoint, but it is expensive relative to IPA.

In addition, each of the aforementioned chemicals can take approximately 30 minutes to fully remove resin from an SLA build tray. A reduction in processing time can dramatically im-pact a user's throughput capabilities. Finally, each of these options requires disposal of the generated waste. It is expensive to dispose of this waste because the chemicals to be dis-posed of are considered to be hazardous due to their properties combined with the resin removed by the chemicals. In summary, each of these solutions suffers from safety hazards, inefficiencies, longevity issues, and throughput limitations.

Utilizing the Post-Process comprehensive SLA resin removal solution, a combination of a new PG1.2 detergent, and the SVC technology, uncured resin removal can be accomplished in 10 minutes or less for simultaneous trays of SLA printed parts. The new detergent has a much higher resin capacity yielding a longer useful life compared to other chemical methods. With intuitive software controls and process monitoring, the speed and ease of use of the solution results in increased consistency at levels required for production volumes. Finally, the attended operator time is greatly reduced and the new PG1.2 detergent is inherently safer to use.

5.4.5. Surface finishing

Although surface finishing has been around for many decades, the methods have not kept up with the advancements in technology. Manual surface finishing has become a bottleneck for users attempting to fully leverage the flexibility of their 3D print tech-nology. Hand sand blasting is an art and not scalable, and semi-automated manufacturing equipment was never designed with Additive Manufacturing in mind. This results in inconsistent surface finishes, breakage, and an unpredictable workflow.

Surface finishing requires and deserves the same degree of a step-change that ad-ditive brought to traditional manufacturing. In short, it requires a digitized approach. Software and data are required to achieve the intense variability in surface finishing that is the natural companion to the variable geometries and materials native to Additive. Likewise, software and data are critical to aligning the post-printing step with the upstream design and print phases. This is a natural progression toward a digital factory.

The Suspended Rotational Force technology has the intelligence to learn and adapt to a wide range of materials with minimal operator intervention and downtime. Combined with the AUTOMAT3D software, SRF mimics the 'art' of surface finishing in a manner that frees up skilled labour to further scale the operation.

5.4.6. Metal AM post-processing

Considering metal AM, the quality of the final product is defined by five key elements: (1) microstructure, (2) surface roughness, (3) residual stresses, (4) porosity and (5) dimensional tolerance. Required post processing steps must be considered while designing the AM manufacturing of a product. Post processing is crucial to control undesired part properties which are the result of the building up during the manufacturing process.

Procedures for post processing can be subdivided in two wide sections. As a first section, **heat treatments (#PP2)**, which comprises heating procedures with the aim of reaching the appropriate microstructures, relieving residual stresses and porosity of the AM product. The second segment is **mechanical post processing**, which pursues for surface properties and dimensional tolerances of the product.

- **Heat treatments**

Stress Relieving

Due to rapid heating and cooling cycles, thermal and residual stresses are formed. These stresses, when not controlled or treated, will cause the component to become distorted from its original shape. In order to remove the stress within a component, a stress relieving cycle is applied. The treatment will not affect the material’s microstructure or hardness.

Annealing Cycles

Alike stress relieving, the annealing cycles are also used to remove the mechanical stresses generated during processing of material. The main difference between them is that the annealing process restores ductility in the material without cracking.

Hot Isostatic Processing (HIP)

Quantity and shape of residual porosity could affect fatigue behaviour of the part. To reduce it and to give it a rounded shape, HIP is applied by using the combination of high temperatures and pressures. This improves the material’s mechanical properties such as ductility, impact strength, fatigue resistance and reliability. However, the part size is a limiting factor due to the HIP chambers available dimensions

- **Mechanical post processing**

Powder Removal

In PBF AM, after the building process and when the temperature conditions are appropriate to extract the part, technicians get out the powder. This can be done manually or introducing the platform into a Powder Recovery System (PRS), for sandblasting the part.

Sand blasting

The purpose is to clean the part and get rid of unfused material from external and accessible internal surfaces.

After the operation, the following aspects have to be controlled:

- Visual control of the final part
- Roughly dimensions control

Remove parts from substrate

Before allowing an AM manufactured part for heat treatment, a decision must be made whether the AM manufactured part will be removed from the substrate before or after heat treatment. It must be taken into account that the substrate can influence the conductivity of the heat treatment within the part, this affects the heating and cooling cycles. An analysis of the specific part will allow to decide whether heat treatment is more useful with, or without the attached substrate.

- Powder removal

Another aspect in post processing is the removal of trapped powder. Previous to manufacturing an exhaustive analysis should be done in order to allow powder to be released and avoid upon heat treatment caking of trapped powder. Caking of trapped powder can impede the powder removal or result in a fusion of the trapped powder cake with the metal product.

- Support removal

Supports can be removed manually after that with the help of hand held tool. When supports are fully solid they can be machined away by wire electro discharge machining (EDM) from the substrate by submerging the part in de-ionised water. Then, a conductive brass wire is fed through continuously in a slot with the power supply which causes electric pulses to create the discharge between component and wire. This discharge melts the material and vaporises it slowly and the part is released form the support.
Chemical removal techniques are now under development in order to remove complex supports.

Mechanical Machining

Depending on the final surface requirements, mechanical machining processes such as milling, turning, grinding may need to be used. During the design phase for AM or build preparation process machine allowance should be provided for any of these machining processes.
Holes or critical tolerance adjustments for the components need to be finished by drilling/machining them to their nominal dimensions. CNC programmed machining centres can be programmed to do all these operations in one go.

Mechanical surface finishing

Abrasive flow machining can be a mechanical way of removing material but without using any cutting tools. Components are placed in an environment of clay like non-corrosive and chemical inactive material loaded with very fine abrasive particles. These fine particles grind away the material off the component's surface.

Non-mechanical machining for surface finish improvement

Electro Polishing is an alternate process for mechanical machining. A voltage is applied and particles of the component surface are removed and attracted towards the cathode through an electrolyte.
As can be seen in the following table, depending on the AM manufacturing process, different treatments and second operations can be applied.

		AM Manufacturing Technique		
		DED	PBF	EBAM
Heat treatments	Heat treatments of the metal AM manufactured product.	X	X	X
	Annealing Cycles	X	X	X
	Stress Relieving	X	X	X
	Hot Isostatic Processing (HIP)	---	X	---
	Powder removal control	---	X	---
Mechanical post processing	Sandblasting	---	X	---
	Remove parts from substrate	X	X	X
	Mechanical Machining	X	X	X
	Mechanical surface finishing	X	X	X
	Non-mechanical machining for Surface finish improvement	---	X	---

To sum up, industrial companies are currently investigating in fully automated, safe, sustainable, and digitally connected post-processing solutions. The research is mainly focused on the following topics:

- **Novel surface treatment/finishing/post-processing techniques (#PP2) and quality standards (#PP10)** for AM materials:
    - New and improved finishing methods for AM components are needed, in order to fulfil functional and aesthetic requirements of plastic and metal AM components. Finishing in this context means for instance:
        - **De-powdering of AM parts (#PP7)**
        - **Surface finishing techniques in order to reduce the surface roughness (#PP5)**
        - Applying coatings

- Research in this area should lead to:
  - **New types of coatings (#PP8) (**e.g. coatings for reduced surface roughness, conductive coatings)
  - **Automation of (existing) finishing techniques (#PP4).**
- Important requirements here are cost-efficiency, throughput and **scalability** of the finishing.
- Preferred AM technologies in this area could be Powder Bed Fusion of plastics or metals, Fused Deposition modelling (Material extrusion) or Stereolithography (VAT Photopolymerisation);
- Application areas could be (but not limited to):
  - Functional parts for high-end industries such as aerospace or medical industry. A specific use case could be: how can coatings or finishing can maintain the basic properties of the material (for instance if the AM material is flame retardant, application of the coating has to maintain these properties)
  - Finishing of large automotive prototypes with SLA, currently time consuming.
  - Wearables, for instance printed footwear, eyewear, underwear; in these application coatings or finishes need to fulfil requirements for contact with human skin (in terms of surface roughness, sweat resistance).
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- Finishing of large automotive prototypes with SLA, currently time consuming.
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5.5. Process and product quality

Additive Manufacturing has slowly evolved from a (rapid) prototyping technique towards mass production of functional parts. The less stringent requirements concerning product quality and process reliability in prototyping still today cause many quality issues in AM. There are several reasons for this:

- AM is mainly cost effective for small series and even unique products. Modern Total Quality Management (TQM) systems focus more on large series and product certification.
- AM is a young technology, so it is a maturity problem.
- AM is evolving fast. New technologies are emerging. It is hard to keep quality standards up-to-date with these technologies.

Some basic numbers illustrate how serious the quality problems are in AM. In standard laser sintering of PA12, the most commonly used in manufacturing applications, 5% to 20% of the builds fail. In standard injection moulding the failure rate is below 0.1%. AM has a bad reputation concerning quality and reliability. It is naive to think that it is possible to improve AM with a factor 100 by just adjusting a few process parameters. That requires something more fundamental.
For quality however, AM has a major advantage over subtractive and forming manufacturing processes: during the process, it is possible to verify each volumetric part of the manufactured part, that is, they are accessible to do so. Simply said: While printing, it is possible to look inside the part. This simple fact (advantage) is only marginally used today as a quality instrument. The state-of-the-art is merely scratching the surface of what is possible with respect to in-process control and related quality systems. The minds in the industry are changing though. Research and development are taking place, currently mainly behind closed doors unfortunately but some initiatives open up the

traditionally closed world and technology of **AM-process control (#Q2)** (e.g. the Materialise Control Platform (MCP) is an open controller for laser-based powder-bed and VAT polymerization systems).

As is clear from the above, the in-process quality data in AM is many times larger than in conventional manufacturing processes and still growing. This requires a new approach towards the practical handling of this quality data. A standard practice in quality management is to store all raw data in order to enable the extraction of useful information afterwards. A small test based on the requirements for a metal built for ESA (high-frequency (10kHz) melt pool monitoring) would give 34 Terabyte of raw quality data. Needless this becomes unmanageable when being upscaled.

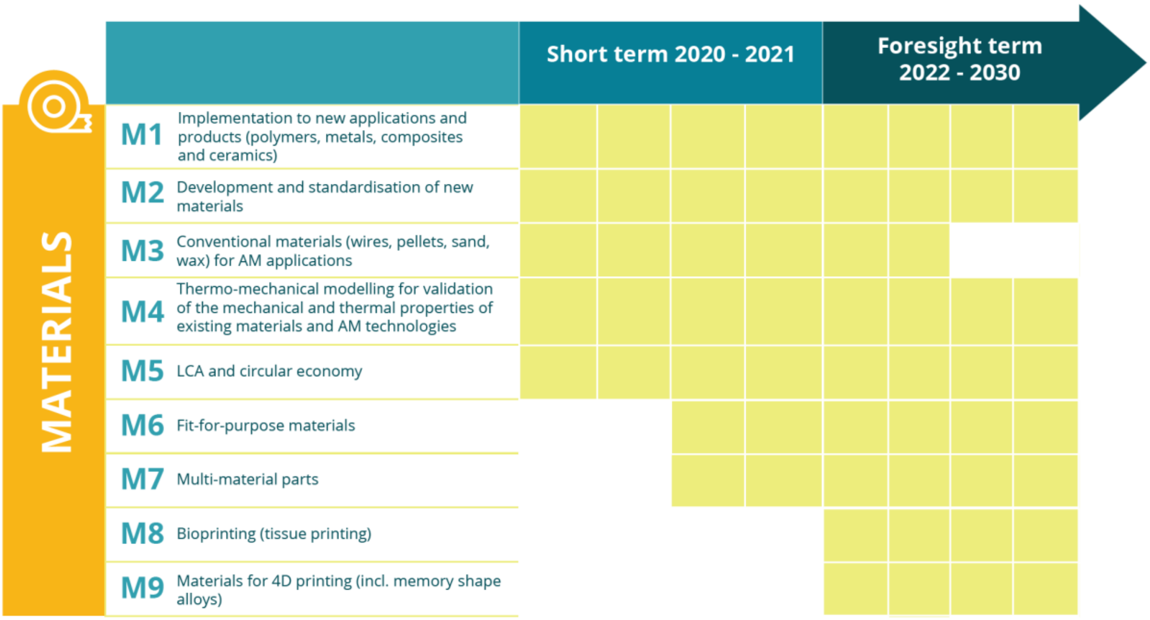
All the above is only related to the quality of the AM process itself. There is almost nothing existing on how this process quality can be integrated in a **Total Quality Management (TQM) system (#Q1)**, which is standard practice in conventional manufacturing. The mere size is typically disproportional. The TQM system tries to capture much more than only the quality of the AM process. It needs to take into account:

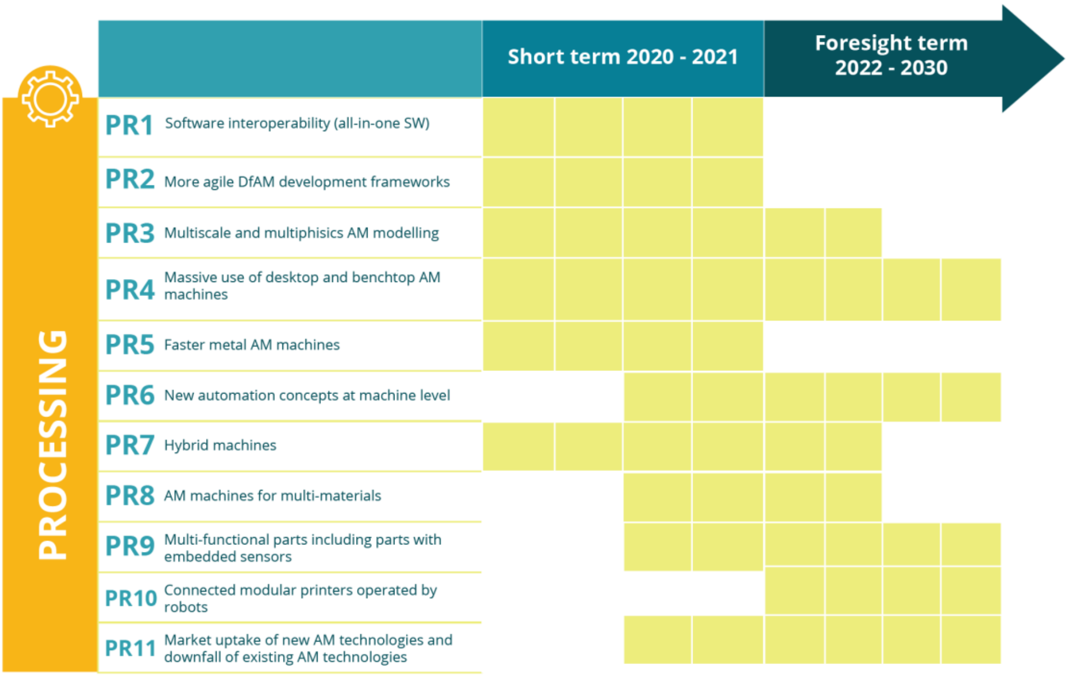
- The quality of the raw materials
- The pre-processing of the raw material (powder, melting, pelleting, storage, transport…)
- The maintenance of the AM-machine
- The design of the part
- The postprocessing of the AM-part (cooling down, atmospheric situation, depowdering, support removal, baking, post-curing, HIP/WIP, impregnation, coating, painting…)
- Part inspection (geometry, strength, porosity, function…)
- Part integration (assembly, composition…)
- Functionality for the customer (part as well as product)
- Part maintenance
- Part recycling

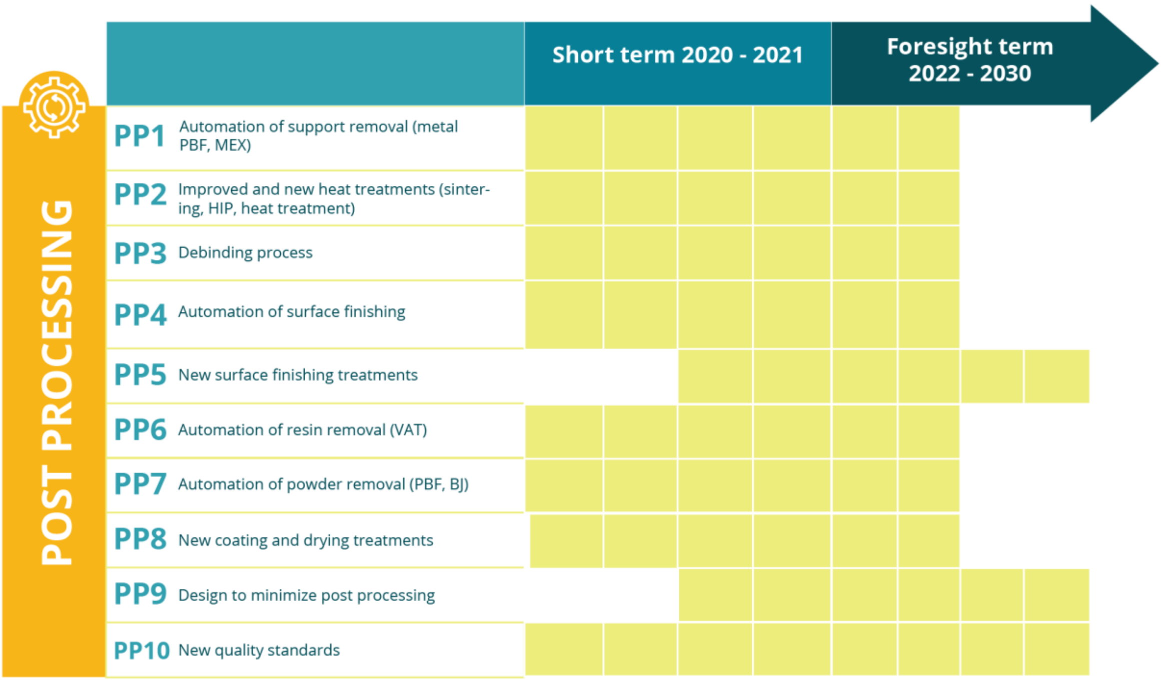
It is to be expected that this list will soon be obsolete: it needs to be maintained. This is part of the inspiration that lead to the concept of the **digital twin (#Q4)** (which even goes beyond quality).
This is not exclusive for AM. The evolution towards TQM is a trend for all manufacturing processes. The difference is that AM has a historic backlog for even the standard quality systems. What is specific for AM parts is their complexity. Especially for **part inspection (#Q3)**, this causes problems, tactile and optical scanning systems for (geometrical) inspection. This might require new inspections techniques. Quite some research has been done already on X-ray based systems like Computed Tomography (CT) scanning. This is today however expensive and time-consuming. Variants on CT and new hybrid approaches of X-ray are expected to become available.
Another issue is the fact that TQM can be dependent of the market sector. The medical sector has different ideas about quality than the aerospace sector. This implies that bespoke systems, especially with respect to the AM-process, will need to be developed

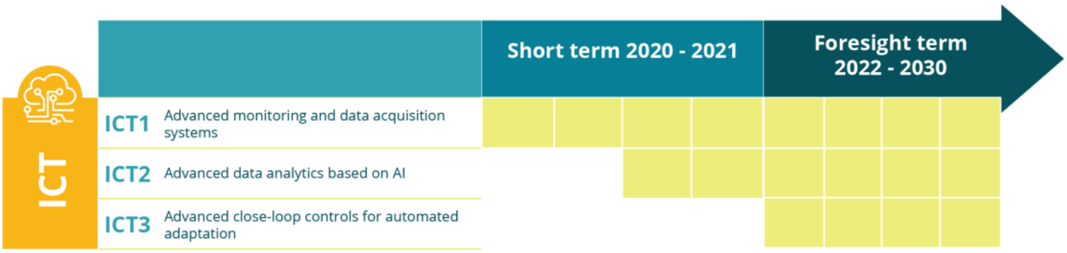
6. Conclusion

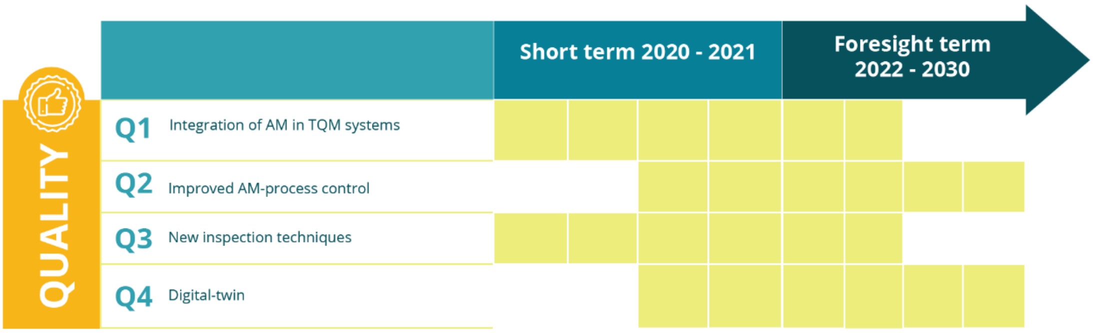
The future of AM is bright and is an increasingly important pillar for the future manufacturing industry. Currently there are an increasing number of use cases and demo business showing the benefits that AM can bring as mainstream manufacturing technology. There are several technological trends at material, technology, post-processing, ICT and quality assessment fields that will bring new innovations in the coming years to deal with current AM challenges and industrial needs.
Along this technological and industrial plan, specific roadmaps in AM were compared to identify most promising technological challenges. The conclusion points out a list of main trends which can determine the evolution of these technologies and have a direct influence on skills development in a short (2020-2021) and long term (2022-2030) period in the field of AM.
As a result of the preceding analysis, a graphic representation of the main points identified in the 3 segments and the cross-cutting quality and ICT fields are shown below.











The overall conclusion is that the identified segments confirmed to be the most required technological breakthroughs at short and long-term.

Regarding the cross-cutting ICT field, the prospect of using ICT solutions (e.g., smart software, robotics, Artificial Intelligence and Big Data) and massive automation in AM processes, it requires the need for specialized workforce to undertake research and innovation activities towards the successful industrial implementation of both existing AM technologies and new innovations.

Also, from the analysed roadmaps, quality in AM appears as the most covered cross-cutting field, indicating the need to address this topic in the future.

For that reason, the main skills defined for AM will be focused on Materials, Processing, Post-

processing and Quality. Nevertheless, as already mentioned, SAM will use a collaborative approach through the AM Observatory, to promote the use of AM technology, which requires analysing current and future needs in AM, undertaking raise awareness and training activities at European level and in within the partner countries as a starting point. This means that these conclusions may be adjusted over time.
Finally, the mapping of initiatives in AM and related areas enabled to conclude that the range of initiatives at International and European levels are aligned, foreseeing to boost the competitiveness of the manufacturing industry by investing in policies, infrastructures, research and human resources.

These conclusions provide the main technological inputs for the establishment of a European AM skills strategy to be uptake within SAM project and further accompanied within the AM Observatory (WP4) afterwards.

The identified technological trends should be thoroughly addressed in the design and review of professional profiles and skills learning pathways (WP3) while simultaneously it´s status of priority in terms of skills needs (real case, short term or foresight) should be assessed during the implementation of SAM Forecast methodology (WP2) .

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9. Annexes

9.1 Non-European (National) Initiatives

Initiative	Description	Type	Timeframe/Period	Country/City/Region	Target Group
National Network for Manufacturing Innovation (NNMI) https://www.manufacturingusa.com/	Also known as Manufacturing USA, is a network of research institutes that focuses on increasing U.S. manufacturing competitiveness and promote a robust and sustainable national manufacturing R&D infrastructure through public-private partnerships.	Association	2014 - Present	USA	Industry, academia and federal partners within a network of advanced manufacturing institutes
Innovation America Makes https://www.americamakes.us/	Flagship Institute for Manufacturing USA, the National Network for Manufacturing Innovation. Leading and collaborative partner in AM and 3DP technology research, discovery, creation, and innovation. leading and collaborative partner in additive manufacturing (AM) and 3D printing (3DP) technology research, discovery, creation, and innovation. Structured as a public-private partnership, we innovate and accelerate AM/3DP to increase our nation's global manufacturing competitiveness.	Framework	2012- Present	USA	Industry, academia and federal partners within a network of advanced manufacturing institutes
National Technology Initiative https://asi.ru/eng/nti/	NTI is a programme for creation of fundamentally new markets and the creation of conditions for global technological leadership of Russia by 2035. It includes changes of regulations, effective financial and human resources developments.	Policy	2014 - Present	Russia	Universities; research centres; business associations of the country; development institutions, expert and professional communities; ministries
Manufacturing R&D Mid- to Long-term Roadmap		Policy /Framework	N/A	South Korea	Industry, academia, network of advanced manufacturing institutes
National Additive Manufacturing Cluster https://www.ntuitive.sg/	Aims to develop an innovative ecosystem to encourage innovation, foster entrepreneurship and facilitate the commercialisation of research.	Cluster	N/A	Singapore	University of Nanyang

Advanced Manufacturing Growth Fund https://www.business.gov.au/Grants-and-Programs/Advanced-Manufacturing-Growth-Fund	Aims to increase investment in advanced manufacturing activities and boost the transition from a traditional industry to knowledge-based manufacturing of higher value products	Policy /Framework	2018- 2020	Australia	Small Medium Enterprises (SME) from Victoria and South Australia
Made in China 2025	Strategic plan to increase Chinese-domestic content of core materials, focused on high-tech fields which include the pharmaceutical industry, automotive industry, aerospace industry, semiconductors, IT and robotics etc, which are presently the purview of foreign companies.	Policy	2015 - Present	China	Chinese Industry
Made in India https://www.pmindia.gov.in/en/major_initiatives/make-in-india/	Aims to boost entrepreneurship in India in manufacturing and other sectors, though the following actions: facilitate investment, foster innovation, enhance skill development, protect intellectual property & build best in class manufacturing infrastructure.	Policy	2014 - Present	India	Indian Industry, academia and federal partners within a network of advanced manufacturing institutes

9.2 Transnational Initiatives

Initiative	Description	Type	Timeframe/Period	Country/City/Region	Target Group
AM Platform https://www.rm-platform.com/	Contribute to a coherent strategy, understanding, development, dissemination and exploitation of AM.	Platform	2007-Present	Europe	Companies, RTOs and Academic institutions. EC and other policy makers. Society
ISO TC261 Group	Committee of ISO/Standardization in the field of Additive Manufacturing (AM) concerning their processes, terms and definitions, process chains (Hard- and Software), test procedures, quality parameters, supply agreements and all kind of fundamentals.	Standardisation Organisation	N/A	N/A	Stakeholders, Policymakers, End Users
European AM Committee	This Committee is the preeminent platform to discuss EU policy challenges and opportunities in the field of AM. Acts as an umbrella for all CECIMO's current activities as the voice of AM technologies at European level.	Policy	2018-Present	Brussels (BE)	Policy makers, industry representatives
EIT Manufacturing "Additive manufacturing for full flexibility" flagship http://eitmanufacturing.eu/	EIT Manufacturing is a pan-European partnerships among leading universities, research labs and companies working together to fully integrate business, education and research. "Additive manufacturing for full flexibility" is one of the 4 flagships of EIT manufacturing.	Framework	2019-Present	Milan (IT)	Companies, RTOs and Academics
Mobility goes Additive (MgA) https://mobilitygoesadditive.com/en/	Joint development of innovative products and thus the targeted transfer of know-how and information. The identification of new business fields, the establishment of profitable business contacts and the opening of new international markets are all in its scope	Platform	2017 -Present	Berlin (DE)	Companies, institutions and research institutes
Medical goes Additive https://medicalgoesadditive.com/	Platform that combines synergies between AM businesses through cooperation with the Mobility goes Additive network. The platform encourages sharing knowledge of use cases and in-depth understanding of the medical AM market as well as of user needs	Platform	N/A	Berlin (DE)	Companies, institutions and research institutes
Vanguard Initiative https://www.s3vanguardinitiative.eu/	Network of European regions dedicated to advancing industrial innovation in Europe, which cooperate to deliver a platform for business, clusters and knowledge institutions	Policy	N/A	Spain, France, Italy, Germany, Slovenia, Netherlands, Austria, Poland, Portugal,	Companies, institutions and research institutes

	to meet and join force in finding new and innovative solutions.			Scotland, Denmark, Sweden, Belgium,	
S3 - Smart Specialisation platform https://s3platform.jrc.ec.europa.eu/what-is-smart-specialisation-	Smart Specialisation is a place-based approach characterised by the identification of strategic areas for intervention based both on the analysis of the strengths and potential of the economy and on an Entrepreneurial Discovery Process (EDP) with wide stakeholder involvement. It is outward-looking and embraces a broad view of innovation including but certainly not limited to technology-driven approaches, supported by effective monitoring mechanisms.	Policy / platform	N/A	Albania, Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, North Macedonia, Malta, Moldavia, Montenegro, Netherlands, Norway, Poland, Portugal, Romania, Romania, Serbia, Slovakia, Slovenia, Sweden, Turkey, Ukraine, United Kingdom, https://s3platform.jrc.ec.europa.eu/s3-platform-registered-regions	Industry, Research
I4MS initiative. The EU initiative to digitalise the manufacturing industry https://i4ms.eu/	It is a programme promoted by the EC to expand the **digital innovation of manufacturing SMEs in Europe.** SMEs can apply for technological and financial support to experiment with different technologies and services to improve innovation skills of their staff and the technologies and services that they provide.	Framework	2012-Present	Europe	Private companies, particularly SMEs
MANufuture-Eu http://www.manufuture.org/	The mission of the European Technology Platform Manu*future* is to propose, develop and implement a strategy based on Research and Innovation, capable of speeding up the rate of industrial transformation to high-added-value products, processes and services, securing high-skills employment and winning a major share of world Manufacturing output in the knowledge-driven economy.	Platform	N/A	Brussels (BE)	Industry and Research
EFFRA - European Factories of the Future Research Association	Is a non-for-profit, industry-driven association promoting the development of new and innovative production	Association	N/A	Brussels (BE)	Organisation involved in project funded by the

https://www.effra.eu/effra	technologies. It is the official representative of the private side in the 'Factories of the Future' public-private partnership.				Factories of the Future Calls, EFFRA Members
World Manufacturing Forum https://www.worldmanufacturingforum.org/	The WMF is an open platform that aims to enhance and spread industrial culture worldwide, as a means to ensure economic equity and sustainable development. The WMF annual meeting is an annual international conference which seeks to raise awareness and seek cooperative solutions to global manufacturing challenges through discovery, dialogue, and sharing of best practices between government, manufacturing, and innovation leaders.	Platform	2018 - Present	Milan, Lombardy (IT)	Companies, RTOs and Academics, industrial associations, policy makers, education/training providers etc.
ERRIN European Regions Research and Innovation Network http://www.errin.eu/	Platform that promotes knowledge exchange between its members, focusing on joint actions and project partnerships, supporting regional research and innovation capacity building by facilitating regional collaboration and partnerships that enhance EU's research and innovation to build a competitive Europe that supports smart, sustainable and inclusive growth in all regions.	Platform	2001 - Present	Brussels (BE)	Regional authorities, universities, research organisations, chamber of commerce and clusters
EMIRI - Energy Materials Industrial Research Initiative https://emiri.eu/	EMIRI contributes to Industrial Leadership of developers, producers & key users of Advanced Materials for low carbon energy by shaping an industry-friendly innovation-oriented EU policy framework based on SET Plan. It also promotes public and private interactions and public innovation.	Framework	2012-Present	Brussels (BE)	Industry, research, organizations
NANOfutures http://www.nanofutures.eu/	NANOfutures environment is a multi-sectorial, cross-ETP, platform with the objective of connecting and establishing cooperation and representation of Technology Platforms that require nanotechnologies in their industrial sector and products	Platform	N/A	N/A	Industry
European Green Vehicles Initiative https://egvi.eu/	Launched as part of the "Smart, Green and Integrated Transport" (H2020), it is dedicated to delivering green vehicles and mobility system solutions of the future, matching societal, environmental and economic challenges through a system approach to tackle the challenge of decarbonisation of road transport, and contribute to the transition to greener road transport, while boosting the	Framework	2013-Present	Brussels (BE)	Stakeholders from the European Technology Platforms (ERTRAC, EPoSS and Smart Grid) and EC services GR RTD, DG Move and DG Connect

	innovative strength and competitiveness of the European economy.				
European AM Qualification System (www.ewf.be)	The European AM Qualification System is managed by EWF, which is expected to be the European reference for the harmonised qualification of personnel for the manufacturing industry through the facilitation of an international harmonised education, training and qualification system to provide the welding industry with qualified and skilled personnel at all levels.	Framework	1992-Present	Brussels (BE)	National Welding Societies, Manufacturing Industry, End-users
European Additive Manufacturing Group (EuroAM) https://www.epma.com/european-additive-manufacturing-group European Powder Metallurgy Association (EPMA) https://www.epma.com/	EPMA mission is: · To Promote and Develop PM Technology in Europe · To Represent the European PM Industry within Europe and Internationally · To Develop the Future of PM These are achieved using a variety of means, a selection of which are described on the EPMA Activities page. The European AM group aims to increase the awareness of AM technology, with a special focus on metal powder based products and to enable the benefits of joint action (e.g. research programmes, workshops, benchmarking and exchange of knowledge)	Association	1989-Present	Brussels (BE)	Member organisations, equipment producers to end-users, research centres, universities, and individuals.
The European Association of the Machine Tool Industries (CECIMO) www.cecimo.eu	CECIMO brings together 15 national associations of machine tool builders, which represent approximately 1500 industrial enterprises in Europe, over 80% of which are SMEs. CECIMO defends the common interests of its members, particularly in relation to authorities and associations. It also promotes the European Machine Tool Industries and their development in the fields of economy, technology and science.	Association	N/A	Brussels (BE)	National associations of machine tool builders
ESCO https://ec.europa.eu/esco/portal/home	Classification of European Skills, Competences and Occupations. ESCO provides descriptions of 2942 occupations and 13.485 skills linked to these occupations, translated into 27 languages (all official EU languages plus Icelandic, Norwegian and Arabic). Over time, it will also display the qualifications awarded in the education and training systems from Member States, as well as qualifications issued by private awarding bodies.	EC (Policy)	2017 - Present	Brussels (BE)	Employers, job seekers, Education bodies

Skills Panorama https://skillspanorama.cedefop.europa.eu/en	Skills platform providing data on the labour market data into accurate and timely intelligence to offer new insights into skill needs in the European Union.	EC (Policy)	2017- Present	Thessaloniki (Greece)	Policy makers, education bodies, employers, end users

9.3 National Initiatives

9.3.1 Czech Republic

Initiative /Policy	Description	Type	Timeframe/Period	Country/City/Region	Target Group
Additive Manufacturing Cluster (KAV)	KAU supports the higher innovation and competitiveness of its members, popularizes their activities in the field of additive production as well as the ability to solve very complex projects using the latest 3D printing technologies. As part of its activities, KAV creates a common identity of legal and natural persons, members, contributing to the promotion of the use of additive production as well as its popularization as a sovereign component of the manufacturing processes of Industry 4.0	Cluster	N/A	Ostrava-Poruba (Czeck Republic)	Industry, Education

9.3.2 Denmark

Initiative	Description	Type	Timeframe/Period	Country/City/Region	Target Group
Norrama Nordic Network of Rapid Manufacturing http://norden.diva-portal.org/smash/record.jsf?pid=diva2%3A707175&dswid=709	The ability of Rapid Manufacturing, RM, to manufacture any design created in a 3D CAD system, without having to consider the geometrical limitations of production processes or expensive tooling, opens new possibilities for individual design of products and parts	Cluster	2010 - Present	Copenhagen (Denmark)	Industry

9.3.3 Finland

Initiative	Description	Type	Timeframe/Period	Country/City/Region	Target Group
FIRPA Finnish Rapid Prototyping Association http://www.firpa.fi/html/in_english.html	FIRPA promotes Additive Manufacturing information in Finland, acting as an independent source and distributor of information in all areas of Additive Manufacturing and as an impartial channel for the transfer of know-how in the manufacture of the latest material.	Association	Aalto (FL)	Industry	1998 - Present

9.3.4 France

Initiative	Description	Type	Timeframe/Period	Country/City/Region	Target Group
Additive Factory Hub (AFH) https://www.additivefactoryhub.com/	Offers SMEs the opportunity to take part in a shared platform installed on the site and thereby test additive manufacturing by minimising the risks and investments	Association	N/A	Saclay (France)	Industry
Association Française du Prototypage Rapide https://www.afpr.asso.fr/objectifs/	The Association promotes a network among its French stakeholders in the field of AM, by answer to multisectorial needs, foster training and technology transfer, disseminating information and news, supporting innovation projects and positioning on a European and international framework	Association	1992 - Present	(N/A) France	Industry, Education
Alliance Industrie du Futur (Fabrication Additive) http://www.industrie-dufutur.org/	Operational instrument of the Programme "Industry of the Future for the new Industrial France", gathering the main stakeholders of the French industry. The French Additive Manufacturing Initiative has the goal to build up a solid French network dealing with topics about AM. Based on the actions undertaken by its working groups, a National Roadmap is created.	Framework	2015- Present	Courbevoie (France)	Industry
ViaMéca https://www.viameca.fr/	Competitiveness French cluster devoted to "design, production and integration of intelligent mechanical systems" aiming to accelerate innovation and to enable the emergence of innovative collaborative projects.	Cluster	2005 - Present	Clermont-Ferrand (France)	Industry, R&D, Education

9.3.5 Germany

Initiative	Description	Type	Timeframe/Period	Country/City/Region	Target Group
Fraunhofer Additive Manufacturing Alliance https://www.fraunhofer.de/en/institutes/institutes-and-research-establishments-in-germany/fraunhofer-alliances/additive-manufacturing.html	It integrates eighteen Fraunhofer institutes across Germany, which depending on their main focus, deal with subjects concerning additive manufacturing and represent the entire process chain. This includes the development, application and implementation of additive production processes as well as associated materials.	Association	N/A	Chemnitz (DE)	Industry
VDMA Additive Manufacturing Working Group https://am.vdma.org/en/	Platform open to all participants in the AM supply chain that carries out its activities under the umbrella of VDMA, the Germany association representing the machinery industry	Platform	N/A	Frankfurt (DE)	Industry
VDW German Machine Tool builders' Association https://vdw.de/en/	Industrial association in the metalworking sector, it provides information, consultancy and support in response to individual questions and problems. Permanent committees and working groups guarantee the exchange of sector-specific views and empirical feedback. VDW provides regular information for its members on topical technical, commercial and legal issues.	Association	1892 - Present	Frankfurt (DE)	Industry
Division 4.13 "Training in additive manufacturing http://dvs-loeten.de/AfT/AfB/AGSP/FG4/FG4.13	In the DVS, the Division (FG) 4.13 "Training in Additive Manufacturing" of the Committee for Education (AfB) is responsible for initiating and actively accompanying training standards for additive manufacturing in the fields of metal and plastics. This is also increasingly happening internationally.	Framework	N/A	(DE)	Qualified skilled workers, foremen and technicians
3D-Printing Cluster https://www.am-cluster.de/	3D-Printing Cluster, formerly known as MUST3D, is a network in the field of Additive Manufacturing. Our goal is to promote startups and initiate collaborations	Cluster	2014 -Present	(DE)	Startups, established companies, investors and research institutes.

	between different industry players via targeted networking in order to mutually reinforce innovation.				
TUM-Cluster Additive Manufacturing - Competencies and knowledge around additive manufacturing https://www.mw.tum.de/cluster-additiv/startseite/	Initiative of the Faculty of Mechanical Engineering and the Institute of Machine Tools and Industrial Management (iwb), the TUM Additive Manufacturing Cluster stands for the interdisciplinary bundling of competences in the field of additive manufacturing.	Cluster	2017 -Present	(DE)	Technical University Munich
SIT AM , Cluster Mechatronik & Automation http://www.cluster-ma.de/strategic-innovation-teams/additive-fertigung/index.html	The Mechatronics & Automation Cluster is planning to establish a strategic innovation topic (SIT) “Additive Manufacturing” (AM).	Cluster	Planned for 2019	(DE)	All actors associated with 3d printing
Technical Committee 13 “Additive Fertigung” https://www.dvs-ev.de/fv/neu/index.cfm?Navigation=FAInfo&FA=13	The Technical Committee 13 deals with metallic and non-metallic materials in the research fields of additive manufacturing and considers these in consideration of the entire process chain, including pre-treatment and post-treatment. The focus here is on technology development, increasing the acceptance of this technology among SMEs and creating new areas of application. The focus is on the component itself.	Technical Committee	N/A	(DE)	SMES
VDI Technical Committee “FA105 - Additive Manufacturing” https://www.vdi.de/tg-fachgesellschaften/vdi-gesellschaft-produktion-und-logistik/produktionstechnik-und-fertigungsverfahren	In the technical committees, highly qualified experts and specialists therefore deal with the critical evaluation of new trends in technology and organisation and the development of new ideas. They pave the way for innovations into industrial practice and formulate national technical standards in the form of VDI guidelines and recommendations for action.	Technical Committee	N/A	(DE)	Industry
Expert CommitteeAdditive Fertigung“	This DGM technical committee concerns itself with all matters relating to the process chain: from the preparation of raw materials through the evaluation, characterisation and qualification of materials and their	Technical Committee	2016- Present	(DE)	Science, Industry, Policy makers

https://www.dgm.de/netzwerk/fachausschuesse-gesamtuebersicht/additive-fertigung/	properties up to the follow-up treatment of the components. Members are therefore scientists, as well as manufacturers of raw materials and facilities, producers and users from the industry, where the whole range of materials (plastics, metals, ceramics, glasses etc.) plays a role. The committee maintains a regular exchange with thematically connected committees of the VDI and DVS as well as with groups involved in the standardization process and the Fraunhofer Additive Manufacturing Alliance. In addition to the arranging of their own conferences, other conferences such as the "International Symposium Materials Science and Technology" are supported.				
Verband3DDruck e.V. https://www.verband3ddruck.berlin/	The association 3DDruck e.V. represents the interests of all players involved in 3D printing technology in German-speaking countries. The association 3DDruck e.V. is the manufacturer-neutral and process-spreading interest representation of all participants approximately around the 3D pressure technology in the German-speaking countries. The association bundles the interests of manufacturers, research institutes and users in order to represent them vis-à-vis politicians and to promote a broad social discourse on this future technology.	Association	2016 -Present	(DE) * German-speaking regions	All actors associated with 3d printing
DIN standards committee technology of materials NA 145.04 FB Section Additive Manufacturing https://www.din.de/de/mitwirken/normenausschuesse/nwt/nationale-gremien/wdc-grem:din21:135437062	Committees: NA 145-04 FBR Steering committee Additive Manufacturing NA 145-04-01 AA Additive Manufacturing Interdisciplinary topics/Digitalization NA 145-04-02 GA Additive Manufacturing - NWT & NAS Joint working committee Metals NA 145-04-03 GA Additive Manufacturing - NWT & FNK Joint working committee Plastics & Elastomers	Standardisation Organisation	2019 -Present	(DE)	Industry
Agentur zur Förderung von Sprunginnovationen (SprinD)	The new agency SprinD is to launch innovations that are technologically radically new and contain a high potential	Policy	N/A	(DE)	

https://www.bundesregierung.de/breg-de/aktuelles/sprunginnovationen-foerdern-1527000	for a market-changing effect with new products, services and value chains. The first announcement was for a pilot competition in the field of AI electronics in preparation for the founding of the agency.				
New large-scale equipment initiative: Laser deposition welding for high-throughput investigations and additive 3-D production of complex alloys and composite materials https://www.dfg.de/foerderung/info_wissenschaft/2019/info_wissenschaft_19_10/index.html	As part of this large-scale equipment initiative, the German Research Foundation is funding newly available technologies for laser metal deposition (LMD), which enable high-throughput investigations and additive 3D production of complex alloys and composite materials.	Framework	N/A	(DE)	Research, Development, Industry, SMES
Guideline for the promotion of the topic “Line integration of additive manufacturing processes”. (Part of Program „Photonics Research Germany“ [https://www.photonikforschung.de/] https://www.bmbf.de/foerderungen/bekanntmachung-1421.html	Funding the field of “Line integration of additive manufacturing processes” on the basis of the “Photonics Research Germany” programme, thus contributing to the implementation of the German government’s new high-tech strategy.	Framework	N/A	(DE)	Research, Development, Industry, SMES
Funding measure “Additive manufacturing - individualized products, complex mass products, innovative materials”. (ProMat_3D) https://www.bmbf.de/foerderungen/bekanntmachung-1037.html	Funding measure for “Additive manufacturing - individualized products, complex mass products and innovative materials (ProMat_3D)”. The Federal Ministry of Education and Research supports companies and research institutions in further developing this innovative form of production. The measure is part of our initiatives, with which we support in particular the innovation dynamics of small and medium-sized enterprises in Germany.	Framework	N/A	(DE)	Research, Development, Industry, SMES
High-Tech-Strategy 2025	Addresses the excellent research and an effective transfer of ideas, insights and results into application will	Policy	N/A	(DE)	Policy makers, Industry, SMES, Research and Development organisations

https://www.hightech-strategie.de/de/hightech-strategie-2025-1726.html	we be able to find creative answers to the major challenges facing society and strengthen Of German economy in times of ever faster change and ever tougher global competition.				

9.3.6 Italy

Initiative	Description	Type	Timeframe/Period	Country/City/Region	Target Group
Cluster Tecnologico Nazionale "Fabbrica Intelligente" https://www.fabbricaintelligente.it/	The Italian Technology Cluster Intelligent Factories – CFI is an association that includes large and medium-small companies, universities and research centres, company associations and other stakeholders active in the advanced manufacturing sector. It produces roadmaps for research and innovation, coordinate technical and scientific working groups, and Lighthouse Plants research and development projects.	Cluster	2012 - Present	Bologna (IT)	Industry, company associations, universities and research institutions
UCIMU - Sistemi Per Produrre http://www.ucimu.it/en/association/	Association for the manufacturers of Italian machine tool, robots, automation systems and ancillary products supporting and increasing the visibility of the companies of the sector in traditional and emerging markets. The association takes the requests of the companies of the sector to national, European, and Extra-European institutions, through established continuous dialogues on the main topics of interests for field operators	Association	N/A	Milan (IT)	Industry
Italian Industry 4.0 Competence Centers	Within the Italian "Enterprise 4.0" Plan, the 8 Italian Competence Centers (Torino, Milano, Bologna, Pisa, Padova, Napoli, Roma, Genova) are public-private partnerships aimed at supporting manufacturing companies in their adoption of Industry 4.0 technologies.	Cluster	from 2019	(It)	Manufacturing companies, technology providers, RTOs and Academics, Education/Training providers, etc.
MADE Milan Competence Center https://www.som.polimi.it/nasce-made-il-competence-center-per-lindustria-4-0-a-guida-politecnico-di-milano/	Italian competence center located in Milan, led by Politecnico di Milano and formed by 39 partners from the business and academic world with the goal of providing Italian businesses (particularly SMEs) with orientation, training and support on Industry 4.0 (including AM) .	Association	from 2019	Milan, Lombardy (IT)	Manufacturing companies, technology providers, RTOs and Academics, Education/Training providers, etc.
Italian network of Digital Innovation Hubs	Within the Italian "Enterprise 4.0" Plan, the Digital Innovation Hubs led by confindustria have the task of stimulating and promoting the demand for innovation in the production system,	Cluster	N/A	(It)	Industrial associations, companies

http://preparatialfuturo.confindustria.it/	strengthening the level of knowledge and awareness of the opportunities offered by digitalisation and are the "gateway" for companies in the world of Industry 4.0.				
Italian association of Additive Technologies (AITA) http://www.aita3d.it/chi-siamo/	Cultural association aiming to represent the interest of Italian Additive Manufacturing Sector and encouraging dialogue with institutions and other industrial associations in order to develop and foster additive technologies and 3D printing.	Association	Milan, Lombardy (IT)	Companies, RTOs and Academics, industrial associations, etc.	2014 - Present

9.3.7. United Kingdom

Initiative	Description	Type	Timeframe/Period	Country/City/Region	Target Group
Additive Manufacturing UK http://am-uk.org	To Provide a single "go to" place to access independent information on Additive Manufacturing To Generate links to key bodies and activities in the field of Additive Manufacturing To Support the development, dissemination and implementation of the UK's Additive Manufacturing strategy	Framework	2017 - Present	United Kingdom	Companies, RTOs and Academics, Policy Makers
MAPP Manufacture using Advanced Powder Processes https://mapp.ac.uk/	Future Manufacturing Hub in Manufacture using Advanced Powder Processes of the Engineering and Physical Science Research Council. It is led by the University of Sheffield and brings together leading research teams from the Universities, industry partners and the UK's High Value Manufacturing Catapult. Its vision is to deliver on the promise of powder-based manufacturing to provide low energy, low cost, and low waste high value manufacturing routes and products to secure UK manufacturing productivity and growth	Cluster	N/A	Sheffield (UK)	Industry, Universities
MTA Additive Manufacturing and Digital Working Group https://www.mta.org.uk/additive-and-digital-manufacturing	The group operates under the umbrella of the MTA, the UK's Manufacturing Technologies Association. The platform brings together AM businesses active in the country	Association	N/A	London (UK)	Industry

UK Additive Manufacturing Strategy http://www.amnationalstrategy.uk	Additive Manufacturing National Strategy sets out to establish the UK as a world leader	Policy	2015 -Present	UK	Companies, RTOs and Academics, Policy Makers
UK Additive Manufacturing Special Interest Group https://ktn-uk.co.uk/interests/additive-manufacturing	This Special Interest Group (SIG) aims to create and promote new knowledge and knowledge transfer in the area of additive manufacturing and 3D printing (AM/3DP), primarily for the benefit of UK business and economic growth. The SIG will help to foster new commercial opportunities, enhance awareness and build UK capability and capacity in AM through delivering structured workshops and roadshows and developing a capability map and understanding of the value chain in the UK.	Cluster	2017 -Present	UK	Companies, RTOs and Academics, Policy Makers
UK Digital Catapult for Manufacturing https://www.digicatapult.org.uk/industries/manufacturing/	Accelerating the number of trailblazer companies working with advanced digital technologies in UK manufacturing	Cluster	2017 -Present	UK	Companies, RTOs and Academics, Policy Makers

9.3.8 Netherlands

Initiative	**Description**	**Type**	**Timeframe/Period**	**Country/City/Region**	**Target Group**
AddFab http://www.addfab.nl/en/	Funded by 3 industrial partners and run by AM professionals, it is a 3D printing factory that produces industrial metal parts for a broad range of high tech and high end manufacturing applications. It also supports partner companies in the production and supply of 3D metal parts for end-users.	Cluster	N/A	Eindhoven (NL)	Industry
Field Lab Multi-M 3D Partners http://amsystemscenter.com/fieldlab-multi-material-3d/fieldlab-multi-m3d-partners/	Co-creation platform in which (in some cases even different) industries along the value chain work together with research organisations and universities, in order to develop and validate the next generation multi-technology and multi-material solutions.	Platform	N/A	Eindhoven (NL)	Industry, universities and research institutions

9.3.9 Spain

Initiative	Description	Type	Timeframe/Period	Country/City/Region	Target Group
ADDIMAT Spanish Association of Additive Manufacturing Technologies and 3D https://www.addimat.es/en/about-addimat	Provides a forum for manufacturers of AM and 3D printing equipment where they can share information about market intelligence and development of additive manufacturing technologies, and deal, as a group, with topics of mutual interest. Finally, to foster business cooperation, creating networking opportunities between the different market groups	Association	N/A	San Sebastian (ES)	Industry
ASERM Spanish Association of Rapid Manufacturing http://www.aserm.net/	Platform that gathers Spanish stakeholders to promote and foster R&D and innovation in the field of Advanced Manufacturing (research and technology development and technology transfer)	Association	2004 - Present	Cerdanyola del Vallès (Spain)	Industry, Technology centers, R&D, Academy
Manu-Ket |Spanish Technological Platform for AM http://www.manufacturing-ket.com/en/manu-ket-2/	Aims to identify technological needs required by future products and services, in which the incorporation of advanced materials, microelectronics, photonics and nanotechnologies require new processes, equipment and production systems with new levels of productivity, safety, functionality or precision.	Platform	N/A	Spain	Spanish manufacturing sector
MATERPLAT Advanced Materials and Nanomaterials Spanish Technological Platform http://materplat.org/en/what-is-materplat/	Fosters and promotes innovation in the R&D&I National System, as a key tool and instrument to improve and increase the competitiveness of the collective of Spanish companies, for which materials and nanomaterials, as well as their transformation processes are fundamental elements in the development and commercialization of their products and services.	Platform	2008 - Present	Madrid (ES)	Industry, R&D
Move to Future https://www.move2future.es/	Its purpose is to serve as an instrument for the development and monitoring of initiatives among the different actors involved in the innovation chain of the sector in Spain, to create a culture of innovation	Platform	N/A	Madrid (ES)	Industry

	and a common line of work in order to increase the competitiveness of companies before new challenges that arise, through research, development and innovation in products and processes				
UPTEK https://www.uptek.es/en/home	UPTEK is the Spanish association of technology-based companies and start-ups for advanced and digital manufacturing. From UPTEK we promote the presentation, defence, internationalization, standardization and promotion of common interests of our members, as well as the realization of actions aimed at improving the competitiveness of the sector through inter-company cooperation. UPTEK is part of AFM Cluster	Association	N/A	San Sebastian (ES)	Manufacturing companies, technology providers, RTOs and Academics, Education/Training providers, etc.

9.3.10 Switzerland

Initiative	Description	Type	Timeframe/Period	Country/City/Region	Target Group
Swiss Additive Manufacturing Group https://www.swissmem.ch/en/products-services/networking/specialist-groups/swiss-additive-manufacturing-group.html	Brings together companies in the additive manufacturing sector in development, planning, engineering, manufacturing, supply, equipment and services active in Switzerland	Cluster	N/A	Zurich (Swiss)	Industry

9.3.11 Poland

Initiative	Description	Type	Timeframe/Period	Country/City/Region	Target Group
Association of Polish Industry Printing 3D http://druk3d.org/	The association mission consists on building an environment that supports companies and institutions in the 3D printing industry by building a positive image of the 3D printing industry, Integrating companies wanting to work for the benefit of the industry and supporting the development of companies in the industry	Association	N/A	(N/A) Poland	Industry

9.3.12 Portugal

Initiative	Description	Type	Timeframe/Period	Country/City/Region	Target Group
Produtech http://www.produtech.org/?set_language=en&cl=en	Production Technologies Cluster, it is an articulated network of manufacturing technology providers capable of responding to both competitiveness and sustainability challenges and to manufacturing industry's requirements with innovative, flexible, integrated and competitive solutions. It fosters several projects and activities promoting cooperation, innovation and internationalization.	Cluster	N/A	Porto (PT)	Industry and relevant stakeholders

9.4 Regional Initiatives

9.4.1 Germany

Initiative	Description	Type	Timeframe/Period	Country/City/Region	Target Group
Showcase production and automation technologies - Chamber of Crafts for Upper Franconia ranken) https://handwerkdigital.de/ueber-uns/themen/einsatz-neuer-produktions-und-automatisierungstechnologien-im-eigenen-betrieb/	In the Manufacturing and Automation Technologies showcase, interested craft businesses can experience the digitisation of manufacturing and automation technologies in the various trades and take suggestions for the digitisation of their own business with them. The Competence Center acts as a source of ideas and a demonstration location for specific digitization issues. The innovation path accompanying the project presents various stations of digital applications on interactive screens.	Cluster	N/A	(DE)	Crafts business

9.4.2 Italy

Initiative	Description	Type	Timeframe/Period	Country/City/Region	Target Group
AFIL Associazione Fabbrica Intelligente Lombardia https://www.afil.it/engineeringspa/	Promotes research and innovation as well as best practices on technology development in the advanced manufacturing sector, including AM, in order to support and develop the leadership and competitiveness of the Lombard production system	Association	N/A	Lombardia (IT)	Companies, Universities, Research Institutions and Associations
MESAP https://www.mesap.it/?lang=en	MESAP is the Piedmont Cluster for Mechatronics and Advanced Manufacturing. It promotes and supports projects and working relationships between companies, universities and research institutes in order to strengthen the technological and industrial production chain in Piedmont.	Cluster	2009 -<present	Piedmont (IT)	Companies, RTOs and Academics, Policy Makers

9.4.3 Spain

Initiative	Description	Type	Timeframe/Period	Country/City/Region	Target Group
EIT Regional Innovation Scheme (RIS) | Co-Location Centers https://eitrawmaterials.eu/eit-regional-innovation-scheme-ris/	Provides access to activities and services of the KIC to those who might otherwise have no access. Co-Location Centres (covers Europe) stimulate regional businesses development by triggering the emergence of new ideas and innovations.	Framework	N/A	Spain	Spanish manufacturing sector
IAM 3D HUB https://iam3dhub.org/	Designed for the integration and coordination of economic activity in the AM innovation ecosystem of Catalonia and for developing strong ties with the AM European and worldwide ecosystem	Cluster (HUB)	N/A	Catalonia (ES)	Private companies, public agents and research centers
Basque Digital Innovation Hub Additive Manufacturing node https://basqueindustry.spri.eus/en/basque-digital-innovation-hub/additive-manufacturing/	The node of Additive Manufacturing has been created within the framework of the Basque Digital Innovation Hub, where the main Science and Technology agents with capacities in this field collaborate together to offer the best service to the needs of SMEs	Cluster (HUB)	2018 - present	Basque Country (ES)	Private companies, particularly SMEs

9.4.5 Belgium

Initiative	Description	Type	Timeframe/Period	Country/City/Region	Target Group
STREAM/SIM: https://www.sim-flanders.be/research-program/stream	The STREAM consortium consists of industrial partners from different segments of the AM value chain: material producers, AM-technology companies, software developers, companies with post-processing & functionalization expertise and end-users of different market segments (aerospace, medical, PVC-products). The latter are very important to define the required AM – end product features.	Cluster	2013 - Present	Flanders (BE)	Industry, Universities, R&D

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