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SAM
SECTOR SKILLS STRATEGY
IN ADDITIVE MANUFACTURING

A COLLECTION OF SAM ARTICLES

Co-funded by the Erasmus+ Programme of the European Union

INTRODUCTION

SAM - Skills for Additive Manufacturing (AM) - is an EU-funded initiative widely recognised as the "blueprint project" for the Additive Manufacturing sector. Launched in January 2019, SAM plays a pivotal role in establishing a globally acknowledged program dedicated to fostering and certifying skills in Additive Manufacturing. Its primary objective revolves around the implementation of the International Additive Manufacturing Qualification System (IAMQS). Over a span of four years, the SAM consortium has produced an impressive collection of 13 articles, releasing three articles per year, focusing on crucial subjects related to education and training for the AM industry and its overall impact on manufacturing. As a culmination of these efforts, this booklet compiles all 13 articles, providing a concise overview of their contents.

In 2019, SAM partners undertook three projects that highlighted the alignment of SAM with qualification strategies for industries and the requisite skills for the future workforce in Additive Manufacturing. Notably, the initial article titled "Fit for 3D printing: EU project develops qualification strategy for skilled workers" emphasized the project's suitability. Materialise contributed the second article, titled "Why is the SAM project interesting for industry?" while Brunel University published the final article, titled "Preparing for a Future-Ready Workforce - A Review of Additive Manufacturing Jobs in Europe."

The focus of 2020 revolved primarily around addressing the existing skills gap in AM, considering its significance to the industry and education system through tailored training programs. Consequently, CECIMO authored the first article, "SAM: The solution to AM skills shortage in Europe," followed by the publication of the second article, "Relevance of the SAM Project for Industry," by IMR. The final article for that year, "SAM: An opportunity to enhance AM educational programs through training centres and universities," was developed by EC Nantes.

In 2021, the emphasis shifted towards exploring the impact of AM on environmental sustainability and the AM supply chain. LMS contributed the first article, "Relevance of the SAM Project for academia," while LORTEK and EWF collaborated on the second article, "Impact of Additive Manufacturing towards Environmental Sustainability." The final article, "Relevance of new AM developments for AM Supply Chain in terms of Powder Supply," was developed by EPMA.

Throughout 2022 and 2023, four articles were developed, focusing on the need for upskilling in AM, education and the positive influence of AM in propelling industries towards a sustainable future. The first article, "Recognition of Prior Learning: an agile mechanism for upskilling in the field of additive manufacturing," was jointly published by IDONIAL, EWF, and Ecole Centrale de Nantes. MTC authored the second article, titled "Metal Binder Jetting: Taking metal Additive Manufacturing into high-volume production," while AITIIP Centro Tecnologico developed the third article "Additive Manufacturing for a sustainable industry of the future." Concluding in 2023, Fan3D developed the article "Relevance of the SAM Project for K-12 Education" highlighting the benefits of 3D printing on students.

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FIT FOR 3D PRINTING: EU PROJECT DEVELOPS QUALIFICATION STRATEGY FOR SKILLED WORKERS

Sandra Kramprich, Ilka Zajons & Henning Ahlers - LAK, 2019

3-D printing revolutionizes conventional manufacturing and creates completely new possibilities for industrial production processes. In order to successfully exploit this potential, the EU-project SAM is developing a qualification strategy for skilled workers.

The EU-funded project Sector Skills Strategy in Additive Manufacturing (SAM) was launched in January 2019 and has a term of four years. The aim is to develop an industry-specific qualification strategy in the field of additive manufacturing. Currently and in the future relevant qualifications are to be identified and defined and a methodology for the evaluation of essential competences is to be developed.

In this way, growth, innovation and international competitiveness on the European market are to be promoted and strengthened through standardisation in training and further education. An observatory keeps the qualification standards up to date even after the project has been completed and monitors technological trends and market requirements.

With the development of a qualification strategy, the EU-funded project SAM is actively working against the shortage of skilled workers in additive manufacturing. The project aims to meet the increasing demand for skilled workers and the rising qualification requirements in this sector in the future.

By systematizing training and further education in additive manufacturing, the attractiveness of this work area and the perception of career opportunities for potential future employees will be promoted at the same time. In addition, a common and transparent basis will be created for the further specialization and differentiation of the possibilities of additive manufacturing in various application areas and industries. Well-trained and specialized employees produce high-quality products and strengthen innovation and competitiveness in the national and international sector.

You want to support the project?

The SAM network cooperates with various interest groups throughout the EU, for example with companies from industry and organisations from public and private education. You can get involved in different ways, e.g. by:

- Participation in workshops to support the identification and validation of qualification requirements and the development of competence units;
- Support in the implementation of training courses and dissemination of project results;
- Participation in the information campaign for pupils, students and professionals.

Become a cooperation partner and make valuable new network contacts! Support the SAM project in the identification of current and future qualification requirements as well as the design of education and training in additive manufacturing throughout EU.

WHY IS SAM PROJECT INTERESTING FOR INDUSTRY?

Michel Janssens - Materialise, 2019

1. Current situation

Having skills in Additive Manufacturing (AM) today means job security. This makes life easy for people not knowing what to study or obviously for people having these skills. It is however bad news for the make-industry: there is a serious shortage of skilled people, even to the extent that it is slowing down the growth of the AM-industry. Companies are struggling to find skilled personnel. This is the main motivation behind the SAM-ERASMUS+ Blueprint project Sector Skills Strategy for AM (SAM) and its goal is to fill this need by reshaping the AM-related education.

A naive approach would be simply setting up more AM-training centres (at universities, branch organisations, in-house industrial trainings). This would be, apart from being very costly, be insufficient. To understand this, it is important to analyse carefully all reasons behind this shortage. It is not only the fact that there are not enough training centres available.

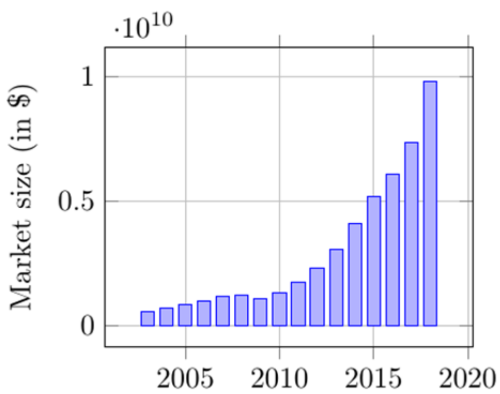
1.1 Young Technology

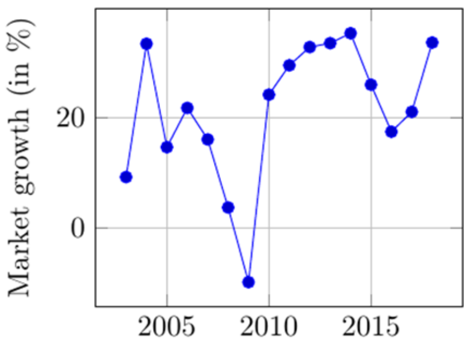
AM is a relatively young technology. In its' modern form, early examples of (industrial) Rapid Prototyping (RP), as it was called back then, appear in the mid-1980s, while the first (synthetic) plastic in injection moulding was patented back in 1909. Casting even goes back to the Bronze Age (3300 BC). Obviously, these more traditional manufacturing technologies have had more time to develop and are part of the standard educational packages in schools and universities dealing with manufacturing.

This is not the case for AM, there are not so many dedicated courses. In many schools and universities, they are part of courses with names like Non-conventional manufacturing processes. Sometimes, however, it is not part of the curriculum at all. Needless to say that this does not contribute to the growth of the AM-working force.

1.2 High Growth

Since the 1990s, the industry has been monitored closely by Wohlers Associates1. Figure 1 gives an overview of the total market evolution until 2018. Today, the AM-market is worth 10 billion $ annually. The right graph shows the evolution of the growth rates. The last 10 years where (almost) consistently over 20%. Even before that, the growth rates were much higher than the average global industrial growth over all sectors. A staggering 33.5% growth in 2018. This causes an extreme raise in demand for skilled people to realise this growth.





1.3 Fast Evolving

This growth cannot be caused only by the natural growth of existing markets, then it would be closer to the overall industrial growth of only a few percent. In order to reach these extreme growth rates, new applications and markets need to be addressed, consistently. This in its turn is only possible due to continuous improvement of the AM processes and materials being used, as well as application specific research. As a consequence, the industrial evolution in AM goes hand in hand with the scientific and technological advances being made and does so at a very fast pace.

The result is a continuously changing state-of-the-art. A person having followed a course five years ago is no longer up-to-date. Also, the courses themselves, given five years ago, are no longer up-to-date. Both need to be updated continuously.

1.4 Large diversity of AM-technologies

These fast evolutions do not only need to improvements of existing AM-technologies but have also generated a wide variety of different AM processes. This is reflected in the standard ISO/ASTM 52900. In order to have some structure in the wide variety of processes, a (standardised) classification of all these processes is defined. There are basically seven types of processes:

- binder jetting
- directed energy deposition
- material extrusion
- material jetting
- powder bed fusion
- sheet lamination
- vat photopolymerization

Each type of AM-process has quite a number of variants. It is very difficult to stay up-to-date with this large number of technologies. Fortunately, most of the time, it is also unnecessary to do so for the basic user. A training centre should at least be aware of the state-of-the-art but can specialise in a subset.

1.5 Impact on the complete product life cycle

Perhaps the most difficult problem to handle is the fact that if a person is trained in AM and becomes skilled in all aspects of the material and process, the training focuses on the manufacturing itself. AM is treated as yet another manufacturing technology. In many applications, the existing manufacturing process for a part is simply replaced by an AM process. The engineer typically looks only at the manufacturing process to produce an existing part. Why does he or she do that? Because it is faster and/or cheaper (no need to make a mould).

This is not exploiting AM to its' fullest extent. AM opens up completely different approaches to product, design, manufacturing, logistics, in fact, the complete product life cycle. In a way, it relates to one of the famous quotes by Henry Ford:

If I would have asked my customers what they wanted, they would have answered:
A faster horse.

The car actually started a completely new approach to transportation. The new approach to designing, making, selling, delivering and recycling a product is not treated sufficiently in modern education.

2. The role of SAM-ERASMUS+

2.1 Requirements on education

The set-up of the SAM-ERASMUS+ project and the targeted goals are defined according to the (industrial) needs described above. These needs translate into some quite challenging requirements for AM-educational programmes:

- **Stay up-to-date** This isn't obvious because of the fast evolving technology
- **Offer modular courses** Because of the wide variety of AM-technologies, it is not possible to have all skills train to all people. It is not required either. Therefore, it should be possible to have AM-courses à la carte.
- **Go beyond the mere manufacturing** In order to fully exploit the possibilities of AM, all aspects of the process and materials need to be adapted accordingly. This is not obvious. Therefore, other aspects (design, logistics, materials, value chain...) need to be handled as well.
- **Update courses** Since AM-technology is evolving so fast, AM-skills quite quickly become outdated. People should be able to follow update courses, without having to go to a full education cycle.
- **Enough and predictable quality** This is perhaps the most difficult requirement. There are simply not enough skilled people at this moment that includes teachers and trainers. This is a chicken-and-egg problem. On top of that, there are quite a lot of self-proclaimed experts, teaching and giving consultancy with varying quality levels. This is mainly due to the fact that the technology is relatively new. Moreover, there is an uncontrolled growth of different courses, which are not comparable. From the perspective of the one seeking further training in AM it is not clear, which courses are available and which ones are of high quality and recognised on the market. Therefore we need a standardisation of further education in AM to create a transparent qualification system with comparable courses, which are aligned to industrial requirement and recognised on the European market.

These are the main demands from industry for the SAM-ERASMUS+ project.

2.2 The SAM-ERASMUS+ set-up

The structure of the complete SAM-ERASMUS+ solution is not yet carved in stone but there are some basic blocks that are already clear. The key element within the SAM-ERASMUS+ project to meet the requirements (especially with respect to keeping it up-to-date) is the European AM observatory. The traditional approach of educational institutes for keeping courses up-to-date is reactive to the market demand. In the best case, the institute combines education and research (e.g. universities) and monitors de facto state-of-the-art in scientific and technological developments. This enables them to keep their educational material up-to-date in their specific area of expertise.

The SAM-observatory uses a different, proactive approach. One of the most important assets of the observatory is the AM timeline for 10 years in the future. The timeline is based on expert knowledge and existing and planned research activities in AM and related technologies and markets. There are two potential problems with that:

- The timeline is based on predictions and extrapolations by experts. This is however no certainty that the predictions (especially the long term over five years) are correct.
- As time progresses, the term of the predictions becomes shorter.

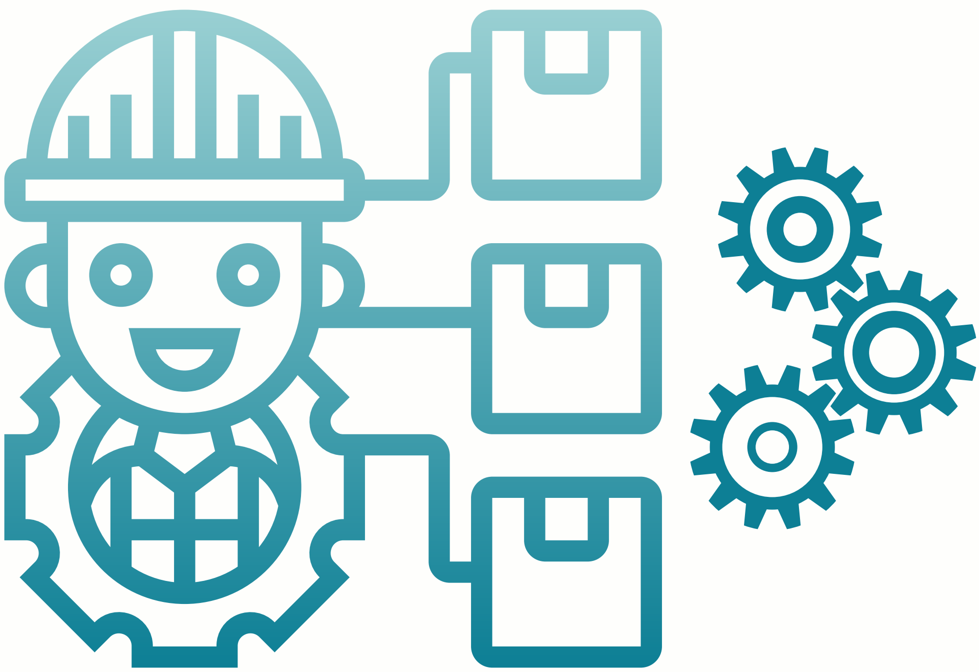
Both problems are solved by regularly updating the timeline based on reality (catching up with the predictions) and new insights. The update frequency should at least be yearly but can be shorter if important events occur.

Based on the timeline the skill needs can be kept up-to-date and the educational programs can be adapted accordingly. There is (or will be) a whole process implemented to adapt the educational material (courses, trainings, internships...). And the material will be spread over the network of European stakeholders (educational institutes, industry, standardisation bodies, governments...). This way of working ensures the courses to stay up-to-date. The differences between the different educational institutes become smaller (if not standardised) providing a predictable quality. Furthermore, it becomes easier to train the trainer so the total offer can be increased. Since the delta's of the state-of-the-art/timeline are monitored, it should be fairly easy develop delta courses or update courses.

Because of the close monitoring and the inclusion of the predictive models of the complete AM landscape, all information is now centralised. It becomes easier to classify the different technologies and the related skill needs and to keep track on the students and AM professionals. This can be used to determine the boundaries between the different skill sets and offer relevant modules of education. Going beyond the mere manufacturing is not ensured by the structure of the observatory and will be a constant point of attention. In a first phase, the AM technologies will be monitored by the observatory. In later phases, this can be extended with the other aspects of AM: the impact on design, the business models, value chains, logistics, legal aspects...

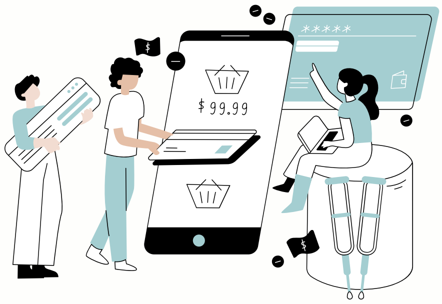
The following videos available at the project website provide a good insight into the project goals:

- AM Observatory
- AM Qualification System



PREPARING FOR A FUTURE-READY WORKFORCE - A REVIEW OF ADDITIVE MANUFACTURING JOBS IN EUROPE

Adeayo Sotayo & Eujin Pei - University of Brunel UBRUN, 2019

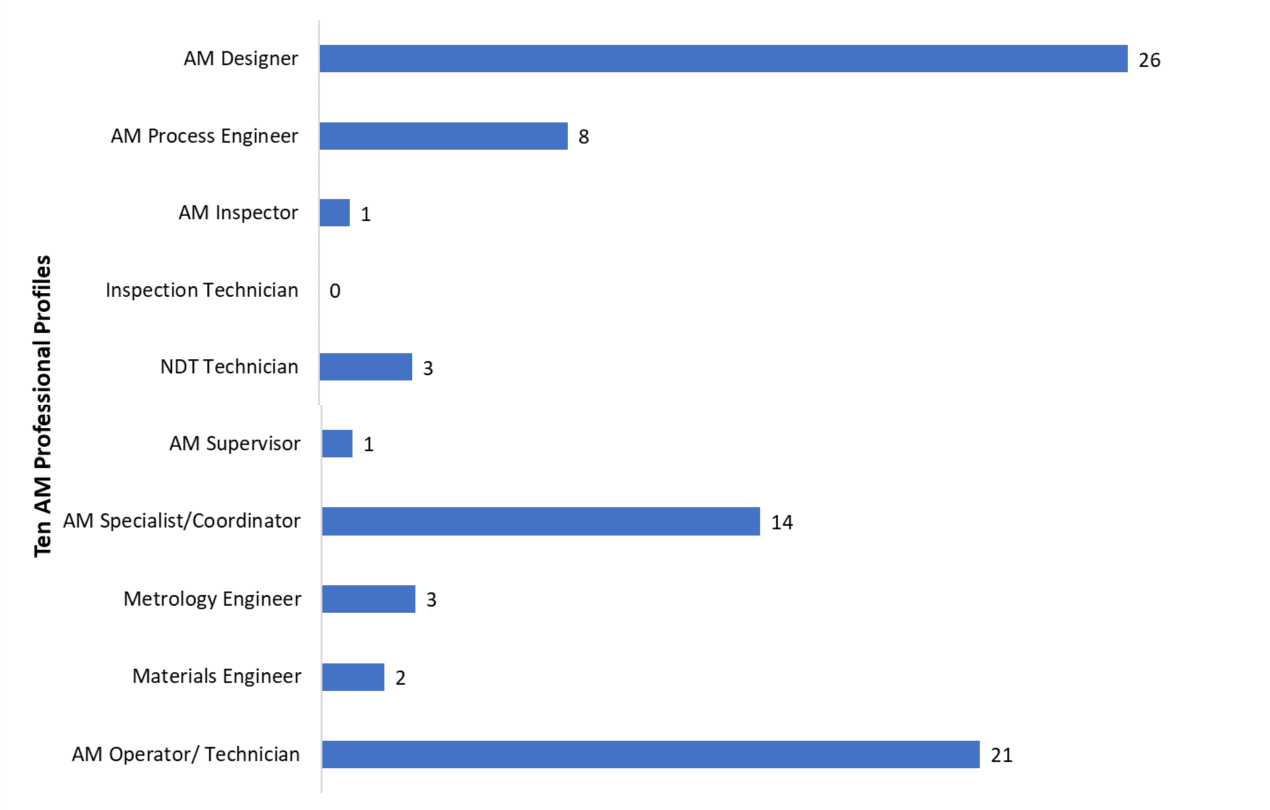


Sector Skills Strategy in Additive Manufacturing (SAM) is a four-year EU-funded project, launched in January 2019 with the aim of developing an industry-specific qualification strategy for the Additive Manufacturing (AM) sector, so that Europe retains its overall international competitiveness. Brunel University London is a UK partner, along with 15 other members of the consortium. For this project, Brunel University London was responsible for mapping the relevant professions working in AM at the moment. The objective was to carefully gather, analyse, categorize, and summarize existing information about professionals working in AM, as a starting point to develop a forecast methodology to assess current and future skills needs in AM. Having relevant and up to date skills and qualifications from a workforce will be key to a successful factory. Taking a step further, we compiled results from the literature review of AM professionals in the industry at the moment; and collected data from recruitment advertisements and other available statistics across Europe. Beyond this mapping activity, Brunel University London would also be responsible to support the implementation of the qualifications. The provision of standardised training for AM would be beneficial to support continuous learning, training and education for a future workforce.

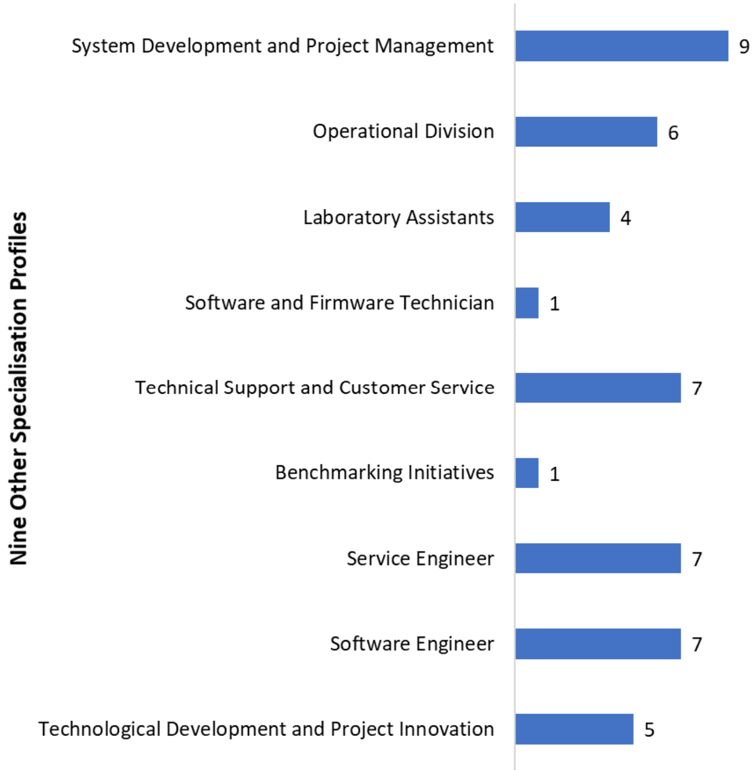
From the literature review, most researchers claimed that in the near future, there would be fewer lower-skilled human jobs as they would be replaced by the use of technology. This would mean that the remaining work available would become more complex and comprehensive. Bowles (2014) highlighted that Northern European countries such as France, Germany, Sweden and the UK would potentially be less affected by the use of computers as compared to Southern European countries where up to 45 to 60 per cent of the workforce could be affected by high and persistent unemployment due to the implications of Industry 4.0. A survey by Naudé, Surdej and Cameron (2019) involved eight Central and Eastern European countries (CEECs) including Bulgaria, the Czech Republic, Lithuania, Hungary, Poland, Romania, the Slovak Republic and Slovenia. It was found that Czech Republic, Lithuania, Hungary and Slovenia were Industry 4.0 ready; and Bulgaria, Slovakia, Romania and Poland were least ready for Industry 4.0. The authors highlighted that unpreparedness for technological changes may result in poor international competitiveness or regions may experience a risk of deindustrialization. The European Commission (2017) identified policies to strengthen each country's industrial competitiveness and modernization to ensure sustainable growth of the manufacturing sector and noted that "national industry 4.0 initiatives tend to focus on technology and infrastructure, with skills development a secondary goal". Gress and Kalafsky (2015) claimed that while AM machines will be expected to perform most production tasks, there will be an increased demand for specific roles such as technicians, trouble-shooters, repairmen, and computer programmers. As manufacturing processes become more complex, it will lead to jobs requiring higher qualifications, and consequently less demand for lowly qualified jobs (Hecklau et al., 2016). Researchers suggested that for readiness, companies should qualify their employees for more strategic, coordinating and creative tasks and assign them with higher responsibilities.

One of the predicted impacts of Industry 4.0, including the use of AM is the replacement of a low-skilled workforce by machines (Ciffolilli and Muscio 2018). Greater use of robotics and computerization will reduce the number of jobs in assembly and production. But this decline will be more than offset by the creation of even more new jobs in the information technology (IT) and data science sectors. The findings by Bonekamp and Sure (2015) undertaken in Germany indicate that Industry 4.0 would see a substantial decrease in lowly-skilled jobs and an increase in highly-skilled jobs which have a greater emphasis on IT-related tasks.

Taking a step further, we utilised a total of 21 online recruitment search engines using two main keywords "3D Printing" and "Additive Manufacturing" to obtain relevant AM Professionals jobs in the Industry. The duration for active job search took place from June to November 2019 to collect an "across-the-board" list of jobs advertised for AM Professionals. Among the websites used to search AM jobs across the EU, was "EURES - The European Job Mobility Portal" (https://ec.europa.eu/eures/public) which provides the most comprehensive search results across more EU countries. The countries captured for this study include Austria, Belgium, France, Germany, Ireland, Italy, Netherlands, Norway, Spain, Sweden, Switzerland and the UK. Due to the nature where this study was conducted in the UK and in English, jobs that appeared within the UK took up a higher percentage, followed by Germany. The 10 listed AM Professional Profiles included AM Designer, AM Process Engineer, AM Inspector, Inspection Technician, NDT Technician, AM Supervisor, AM Specialist/Coordinator, Metrology Engineer, Materials Engineer and AM Operator/ Technician, and their vacancies are shown in Figure 1.



Also, the other Specialisation Profiles included System Development and Project Managers, Operational Managers, Laboratory Assistants, Software and Firmware Technicians, Technical Support and Customer Service Officers, Service Engineers, Software Engineers, and Technological Development and Project Innovation Officers, with their vacancies given in Figure 2. These findings from the online recruitment adverts, as well as the literature, have provided a better understanding of the relevant jobs and employability in the current AM Industry.

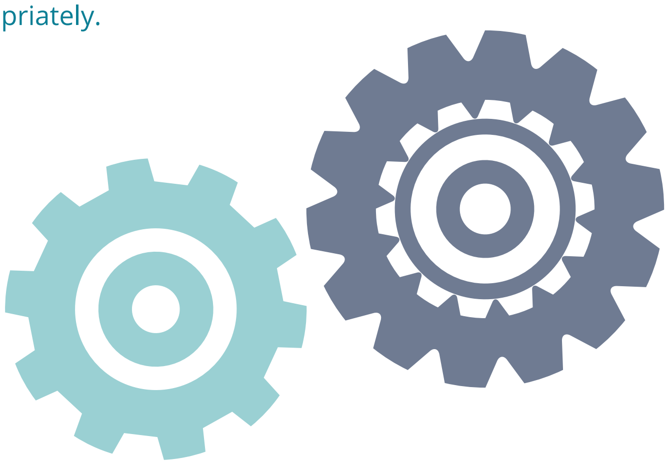

Nine Other Specialisation Profiles
System Development and Project Management
9
Operational Division
6
Laboratory Assistants
4
Software and Firmware Technician
1
Technical Support and Customer Service
7
Benchmarking Initiatives
1
Service Engineer
7
Software Engineer
7
Technological Development and Project Innovation
5

SAM: THE SOLUTION TO AM SKILLS SHORTAGE IN EUROPE

Alessandra Zini - CECIMO, 2020

1. The European context

For the European Industry, it is imperative to provide the European workforce with the right set of skills demanded by the market, in order to foster and remain competitive ahead of future challenges. As highlighted in the recent European Commission New Industrial Strategy “A competitive industry depends on recruiting and retaining a qualified workforce”[1], it is unquestionable that industrial development and skills demand should go hand in hand. Therefore, the European Union has set out several initiatives to help the Member States bridge the gap between skills demand and supply to be able to deliver the 4th Industrial revolution. In 2016, the European Commission issued its guidelines in the “New Skills Agenda” to tackle - with policies and funding - the skills mismatching challenge in Europe. One outstanding initiative presented in the document is the “Blueprint for sectoral cooperation on skills”. As the name suggests, it represents “a new strategic approach that aims to mobilise a wide range of stakeholders to upskill and reskill the workforce”[2]. The Blueprint aims to create a strategy applicable at the European level, where the actual industrial needs in term of skills are timely matched with tailored training offers, as well as to foresee future trends and adapt the training offers appropriately.



2. SAM, the Blueprint for sectoral cooperation on skills for AM

As the European Industry 4.0 will become more and more a reality during the next decade, the Additive Manufacturing (AM) sector has been identified as one of its 'Key Enabling Technologies – KETs', i.e. innovation drivers essential to EU's Industrial Policy. As a result of that, the EU funded project SAM (Sector Skills Strategy in Additive Manufacturing) has been selected under the Erasmus+ framework programme to be the Blueprint in the AM sector. The objective of the project is to develop an effective system to identify and anticipate the skills needed in the AM sector in Europe. With this Blueprint, the consortium also aims to reduce the unemployment rate by providing skilled workers needed by the market and to boost the Industry in Europe. The Blueprint calls for "stakeholders to work together in sector-specific partnerships, called sectoral skills alliances, to develop and implement strategies to address skills gaps in these sectors."[3]

Sectoral cooperation is indeed one of the strengths of the SAM project and, as it can be seen in Figure 1, it includes key actors from across the whole AM value chain and related fields:

- Industries
- Vocational Education and Training Centers and Higher Education Institutes
- Research and Innovation centres

3. SAM and the New Skills Agenda

Being the Blueprint for tackling the skills gap in the AM sector, SAM directly contributes to the achievement of relevant actions identified in the New Skills Agenda by the European Commission.

3.1 Adult Learning

Even if the blueprint is mostly focused on future forecast and anticipation of skills need, the mismatch in the AM skills market - as well as in other competitive sectors - is already perceived at the present date.

This is why the need for re-skilling of the current workforce, such as adult professionals, is felt as much as the need for building the future generation, to keep the pace with the fast changes brought by AM technologies. Encompassing the first action of the New Skills Agenda, 'Upskilling Pathways: New Opportunities for Adults', and embracing the challenge that "in the next five years alone, 120 million Europeans will have to upskill or re-skill"[4], SAM addresses the issue by introducing a European harmonized scheme for Recognition of Prior Learning (RPL) in the AM sector, and intends to develop flexible and independent learning modules tailored and aligned with the Industrial requirements, and that will eventually make current professionals available to the labor market quicker.

3.2 European Qualifications Framework, Digital Skills and Key Competencies

The Commission is currently working on the implementation of the revised 'European Qualifications Framework', with the aim of supporting a better understanding of the qualifications and try to allocate the available skills in the European labor market accordingly. The SAM project is developing a Sectoral Competence Framework that includes:

- Using the descriptors outlined in the European Qualifications Framework to design the qualifications and learning units;
- Reviewing and deploying relevant qualifications in the AM sector;
- Linking the European AM Qualifications System to the European (EQF) and National Qualifications Frameworks (NQF), identified by Cedefop, the European Center for the development of Vocational Training[5].

The project coordinator, EWF, is responsible for the design of the Qualification and Certification system, intended as an open system that ensures that any person, anywhere in Europe, has unrestricted access to education, training, qualification and certification in AM.

According to the two current priorities of the European Commission, namely the Green Deal and the Digital Industry, the new approach for the identification of AM skills takes into consideration environmental change and digitalization. Those factors represent increasingly important drivers of labor demand and skills supply across sectors, including AM. Such trends are taken into consideration in the project by dividing the skills needed into four core categories: technological, green, digital, and entrepreneurship.

3.2 Vocational Education and Training

With this action, the Commission aims to work on a set of measures to support the modernization of vocational education and training (VET) and to offer it as a first choice for students.

The SAM project embraces this action and plays a central role in its development by directly involving the VET providers in the consortium. These partners offer their expertise to foster innovative learning methods and pedagogical approaches - e.g. real case solving methodologies. The result is to make such trainings more attractive to students and encourage them to opt for careers in AM.

3.4 Graduate Tracking

While adult learning has a dedicated initiative within the New Skills Agenda, the 'graduate tracking' has as core objective the assessment of graduates' performance after their education and training experiences to evaluate the quality of the education offered. For this purpose, the SAM project is developing tools to guarantee effective tracking of the students' performances at the end of their education cycle, thus contributing to the monitoring effort of the Commission in the AM sector.

3.5 Activities for children and students

Under the label 'Tech4Kids', SAM partners intend also to raise awareness among children and high school students through various activities. Cartoons, animated videos, tailored questionnaires and webinars have been developed to feature the creative aspects of jobs in AM, to inspire the future generation to pick a study path through an AM related career. The partners are also responsible to organize local AM Open Days targeting students, to promote and create awareness towards the AM technologies and their practical use.

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SAM: AN OPPORTUNITY TO ENHANCE AM EDUCATIONAL PROGRAMS THROUGH TRAINING CENTERS AND UNIVERSITIES

Borzoo Pourabdollahian, Farouk Belkadi & Alain Bernard - EC Nantes, 2020

1. The status of AM education in Europe

Additive Manufacturing (AM) is a promising technology that is expanding quickly in different sectors and domains. However, the wider adoption of AM is delayed by lack of suitability skilled workers. It is a fact that the development of the workers' qualifications drops behind the fast progress of AM technology evolution. To close this gap, therefore, European Commission has given special attention and investment to fund projects and initiatives focusing on developing skills and competences in the AM sectors. According to the result of mapping of projects in AM, conducted in the SAM project, a total of 48 projects were founded by 2019 (5 Erasmus+, 27 Horizon 2020, 16 others). This number corresponds to 29 on-going projects in the period 2019-2022 (14 Erasmus+, 12 Horizon 2020, 3 others). Moreover, according to the results of the AM-Motion mapping of AM educational initiatives, there were 41 courses and learning programs targeted different professional profiles on AM, conducted by universities and training centers across the Europe (AM-motion, 2018).

It is clear that education and research institutes across Europe will play an important role in shortening the existing knowledge and skills gap, through designing new educational programs. Fortunately, in recent years, advanced technological enhanced learning methods have enabled universities and educational institutes to offer specific courses, which address the needs and requests of the AM sector.

Two examples of AM courses for mechanical engineering students and the education of professionals are offered by Zurich University (Switzerland) and Afeka College (Israel).

Centre for Product and Process Development (ZPP) of the Zurich University of Applied Sciences ZHAW presents a training program for both students in mechanical engineering and in the counting education of professionals. This program consists of both theory and practice in the context of the Problem Based Learning method (PBL). Experimental learning and exploration in line with solving real problems achieves a balance between theory and practice in the accomplished learning outcomes. More importantly, the program brings not only a better understanding of the difference between AM technologies and conventional production process, but presents information from both an economic and ecological perspective (Kirchheim et al., 2017).

As another example, Afeka academic college of engineering proposed a novel AM course for mechanical engineering students.

This course followed PBL method with the aim of teaching AM technologies through handling challenges in real projects for manufacturing devices for disabilities. To measure the effectiveness of the course the performance of students was evaluated in every step of the course. The results showed a significant improvement both in technical (e.g. using AM-FDM technology, controlling the orientation of the printed objects, etc.) and soft skills (e.g. communication, team working, problem solving, etc.) (Stern et al., 2019).

2. SAM contribution and effort to elaborate AM education

2.1 Training survey

To gain a better understanding of the growing of number of specialized programs in AM education provided by universities, technical schools and vocational training centres, a survey to map educational practices among European institutes was conducted under the scope of the SAM project in 2020 The result of this survey is presented and discussed in the following section.

2.1.1 General Information

A total of 96 universities and training centers across the Europe participated in this survey. The majority of participants were from Spain (23), France (17), Italy (16) and Portugal (13), respectively. Considering the mode of training, only 27.5% of institutes offered on-line training, however in the last 6 months, due to the Covid-19 crisis, more face-to-face training has been shifting to a virtual environment. Moreover, the result showed the most targeted sectors for AM courses were Industrial equipment and tooling (68%), Automotive (59%), and Aerospace (50%), respectively.

2.1.2 Professional profile

When questioned which AM professional profiles are currently relevant and will be needed in the future, Process engineer was indicated as the most demanding profession both at the present and in the next 5 years with 75% and 91% relevance respectively, followed by AM Designer and AM Material engineers. As shown in Figure 1, it is expected that all surveyed professional profiles in AM will get a higher relevance in the next 5 years.

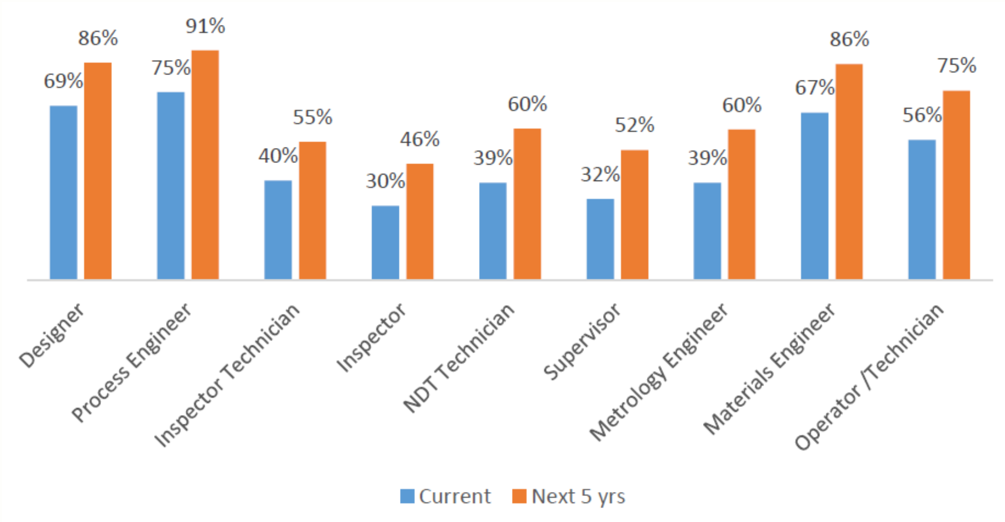


Figure 1: The relevance of Professional Profile at present and in the next 5 years

2.1.3 Taught skills

For Technological skills, the "AM process" was the most taught skill in AM courses as 91% of respondents mentioned its presence in the existing training courses, followed by "AM application" (85%). Regarding the missing AM skills in current available training courses, the SAM industry survey has indicated that only 18% of respondents stated that "Certification and Validation" was addressed in the AM courses, while for "Testing and Quality control" skills only 35% thought these skills were considered.

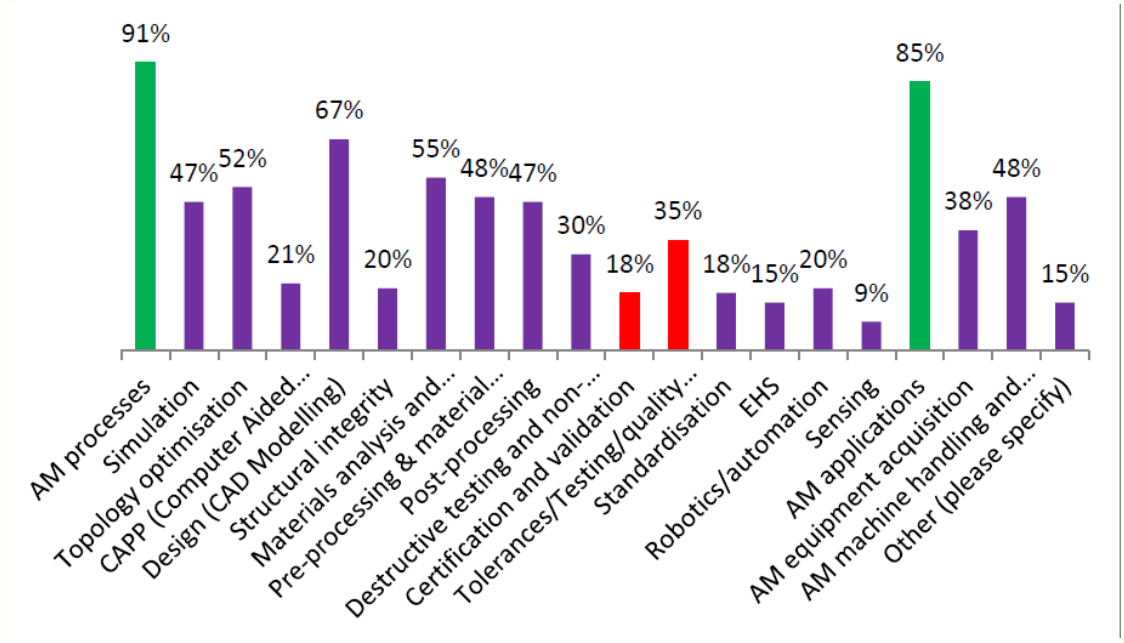


Figure 2: Distribution of Technological skills are being taught in AM courses

For Entrepreneurship skills, "Creativity" was the most taught skill in AM courses as 46% of respondents mentioned its presence in the existing training courses, followed by "Working with other" (42%),while the least one was "Mobilizing resources" (6%).

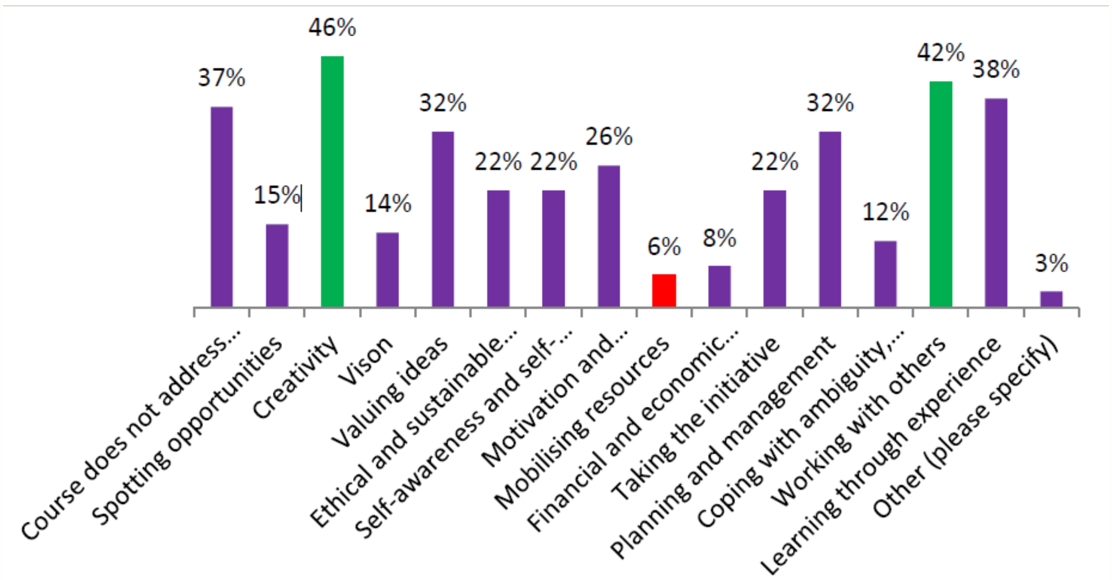
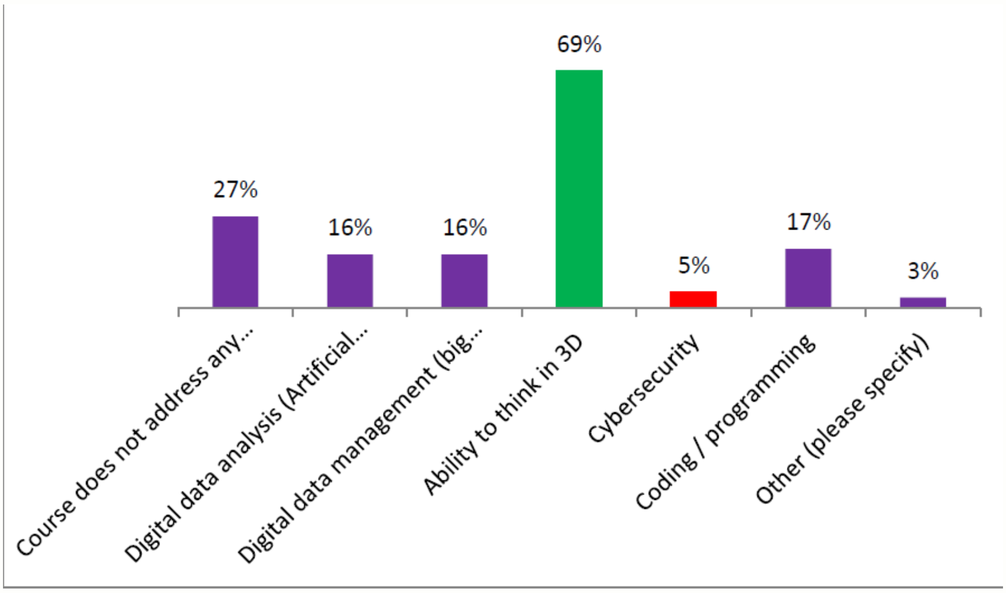


Figure 3: Distribution of Entrepreneurship skills are being taught in AM courses

For Digital skills, “Ability to think 3D” was the most taught skill in AM courses with 69% of respondents mentioned its presence in the existing training courses. The least one was considered was “Cybersecurity” (5%).



For Green skills, the most taught skill was “Eco-design” - 37% of respondents mentioned its presence in the training courses, followed by “Circular economy” (35%). The least skill considered here was “Green resources” (15%).

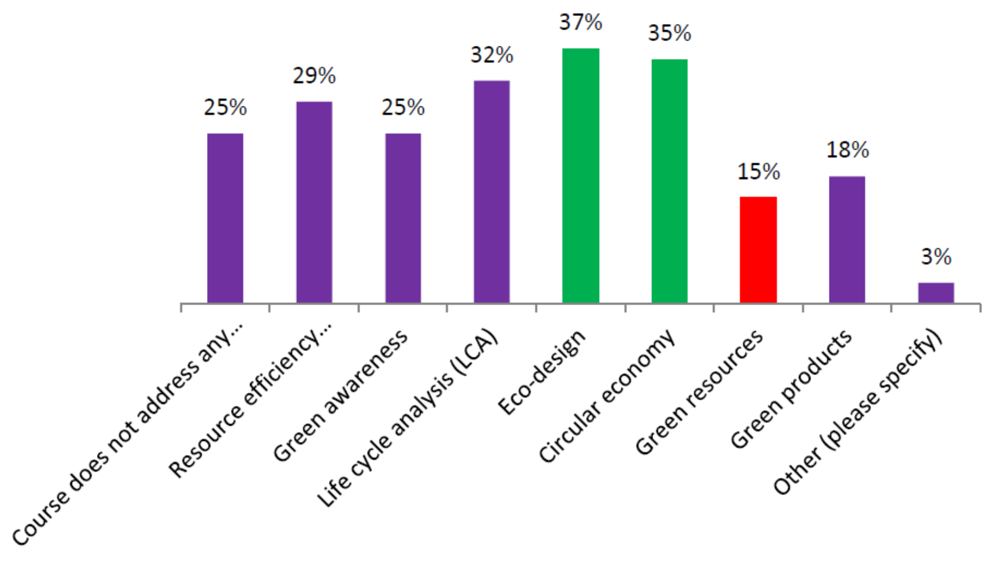


Figure 5: Distribution of Green skills are being taught in AM courses

2.1.4 Training tools

The SAM survey also measured the utilization of different training tools used in teaching AM skills in the training centers. The results have showed that “Lectures” generally was the most widely accepted tool in training the target skills (figure 6).

Namely it was the most popular tool for training Technological, Digital and Green skills with 89%, 67% and 80%, respectively. For the Entrepreneurship skill, it was the second acceptable tool (48%), where the most acceptable one was Case study (59%). Conversely, site visits were the least common of training tools, specifically for Digital and Green skills with 15% and 16%, respectively.

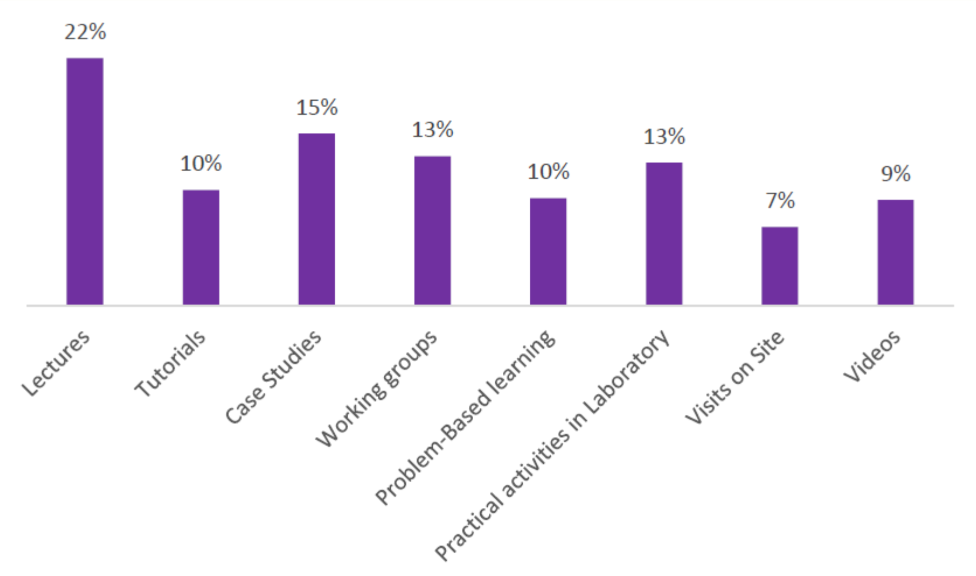


Figure 6: Distribution of usage different training tools in AM courses

2.2 SAM methodology to design professional profiles

A methodology to create and review professional profiles, qualifications, and units of learning outcomes has been developed under the scope of SAM project. Mapping the status of training contexts and training tools in AM education is one of the significant contributions of this methodology. The SAM report describes the currently in-use training contexts/tools consisting of "Advantages", "Constraints" and "Recommendations for AM training". Moreover, it includes examples of implementation of these training contexts/tools conducted by educational institutes from Germany, UK, and Spain.

3. AM education program in Ecole Centrale de Nantes

Ecole Centrale de Nantes delivers several lectures and courses to Engineering students and Master students. Some of those lectures are fully dedicated to additive manufacturing challenges such as: the lecture on Additive Manufacturing and Advanced Manufacturing Processes for the "Advanced manufacturing" Master students, or the lecture on Rapid Manufacturing for 2nd and 3rd year Engineering students, or the lecture Fabrication Additive (in French) for Mechanical Engineering students, delivered by Prof. Hascoët. Other lectures are not fully dedicated to Additive Manufacturing but some specific aspects are addressed, like choice and use of materials, delivered by Dr. Rauch, or CAD/CAM delivered by Prof. Hascoët and Dr. Rauch, or Computer-aided decision-making processes to improve technological performance, delivered by Prof. Bernard. This last lecture includes some practical examples on how to take into account different KPIs (cost, quality and delay) to fix technological aspects (like for example position and orientation of parts, or support structures.

A specific practical exercise for AM costing is also presented to the students and illustrated on different case studies. Projects are also proposed to bachelor students, by Dr. Le Neel.
Most of the teaching activities are also demonstrated on technological platforms, 3D printing machines, shared in the Product and Systems Engineering Department, and an advanced rapid manufacturing platform, used also for research and in relation with companies, managed by Prof. Hascoët.

4. Conclusions

Education for Additive Manufacturing needs to be developed and emphasized in the different lectures and training courses in addition of more conventional practices and skills (Pei et al., 2019). To achieve these goals, the SAM project aims to develop a network of certified training centers through Europe and to encourage the Implementation of European Qualifications that are recognised by different sectors supported by a Quality Assurance System. The International AM Qualification System (IAMQS) has been developed based on industry requirements and engagement/consultations with industry experts to address the needs of different sectors. Currently, the IAMQS comprises covers Metal AM Qualifications for Operators, Designers, Supervisor, Inspector, Coordinator and Engineers. Furthermore, there are plans to create new Professional Profiles/Qualifications and Competence Units/ Training Modules, which will be implemented and recognised across different sectors.

Within the Quality Assurance System underpinning the IAMQS, the scope and curricula for AM are defined at European level through harmonised training guidelines and then taken up at the national level by the training centres, under supervision of the representative organisation in the AM field. The existence of the organisation supervising both AM training and assessment activities at the national level is of utmost importance to ensure harmonisation and quality in the delivery of AM Qualifications. Making it possible to leverage a single syllabus for each level of Qualifications, resulting in the same qualification being awarded in Europe, regardless of the What is important is that in ten years from now, Additive Manufacturing can become as well-known as conventional technologies with all the necessary training and qualifications in place. The main challenge to reach this goal, on one side, is related to technological platform; and on other side, it is associated with a strong dynamic process of technological transfer between research and innovation. Europe will have to face this challenge and requires to help certified centers to increase the number of qualified experts, establish more comprehensive AM training and certifications and to extend their technological platforms with up-to-date technologies, representative of current and future practices.

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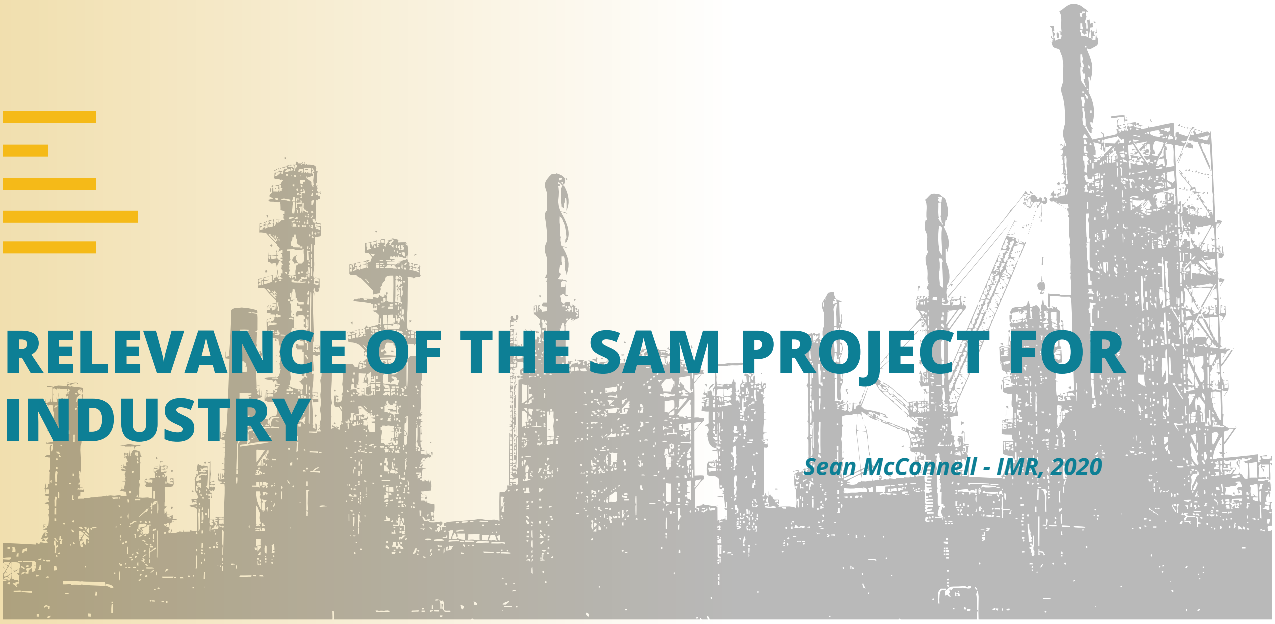

RELEVANCE OF THE SAM PROJECT FOR INDUSTRY

Sean McConnell - IMR, 2020

Additive Manufacturing (AM) is catching on. This may seem implicit given the hype and investment that is present in the industry, but with CAGR's of 25%+ being touted[1], it is no wonder that many of us adopted the various AM associated terms into our lexicon. "Think topology optimisation", "biomimicry" and "anisotropy".

Words that a lot of us are not yet using in our AM conversations are that of; "reliability", "repeatability" and "scalability". This is not to say that many companies are not engaging in these activities, but more to say that if we are to truly realise the potential of this technology, we must take the novelty it brings with a healthy dose of traditional engineering realism.

A core tenant of scaling a manufacturing process is that of standardisation. In order to ensure compliance and scalability we must first ensure that all aspects of the process are captured, understood and standardised. As the various working groups within ISO/ASTM F42 TC 261 (Additive Manufacturing) work hard to create the standards we all need for this technology, we also need to ensure that the skills and qualifications of the individuals working on this technology are standardised. This is where projects such as SAM (Sector Skills Strategy in AM) and the greater effort of the International Additive Manufacturing Qualification System (IAMQS) come in.

SAM is the Blueprint funded through the Erasmus+ programme to develop out industry specific qualifications and skills and the governance model for the proliferation of said qualifications/skills under the IAMQS. Having been funded through the EU, the project is actively engaged with industrial partners, with some forming part of the project consortium. This is critical as the purpose of the project is to serve the existing and coming requirements for qualifications and skills for AM training across all industries in Europe. Without the active participation of industry, projects such as this may run the risk of not satisfying the requirements of industry.

Anecdotally, we have seen companies beginning their AM journey looking for generalist staff to design for, operate and control this production process. In an ideal world these people exist and are transferable across the entire process chain, unfortunately the depth of knowledge required to get the best out of the process is such that it is not possible to fill a factory with generalists. This is where projects such as SAM come into their own. By providing role definitions and qualifications devised from industry led forums and workshops, we can leverage a system that makes the scaling of human capital for this technology possible, alleviating the difficulties in training new and existing staff. This in of itself has made projects such as this extremely relevant to industry.

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RELEVANCE OF THE SAM PROJECT FOR ACADEMIA

Maria Dimopoulou & Harry Bikas - LMS University of Patras, 2021

The Role of AM in the Sustainability Context

Additive Manufacturing (AM) is one of the fastest-growing sectors, with a compound annual growth rate (CAGR)1 of more than 20% [1]. In addition, owing to constant technology maturing, materials development, and integration with downstream processes, AM is becoming more industrially relevant.

Manufacturing industry is keen to use AM and explore the exciting new potential. The introduction of new technology has two implications; it creates an additional production step in the production chain, and it also increases the demand for expertise linked to this technology.

As such, the industry needs the right kind of professionals, with the appropriate skills to fully utilise the available technology [2]. Generally, manufacturing industries already have a skills gap that could leave two million manufacturing jobs unfilled according to Deloitte [3], with even fewer qualified personnel to support the growth in the AM field [4].

The current skills gap can be traced back to the misalignment of the AM industry with the knowledge and training providers that are further increased with the introduction or advancement of new complementary technologies and materials. For instance, a machine operator for a DED AM process, apart from the generic expertise for robot and AM head operation, is now required to operate in-line monitoring and control equipment. The high growth rate of the AM industry cultivates an equally high demand for skilled AM workers and engineers which combined with the limited in number and capacity of training and education institutions specialized in AM, results in the current insufficient status of the AM workforce and expertise.

Academia is very much involved in research linked to most of the developments in the AM field, assisting in maturing the technology and materials involved. Most academic institutions active in engineering fields are involved with research on AM technologies. In addition, most of them have implemented AM training courses in their curricula, in one form or another. However, each institution follows its own approaches and content, which may not follow the actual needs of the industry, and does not follow one unified approach in terms of both content and qualifications.

This is where SAM (Sector Skills Strategy in AM) and the greater effort of the International Additive Manufacturing Qualification System (IAMQS) come in. SAM is the blueprint funded through the Erasmus+ programme to develop out industry-specific qualifications and skills and the governance model for the proliferation of said qualifications and skills under the IAMQS. As referred to above in this text the purpose of SAM Project is to create one unified syllabus for AM.

The project is funded through the EU and is actively engaged with industrial and academic partners, with the aim of serving both the existing and upcoming requirements for qualifications and skills for AM training across Europe. This provides an opportunity for academic institutions to remain relevant in creating the right kind of professionals for AM. Through SAM, these institutions can shape and follow a unified framework for training and education, certifying and qualifying their students of AM.

Get Involved

If you are interested in learning more or engaging in developing skills in Additive Manufacturing mentioned above, please get in contact with us through the SAM website:

http://skills4am.eu/contactus.html

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IMPACT OF ADDITIVE MANUFACTURING TOWARDS THE ENVIRONMENTAL SUSTAINABILITY

Adelaide Almeida - EWF & Simona Masurtschak - LORTEK, 2021

The Role of AM in the Sustainability Context

In 2020, the European Union announced the "European Green Deal" [1] which aims to transform the EU into a modern, competitive and sustainable economy and should lead to climate neutrality in 2050. To achieve this, environmental awareness of Europe´s workforce will be of most importance to advance in creating a cleaner and more circular industry.

Ever since Additive Manufacturing (AM) appeared on the radar, it has been entitled as a "greener" manufacturing method compared to other conventional processes such as machining [2]. The reason for this is the layerwise "build-up" of material only where needed, rather than the subtraction of excessive material. Looking at the life cycle of an additively manufactured product, there is still a lot of potential throughout the single phases (eg., material, design, production, in-service and end-of-life) to even increase it. For example, during the design phase of a part, AM benefits from optimised geometries and lightweight designs which should reduce the material consumption and environmental impact during their lifetime [3]. Furthermore, direct repairing methods and "print-on-demand" lead to extended lifetimes and less waste.

The carbon footprint of an AM part is mainly influenced by the energy consumption during the manufacturing process (machine utilization) and emissions related to the production of the raw material and transportation in between [4]. In Figure 1 the sales revenue by technologies in 2020 is shown.

From this image, it can be seen that Metal and Polymer Podwer Bed Fusion (PBF) processes accounted for 55 % of the market share. Hence, these machines have dominated the production process in 2020 with a trend to further dominate the market towards 2025. In order to work towards sustainability in AM, especially the PBF process needs to be evaluated. To give an example: the process employs lasers in order to melt or sinter powder particles. To become more sustainable, factors such as high energy input (from the laser), processing time, energy loss or time for cooling need to be considered.

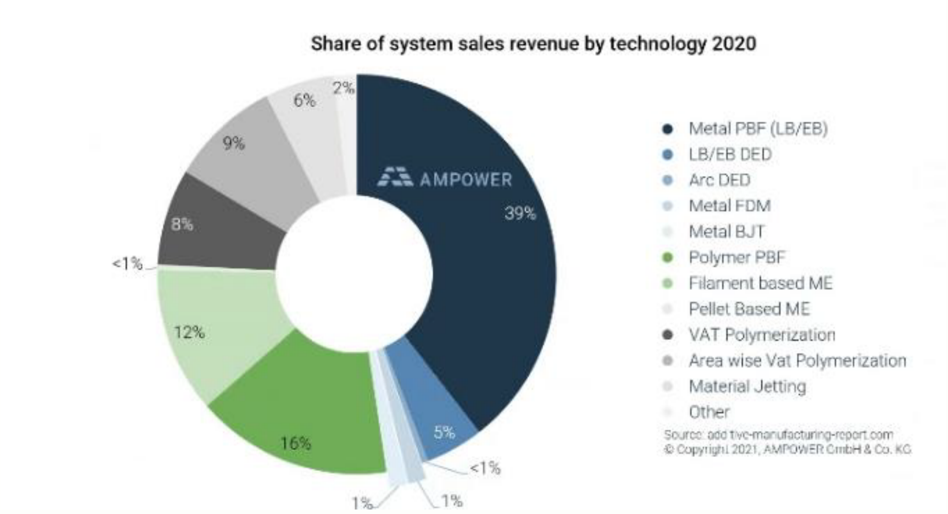


Figure 1 - Overview of System Sales in AM for the Year 2020 (copyright: AMPower 2021)

Furthermore, in both processes powder materials are used for which optimized recycling strategies and waste reduction will lead to more sustainable processes [5] [6]. Recently, MATERIALISE has stated that for Bluesint PA 12, the printing of 100 % recycled material is possible. In general, the optimization of a recycling strategy for metals will be easier than for polymers or composites [7] [8]. Furthermore, since AM is growing together with industry 4.0 and the age of digitalization, more complex materials 4.0 and higher energy-consuming machines will enter the optimization cycles necessary to work for a cleaner and sustainable environment.

As shown earlier, AM has the potential to strive in various different technical life cycle areas in terms of sustainability. There are, at least, two additional characteristics making AM more sustainable: the fact that it is a relatively young and fast-evolving technology already integrating industry 4.0 and 5.0 concepts allowing it to easily advance towards smarter and more resource-efficient processes; and its thrivingness to ever-adapting AM society that is constantly alert about the potentials and benefits towards "greener" environments.

The Role of Education for Environmental Sustainability

A change towards a resourceful, virtuous society and economy does not only involve the development of new and highly efficient products or service, but relies strongly on the adaptation and acquision of different skills [9] among current and future generations.

As many people will be facing new career challenges across different sectors in Europe, a wide range of workers will need to be re-trained for new skills or expand their existing skills to adapt to the changes of the labour market. To encourage the acquisition of green, digital and entrepreneurial skills alongside with technological skills, it is nowadays crucial to show the benefits of implementing sustainable aspects in different industrial ecosystems including AM.

Sustainability, environmental and climate goals are central elements of our society and have been regarded of high importance within the European Commission and United Nations Policy Agendas.
In this context, the "European Skills Agenda for sustainable competitiveness, social fairness and resilience" [10] aims to improve the relevance of green skills. It aims to encourage the integration of green practices in learning aspects and to support the development of green skills and competences. The United Nations Agenda for Sustainable Development until 2030 [11] provides a shared vision for peace and prosperity for people and the planet. At its heart are the 17 Sustainable Development Goals (SDGs), which are an urgent call for action towards ending poverty and other deprivations underpinned by strategies that will improve health and education, reduce inequality, and spur economic growth – all while tackling climate change and working to preserve the environment.

However, the 17 global goals are not achievable without an education for sustainable development (ESD), which includes an interdisciplinary sciences approach, transformational learning, and the active role of students. According to Guia [12] education for sustainable development (ESD) underlines the idea that education is a way to equip students with the necessary set of knowledge, skills, attitudes, and values throughout their lives to enact a sustainable development (or progress or growth).

This concept of ESD entails the continuous involvement of all levels and all forms of education, supported by relevant stakeholders representing education, industry and the society towards a greener future.

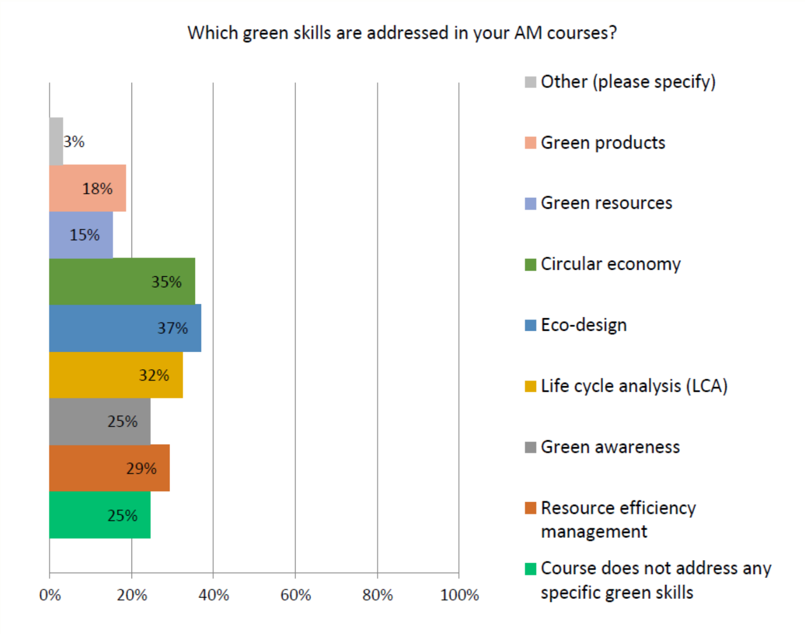
Results of Surveys from the EU-funded Project SAM

The SAM (Sector Skills Strategy in Additive Manufacturing) project is developing an European Observatory in AM that is identifying and anticipating the right skills and deliver them to the Industry. The project plays a key role in the consolidation of the International AM Qualification System (IAMQS) by delivering a comprehensive understanding of the appropriate AM skills-set and its delivery to industry through a network of European approved training centres.

Currently, the IAMQS covers qualifications in metal AM processing for Operators, Designers, Supervisors, Inspectors, Coordinators and Engineers and one qualification in polymers for Designers. The system is implemented through international quanlification guidelines (aligned with industrial requirements) and settles on robust quality assurance procedures to ensure an harmonised delivery of training in several countries and regions across the globe. Its modus operandi is designed in a modular and flexible way, which enables its continuous update of according to the industrial requirements.

In terms of sustainability, topics such as "life cycle assessment", "managing of waste", "recycling", "reuse" and "safe handling" of powders and materials appear in specific AM courses. However, a dedicated training programme per se, covering only sustainability aspects in AM, has so far not been included in the IAMQS. Yet, integrating this topic early in the skills process would be beneficial for the constant awareness of the European Union's green goals [1]. In 2020, SAM conducted a survey on the analysis of AM needs in which different skill gaps and demands in the AM sector were detected. More than 100 European training centres delivering AM courses were contacted to understand and map the educational practices employed. Through this survey it was possible to assess the mostly addressed skills, namely: technological (AM related), green, digital and entrepreneurial. Some common understanding about green skills concept is required at this point. According to CEDEFOP, "green skills" are defined as "knowledge, abilities, values and attitudes needed to live in, develop and support a sustainable and resource-efficient society [13]. Within the SAM project, green skills were categorized as the ones where the following concepts are employed: resource efficiency, green awareness, Life Cycle Assessment (LCA), eco-design, circular economy, green resources and green products. The categorization was based on the CEDEFOP Publication "Green skills and innovation for inclusive growth" [14].

Through the survey it was also possible to assess that eco-design, circular economy and green resources (by this order) are the green skills mostly addressed by AM training courses (Figure 2).



In a different survey, targeting the current AM workforce regarding the short term skill needs (2021-2022), results showed that workers find that green skills will become important (Figure 3).

For workers, the top three green skills which should be covered in AM courses are eco-design, circular economy and life cycle analysis (LCA). A similar perspective is shared by managers, since 86% of the ones inquired wishes for green skills to be developed within their workforce. The difference lays on the relevance attributed to the different topics (see Figure 4).

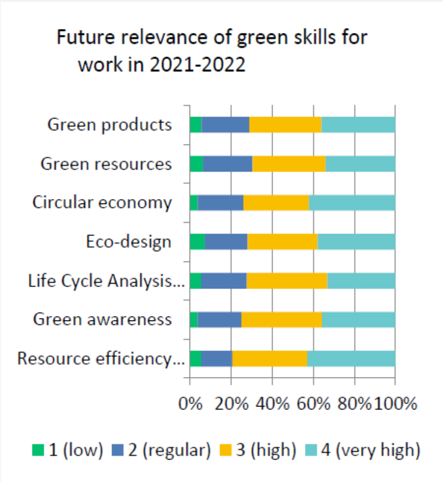


Figure 3 - Relevance of green skills for workers

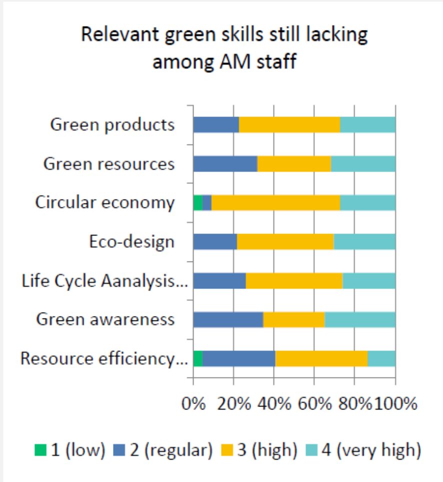


Figure 4 - Current Relevance of green skills according Companies

After the validation of the results by the Industry Council, one of the pillars of the European Observatory responsible for providing inputs on skills needed and for vigilating emerging research topics, and based on the above-mentioned findings, the SAM stakeholders agreed to develop a training unit (competence unit) on Sustainability for Additive Manufacturing. Within this competence unit, green awareness, circular economy and Life Cycle Assessment will be covered in order to raise their awareness of all AM Professionals, including AM Operator, Designers, Supervisors and Engineers, for the short Term.

Proposal of a new competence unit – Sustainability in AM

In order to address the topic of sustainability, a competence unit (CU) was developed for a basic level in alignment with the European Qualifications Level (EQF) [15] level 3, aiming at raising awareness on the importance of sustainability applied to AM.

It is expected, that after successfully completing the course, the students gain basic knowledge in:

- Understanding of economic and social contexts of sustainability policies such as "R" Imperatives, Green Deal, Sustainable Goals and etc.
- How to incorporate sustainability along the product´s life cycle
- How AM is currently implementing sustainability and the limitations and possible routes in sustainability (advantages and limitations)
- Within this course, the participants are expected to gain the following skills:
- Spot ideas and opportunities for alternative, more sustainable and simple solutions for daily AM activities
- Name advantages and disadvantages of AM sustainability topics
- Identify cases and/or examples for which AM may lead to more sustainable products
- Take the initiative to make suggestions for more sustainable choices along the AM product life cycle.

The course will be ongoing for a recommended time of 7 hours. This corresponds to 14 hours of workload in which participants can dive deeper into the topics via self-study. The knowledge and skills towards sustainability for AM will be evaluated via a short written assessment (multiple choice) at the end of the course.

Competence Unit - Sustainability for Additive Manufacturing	*RECOMMENDED CONTACT HOURS*
SUBJECT TITLE	
Economic and social context for sustainability policies	1
Sustainability along the product life cycle	1.5
AM within a sustainable production scheme	3.5
Case studies	1
Total	7
WORKLOAD	14

Table 1 - Subject title covered within Sustainability for AM Competence Unit

Future work

In order to understand how the green AM skills are delivered to the students, an assessment of the training tools and evaluation methods was also conducted during the survey to training organisations. The most employed training approach was lecturing, followed by case studies and on-site visits (Figure 5). In order to gain insight on the evaluation method the survey showed that evaluation of the skills is mostly carried out in working groups, followed by written examination, and thesis writing (Figure 6). Common tools, such as problem-based learning and laboratory practices were not gaining much attention.

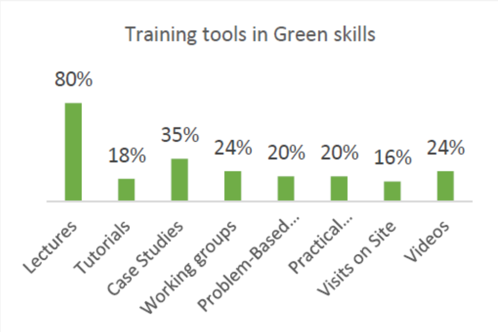


Figure 5 - Training Approach for Green Skills

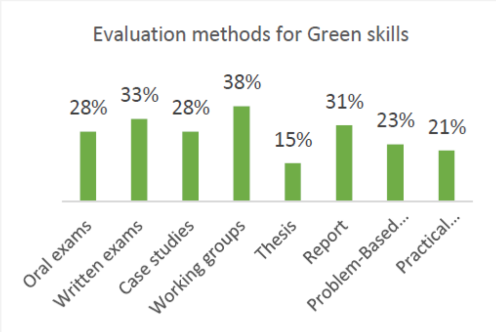


Figure 6 -Evaluation method for green skills

In this context, SAM future work will be focused in piloting the new Sustainabilty for AM competence unit, where the adequacy of the curriculum, as well as the relevance of the learning and assessment tools will be valiated among students and teachers.

Conclusions

The green deal requires a change and awareness for topics such as sustainability, efficient resource and energy handling, circular economy and eco-designs among Europe´s AM workforce. Even though AM is already on a path in which companies are becoming more aware of the "green" topics – yet a lot more has to be done to really create an efficient, sustainable and competitive AM industry for future generations. Within the SAM project, a course aimed at creating a sustainable mindset and generating knowledge in order to harvest sustainable solutions in AM has been created. The course will address the European Skills Agenda in which the integration of "green" aspects should be promoted.

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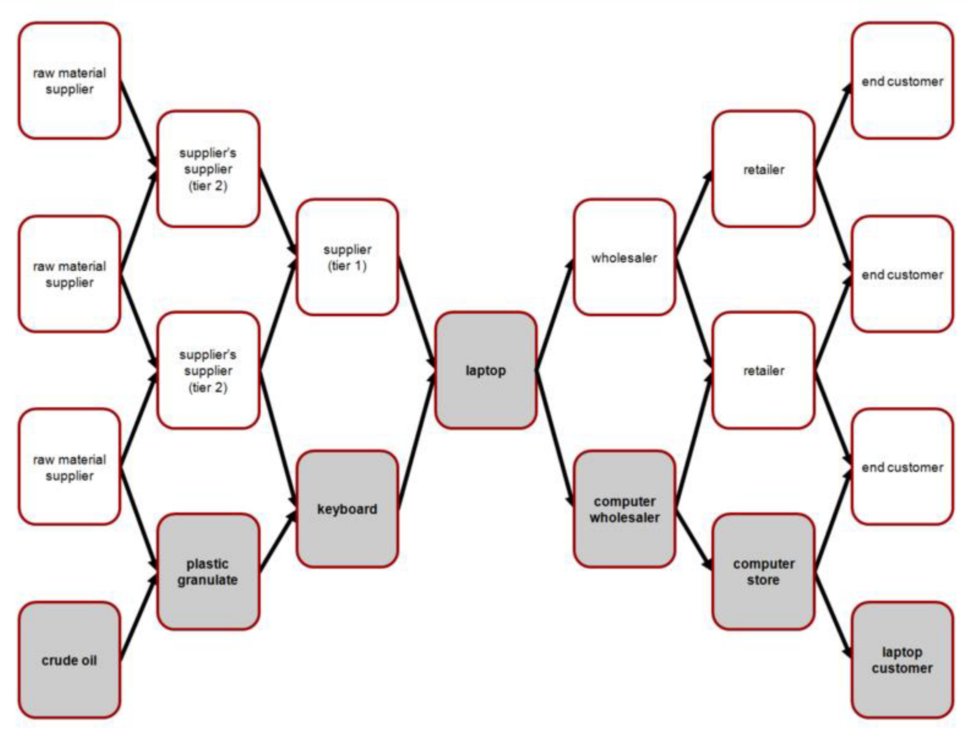
RELEVANCE OF NEW AM DEVELOPMENTS FOR AM SUPPLY CHAIN IN TERMS OF POWDER SUPPLY

Kenan Boz - EPMA, 2021

Introduction

A supply chain is a system of organizations, people, activities, information, and resources involved in supplying a product or service to a consumer. Supply chain activities involve the transformation of raw materials, resources and components into a finished product that is delivered to the end customer [1]. In sophisticated supply chain systems, used products may re-enter the supply chain at any point where residual value is recyclable. Modern consumers are expecting to receive their orders sooner than ever before. The digital marketplace continues to expand beyond the traditional retail business model every day and consequently, customer expectations grow. This has changed the way that supply chain professionals must work to ensure orders are processed and fulfilled.



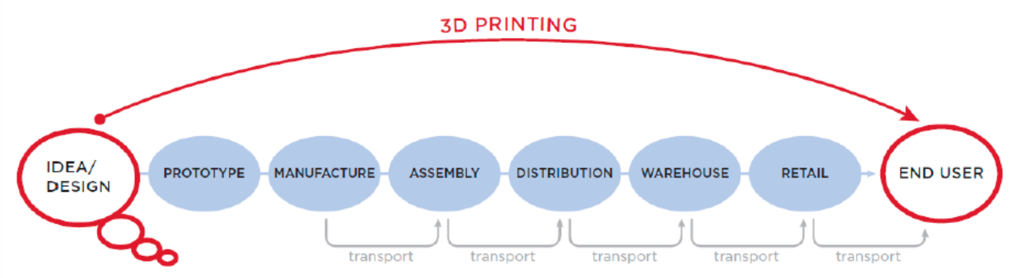
A typical supply chain (Figure 1) begins with the ecological, biological, and political regulation of natural resources, followed by the extraction of raw material, and includes several production links (e.g., component construction, assembly, and merging) before moving on to several layers of storage facilities of decreasing size and increasingly remote geographical locations, and finally reaching the consumer. Many of the exchanges encountered in the supply chain are therefore between different companies that seek to maximize their revenue within their scope of interest but may have little or no knowledge, or interest in the remaining players in the supply chain. Shortly, a chain is actually a complex and dynamic supply and demand network.

Additive manufacturing, which is known as 3D printing, turns digital 3D models into physical objects by building them up in layers. This technology enables small quantities of customized goods to be produced at relatively low costs. 3D printers are used in several and diverse industrial sectors, such as automotive, health-care, aviation, clothing and even in foodstuff.

3D printers give, in fact, the opportunity to manufacture several products, from replacement parts to dental crowns, artificial limbs. The method is seen as a disruptive technology for supply chain management because of its characteristics. Holmström et al. [4] highlight the following benefits of AM methods over the conventional manufacturing methods as:

- No tooling required
- Feasibility of producing small production batches in an economical way
- Possibility for quick changes in design
- Product optimization for functionality
- More economical custom product manufacturing with the capability to produce complex geometries
- Potential for simpler supply chains with shorter lead times and lower inventories

In addition to above benefits, there is the possibility of reducing material waste by as much as 90% according to a report by Markillie [5] on AM. Traditionally, raw materials or components are supplied from suppliers, assembled in manufacturers and shipped to customers through retailers or distribution centers. On the contrary, Additive Manufacturing technology enables organizations to bypass the traditional supply chain and manufacture a product themselves with a digital design (Figure 2).



Nowadays, many companies integrate AM Technology into their supply chains. The average annual growth rate of worldwide revenues produced by all products and services over the past 30 years of Additive Manufacturing is 26.7%, where the growth within the four years from 2016 to 2019 is more than 23%. The Wohler's report states that the total AM industry achieved a size of $12.7 billion by the end of 2020, and according to Lux Research from Boston-USA, the value of additively manufactured parts is to rise at a 15% compound annual growth rate (CAGR) from $12 billion in 2020 to $51 billion in 2030. AM is a growing means to produce both prototypes and products.

Powder Supply Chain

The production of AM metal powder generally consists of three major stages as outlined in the flow diagram shown in Figure 3. Briefly, the first stage involves the mining and extracting of ore to form a pure or alloyed metal product (ingot, billet and wire) appropriate for powder production; the second stage is the production of the powder and the final stage is classification and validation. The supply chain of taking ore and extracting a metal is well established and supplies a vast range of pure metals and specific alloys to global markets.

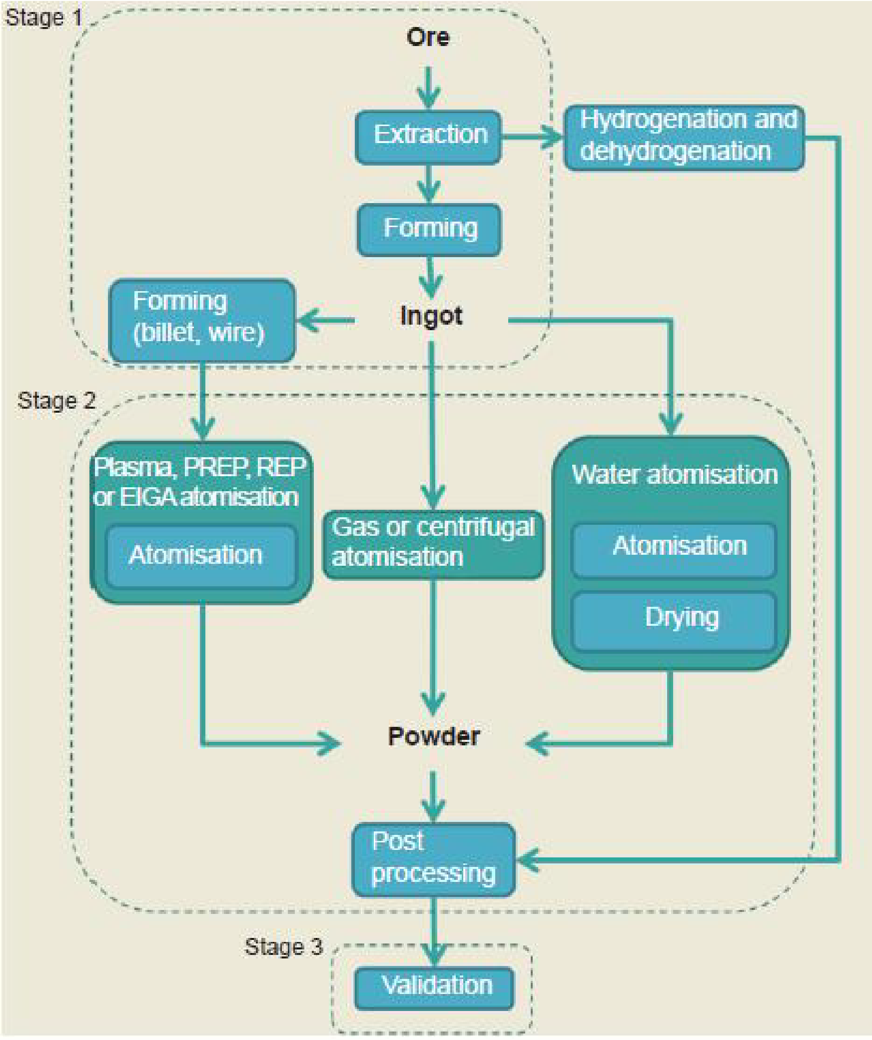


Figure 3. Powder production steps flow chart from ore to validated AM powder [6]

Once an ingot of the metal or alloy has been formed, a number of additional processing steps may be required to make the feedstock suitable for the chosen atomisation process. For example, plasma atomisation requires the feedstock material to be either in wire form or powder form, thus adding additional rolling and drawing work or a first step powder production route.

Manufacturing Process	Particle size, µm	Advantages	Disadvantages	Common uses
Water atomisation	0–500	High throughput Range of particle sizes Only requires feedstock in ingot form	Post processing required to remove water Irregular particle morphology Satellites present Wide PSD Low yield of powder for 20–150 µm	Cu, Al (Non reactives)
Gas atomisation	0–500	Wide range of alloys available Suitable for reactive alloys Only requires feedstock in ingot form High throughput Range of particle sizes	Satellites present Wide PSD Low yield of powder between 20–150 µm	Ni, Co, Fe, Ti, Al
Plasma atomisation	0–200	Extremely spherical particles	Requires feedstock to either be in wire form or powder form High cost	Ti (Ti64 most common)
Plasma rotating electrode process	0–100	High purity powders Highly spherical powder	Low productivity High cost	Ti
Centrifugal atomisation	0–600	Wide range of particle sizes with very narrow PSD	Difficult to make extremely fine powder unless very high speed can be achieved	Solder pastes, Zinc of alkaline batteries,
Hydride–dehydride process	45–500	Low cost option	Irregular particle morphology High interstitial content (H, O)	Ti6/4

Table 1 : Powder Characteristics by Manufacturing Processes [6]

As mentioned above, there are a number of methods available to produce metal powders including such as solid-state reduction, electrolysis, various chemical processes, atomisation and milling. Historically, for reasons rather commercial, atomisation has been identified as the best way to form metal powders for AM regarding the geometrical properties of the powder it yields. Table 1 summarizes powder characteristics obtained by different manufacturing processes.

Importance of Particle Size and Morphology

Particle morphology has a significant impact on the bulk packing and flow properties of a powder batch. Spherical, regular, and equiaxed particles are likely to arrange and pack more efficiently than irregular particles. Research into the effect of particle morphology on the AM process has shown that morphology can have a significant influence on the powder bed packing density and consequently on the final component density; where the more irregular the particle morphology, the lower the final density. As a result of this, highly spherical particles tend to be favoured in the AM process. Figure 4 shows various morphologies of iron powder achieved by different production methods.

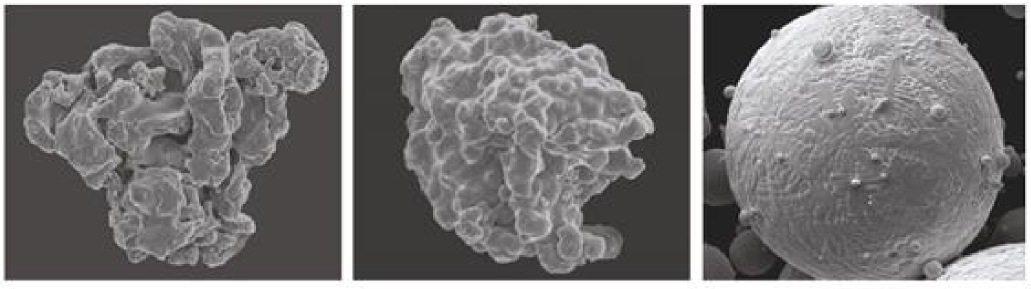


Figure 4: Examples of powders with different morphologies. [8]

The particle-size distribution (PSD) is a list of values or a mathematical function that defines the relative amount of particles present according to size. It can offer the information regarding the particle size span width, and D10, D50, and D90 (as known as D-value or three-point specification) is the most widely used values in PSD analysis. Those values indicate the particle diameter at 10%, 50%, and 90% of the cumulative distribution. Characterisation of Particle Size Distribution (PSD) in a batch of powder ensures that the optimum range of particles, by size, are used in each process.

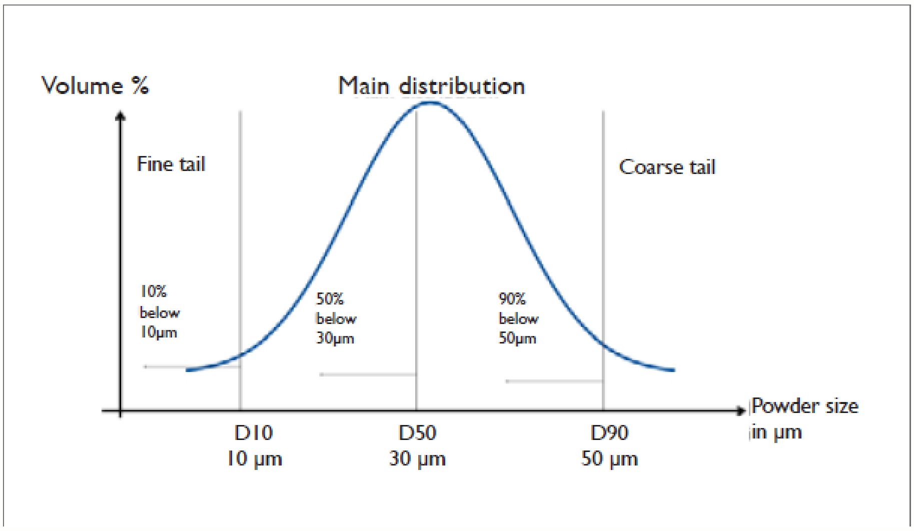


Figure 5: Example of D10, D50 and D90 on a PSD curve for a 10-50 microns powder

In general, Electron Beam Melting uses a nominal PSD between 45–106 μm, whilst L-PBF uses a finer range between 15–45 μm, and Binder Jetting between 5–30 μm. PSD will have an obvious impact on both the minimum layer thickness and the resolution of the finest detail in the component.

An inappropriate combination of PSD and layer thickness can potentially lead to in situ segregation due to the mechanical re-coater pushing coarser particles away from the bed, segregation in this sense could lead to variation in build quality in the vertical direction. It is generally well reported that using powders with a wide PSD and a high fine content produce components with a higher fractional density. However, the use of fine materials increases the risk of health and safety issues. This is particularly true when processing reactive materials such as titanium where finer particulates are likely to be more flammable and explosive. In 2011, a terrible accident took place at Hoeganaes facility in Gallatin, USA with 3 injuries and 5 deaths, due to an explosion of fine metal dusts at nanoscale that were piled up in various areas of production [7].

Impact of AM

Powder flowability is an important technological requirement for powders used in AM. The density homogeneity of the final part depends on the layer-by-layer melting being performed on thin and uniform layers that are accurately deposited by the feeding device. Cohesive powders which exhibit poor flow properties are likely to be more problematic in terms of obtaining homogenous density layers throughout the build than powders which are comparatively more free flowing. Powder flow is difficult to relate to any one given parameter of a powder but there are some general rules which can typically be applied:

(a) Spherical particles are generally flowing better than irregular or angular particles
(b) Particle size has a significant influence on flow. Larger particles are generally more free flowing than smaller particles
(c) Moisture content in powders can reduce flow due to capillary forces acting between particles
(d) Flow properties often show a dependency on the packing density at the time of measurement – powders with a higher packing density are less free flowing than powders with a lower packing density
(e) Short range attractive forces such as van der Waals forces, electrostatic forces and humidity can adversely affect powder flow and may cause particle agglomeration (short range forces have a bigger impact on finer particles)

Although spherical particles with a good flowability are considered to be the most effective ones for AM, as different technologies of AM evolved within the recent years, each one has come out with different requirements of particle size distribution, as mentioned above.

Impact of AM

Using additive manufacturing in the supply chain brings in many advantages in comparison to conventional manufacturing methods. There is less room for human induced error in the supply chain with AM. This results in a 'first time right' production with a lower lead time. Direct shipping becomes an option in the supply chain with AM, and manufacturers can reduce their dependency on different suppliers.

AM drives in decentralized manufacturing, where logistics companies will no longer have to transport finished goods though the globe. However, the last mile delivery of products will increase. Companies need to be agile enough to counter disruptions of this magnitude. The Logistics provider in fact becomes a manufacturer within this new world.

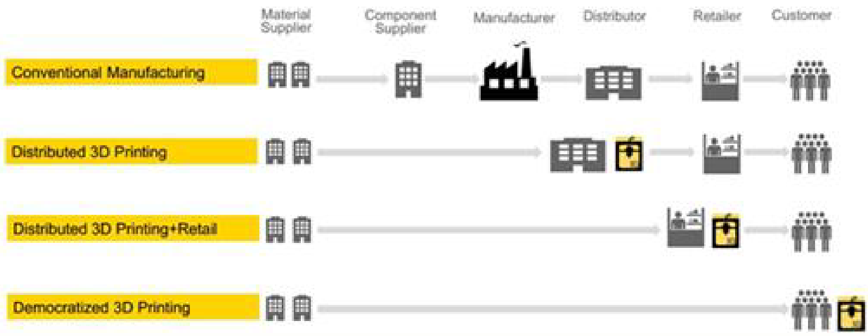


Figure 6 : AM at various levels in the supply chain [9]

AM is definitely creating a brand-new market for powder suppliers, but on the other hand, AM requires more strict qualifications of material supply in terms of metal powders. This narrows the band of usable powder in an ordinary powder production, making the efficiency decrease in comparison to production of powders used in conventional methods such a Press & Sinter. Because of this, price per kilo of powder for the AM market is much higher than the price for the traditional PM market. According to a past report by Roland Berger, increased competition for powder supply reduces today's markups and increasing production volume reduces costs. As an example, steel powder price for AM in 2013 that was more than 90 Euro/kg on average, has dropped down to less than 50 Euros/kg in 2021, which is actually still expensive more than twice the price of the conventional steel powder. As AM industry gets mature, material prices will settle down to reasonable values in the market.

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RECOGNITION OF PRIOR LEARNING: AN AGILE MECHANISM FOR UPSKILLING IN THE FIELD OF ADDITIVE MANUFACTURING

David Santos González & Paula Queipo Rodríguez - IDONIAL, Adelaide Almeida - EWF, Borzoo Pourabdollahian - EC Nantes, 2022

Summary

The SAM Project (Sector Skills Strategy in Additive Manufacturing) is addressing the need at a European level to develop an effective system to identify and anticipate the right skills for the demands of the Additive Manufacturing (AM) sector, in response to the growing needs of the labour market. In this context, one of the main challenges is, in addition to developing accreditation schemes based on training pathways, to recognise and validate the skills of professionals currently working in AM fields. SAM contributes to the recognition of these professionals, through the introduction and validation of Recognition of Prior Learning (RPL) methodologies within the AM training and accreditation scheme promoted by the European Welding Federation5, the IAMQS6 (International Additive Manufacturing Qualification System).

1. The challenge of finding the right skills-set when technological progress is highly disruptive as in the additive manufacturing field

The possible pathways when an organization aims at "ensuring" novel skills among their staff are quite evident: train current personnel and/or hire new personnel who already have those skills. Both alternatives can be achievable as long as skills are easily recognizable, through clear and identifiable training, qualification and accreditation schemes. However, when these skills are related to disruptive technological and/or methodological advances, difficulties arise. Being one of the key manufacturing advances in the last decades, AM currently faces this issue as one of the most important barriers for its full exploitation.

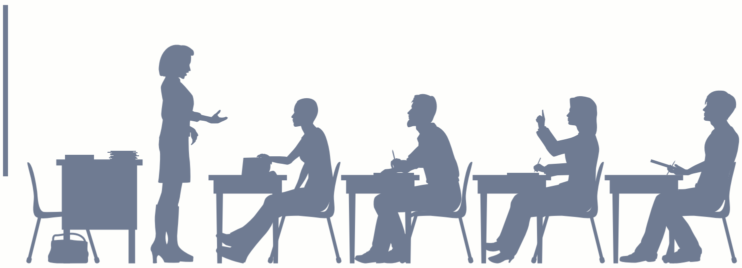
AM is a technology with incredible capabilities, derived from the possibilities of manufacturing directly from a 3D file, the growing base of technology providers and materials, the increasing amount of success stories around them, etc., with potential use in any organization that develops and/or manufactures products. Despite these characteristics, a detailed approach to the different AM technologies reveals different levels of complexity, and beyond some conceptual common points between the 7 groups of technologies currently recognized by the ISO/ASTM 529007 standard, the differences between the specific technologies can be very significant. This applies to the technologies/machines themselves, their manufacturing capabilities, the design rules of application to each one of them, and finally, to the skills required to achieve and efficient implementation of one specific AM technology.

As a technological advance causing a big impact on the industry, different training initiatives have aroused around AM in recent years, but they are focused on limited and/or very specific subjects, and represent isolated efforts for providing knowledge and for generating skills on AM, lacking in recognition at levels beyond the framework that have designed and implemented them, thus most of them lack a wider, international and intersectoral recognition by industry.

2. Generating widely recognized knowledge and experience schemes around AM

If it was exclusively taken into account what have been described in the previous sections, the outlook would be that AM holds a great potential from a technological point of view, but that the lack of wide and internationally recognizable schemes of skills can act as an important barrier for a wider and better industrial implementation. The good news is that remarkable efforts are being made to provide the market with a clear skills training, recognition and accreditation scheme around the different AM technologies. The International Additive Manufacturing Qualification System (IAMQS), for example, is being promoted and developed thanks to the impetus of the European Welding Federation (EWF8), with the support of its partners in the European funded projects CLLAIM9, SAM10 and ADMIRE11, that are coordinated to define and develop:

- AM professional profiles, for different industrial AM technologies.
- Competence units that structure and define the required knowledge and skills for the different AM professional profiles.
- Training pathways, through which potential candidates can obtain recognition and accreditation against the defined competence units and professional profiles.
- Methodologies and tools for the training, evaluation and accreditation of candidates.
- Pilot activities, aimed at validating the identified methodologies and tools.

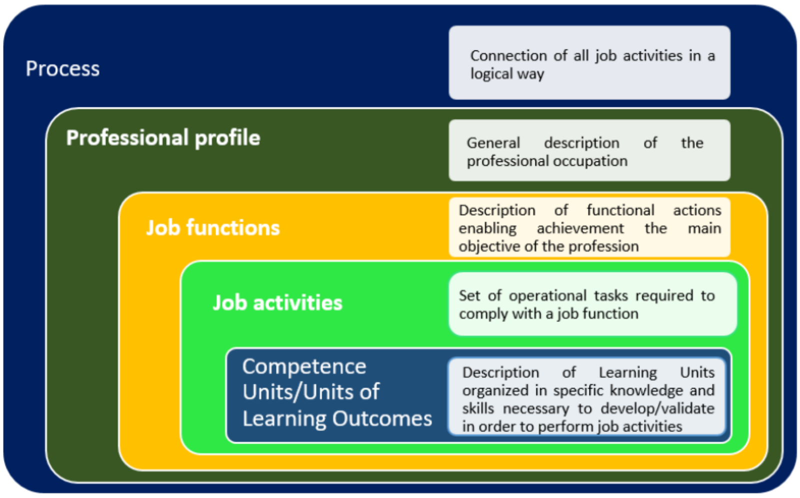


Thanks to these activities, EWF and its partners are producing an internationally recognizable scheme for training and accreditation around AM technologies, aligned with industrial requirements, to which training organizations will be able to associate, and which is the most important effort of standardization of the provision and the recognition of skills around these technologies at European level.

3. IAMQS: a single scheme, several pathways to develop and accredit skills in AM

IAMQS is therefore a training and qualification system that ensures skills recognition and accreditation scheme in the field of AM. IAMQS offers a training-type pathway, which allows the trainee to:

- Identify the fields of AM in which to be trained and/or accredited, based on the different professional profiles available, for the different AM technologies covered by the system.



- Based on the selection of a professional profile, the trainee will be trained in the related competence units, and prove, when appropriate, that he/she has earned the required theoretical and/or practical knowledge for each of them.

- Based on passing the tests and demonstrations (when applicable) for the different competence units, demonstrate having all the necessary knowledge and skills foreseen for a specific professional profile.

The progression within the IAMQS assumes that the trainee starts from low levels of prior knowledge and experience, and therefore demands that she/he will be trained on the different competence units, to undergo then an examination phase. Under this itinerary, positive evaluation for the different competence units allows the candidate to obtain partial or complete qualification for a specific AM professional profile.

However, it is necessary to take into account that although AM is a discipline perceived sometimes as novel by the general public, many professionals have already developed important skills around it, based on previous training activities, based on their own professional activity, or thanks to a combination of both. In this sense, the IAMQS system contemplates a second pathway, which relies on a Recognition of Prior Learning (RPL), that is, the recognition and validation of previously obtained skills without the need to undergo a training process, in line with the same professional profiles and competence units' scheme.

Thus, under IAMQS, three possible pathways for qualification in the field of AM are contemplated:

1) Training itinerary: the trainee can be trained in the required skills for each AM professional profile and competence units, by attending courses developed around them, and by successfully passing the respective qualification exams.

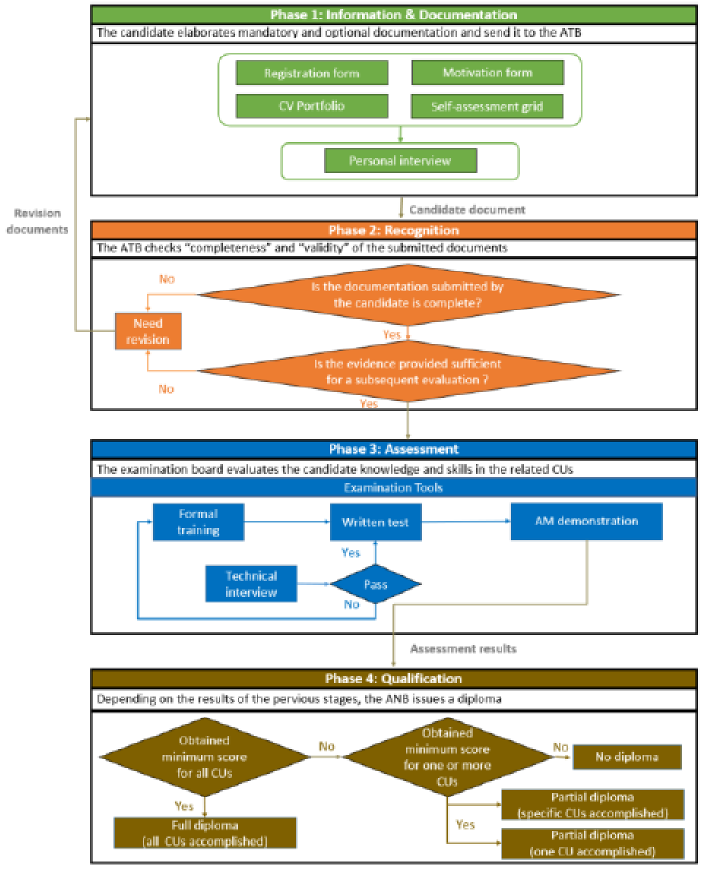
2) RPL itinerary: the candidate can present and show evidences related to skills already obtained on a selected AM professional profile and competence unit/s, which may give the candidate the right to access the qualification exams, without the need to receive a prior training.

3) A “mixed” itinerary, in which the candidate can choose a Training or RPL itinerary for each competence unit, depending on the candidate´s prior level of knowledge and skills.

Especially for experienced AM professionals, the RPL pathway is therefore of high interest, as it provides a skills accreditation alternative that is able to take into account their past experience, compatible with their working activity and time availability. Of course, RPL does not exclude that the candidates can choose to undergo a training in competence units where their skills are less developed.

3. Recognition or Prior Learning within the International Additive Manufacturing Qualification System scheme.

The basic application of RPL in the context of IAMQS was originally developed in the CLLAIM project for the Metal AM Operators, Designers and Supervisors, and later on refined in the SAM project for the Metal AM Engineer Profile. The following diagram shows the main phases of the process:



Taking into account that the previous scheme is applicable for each competence unit, the fundamental steps can be summarized as follows:

- Phase 1: Information and documentation. To access the process, the candidates must provide (to an authorized training body, ATB, authorized to provide training within the IAMQS scheme) with sufficient information to evaluate their profile. In this way, the candidate provides data and documentation on previous background in relation to the profiles and competence units to which the candidate is applying.

- Phase 2: Recognition. The information provided in the previous phase is evaluated by the ATB, determining if the candidate can access the accreditation process via RPL, or if the candidate must take the training courses that correspond to each competence unit in which the previous knowledge and experience shown by the candidate may be evaluated insufficient.

- Phase 3: Assessment. If as a result of the previous phase the candidate has been considered suitable for being assessed under a RPL itinerary for a specific competence unit, the candidate is subjected to a technical interview, based on a questionnaire that is specific to each competence unit. Passing successfully the interview entitles the candidate to take the written accreditation exam for said competency unit (as well as the practical demonstration, if demanded by the competence unit as part of the process); not being passed in the interview would lead to a recommendation for the candidate to undergo a training itinerary for said competence unit.

- Phase 4: Qualification. This is a common stage for any of the pathways, in such a way that:
  - The overcoming of each competence unit will provide the candidate with a partial accreditation for the correspondent competence unit.
  - A complete accreditation for a professional profile is obtained when all the competence units for that professional profile are overcome.

5. IAMQS and RPL as a recognition and accreditation option for current professionals in additive manufacturing.

New technologies traditionally pose challenges when it comes to creating training paths and alternatives for skill recognition. Schemes exclusively focused on mandatory training activities, which are key options for accessing a qualification, are insufficient nowadays, at a time in history when technology advances are fast and with many ramifications, that these schemes alone can't satisfy the demands, either for skills creation, but especially for skills recognition. Besides, the number of professionals accumulating skills in AM through direct experience in work environments is consistently growing. Fortunately, a scheme such as IAMQS provides an additional RPL itinerary, capable of providing these professionals with a more direct path to obtaining skills recognition and a professional profile accreditation.

6. Final remarks

As previously described, SAM project is an important initiative in the implementation of an internationally recognizable scheme for developing and accrediting skills in AM. If you want to know more about the process that has been followed to create and update IAMQS professional profiles, we encourage you to consult the public documents that have been generated in the context of the SAM project in its Work Package “Methodology for developing and revising professional profiles and skills”.

METAL BINDER JETTING: TAKING METAL ADDITIVE MANUFACTURING INTO HIGH VOLUME PRODUCTION

Usama Attia & David Wimpenny - MTC, 2022

1. Sinter-Based Additive Manufacturing

Sinter-Based Additive Manufacturing (SBAM) has witnessed significant growth in the recent years in terms of technologies and applications. SBAM encompasses a family of AM processes based on binder jetting, material extrusion, jetting and vat polymerization (explained in more detail later). All of these routes utilise a final solid-state sintering step to 3D-print metal and ceramic components. In SBAM a sacrificial binder is typically used to join the metal or ceramic powders, forming partially consolidated 'green parts' that are subsequently processed (thermally or chemically) to remove the binder (debind) and densified using conventional sintering in a furnace. The underlying principle behind SBAM technologies is that, unlike traditional 'beam-based' AM, the 3D-printing (shape-forming) step is decoupled from the densification (sintering) step, leading to a multi-step process [1]. This decoupling enables a fully solid-state process route that has a number of key advantages:

- Overcomes the technical challenges associated with powder bed fusion processes that involve melting materials within the build process, such as the need for support structures or heat sinks to manage residual stresses.
- Unlike traditional processes, it does not limit the range of materials to weldable alloys.
- It allows materials with high melting point such as ceramics and refractory metals, to be processed.
- The decoupling of shape-forming and densification increases the throughput of both stages and, hence, enables an increase in overall process yield, especially for small components.
- By avoiding the need for thermal management during part forming step allows the build process to operate at room temperature, making it relatively scalable and allowing for large build volumes to be achieved in recently released systems.

These advantages have attracted increasing interest from industry and resulted in the adoption of SBAM technologies across multiple sectors, such as automotive, medical, aerospace, electronics and jewellery. Technological developments in SBAM have seen rapid increases in recent years, and currently there are 4 specific methods of SBAM, as shown in Figure 1.

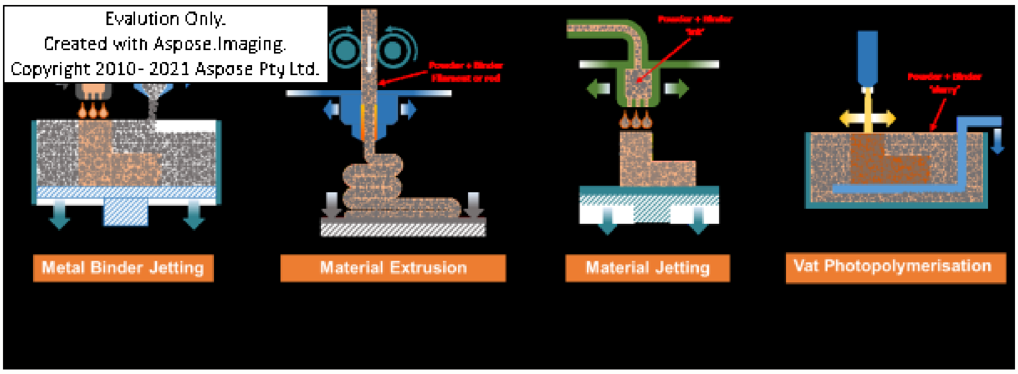
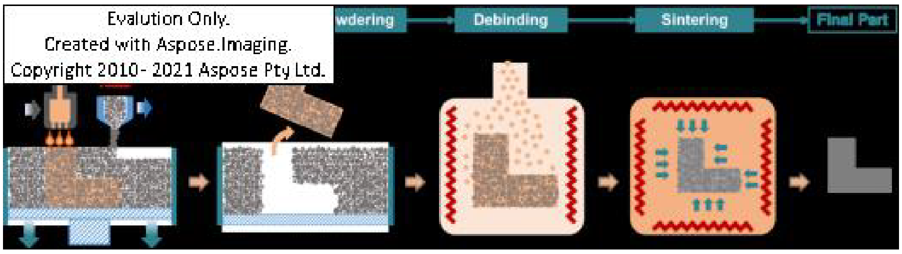


Figure 1: An overview of the main types of sinter-based AM technologies

2. Metal Binder Jetting

Amongst the SBAM processes shown in Figure 1, metal-binder jetting (MBJ) has been one of the fastest growing and earliest to be adopted by industry. In MBJ, metal powder and a binder "ink" are sequentially layered to form a 'green part' which then goes through a debinding step before being and sintered to almost full density (>98%). Figure 2 shows a schematic diagram of the process.
Figure 2:



The process starts with a CAD (Computer Aided Design) file of the part, which is sliced into layers and converted into a printable file format. A layer of metal powder is then deposited and spread over the area of the build box using an applicator. The binder is then selectively deposited on the powder layer following information received from the sliced CAD file, similar in a way to conventional ink-jet printing. The process continues with sequential depositing of powders and binder layers until the print is complete, upon which the bonded 'green' parts are removed from the build box and the surrounding loose powder is recycled. The green parts are then subjected to thermal debinding to extract the binder material forming partially-consolidated 'brown parts', which are subsequently sintered close to full density with the part shrinking to compensate for the space previously occupied by the binder. This shrinking must be considered at the design stage – much like the shrinkage that occurs in the injection moulding of polymers.

3. Advantages and Limitations of MBJ

In addition to the general advantages of SBAM processes discussed earlier, MBJ has the following specific characteristics, which has contributed to its accelerated adoption by industry:

- The powder-bed nature of the process eliminates the need for support structures during printing, which allows for utilising the full build box via part 'nesting' and, hence, increase process throughput.
- The fine particle sizes of powders typically used in binder jetting enables good feature definition, high dimensional accuracy, and excellent surface finish properties.

As shown in Figure 3 produced by AMPower [2], these advantages have placed MBJ in a competitive position compared to other AM technologies and as a credible potential alternative to other traditional processes, such as casting.

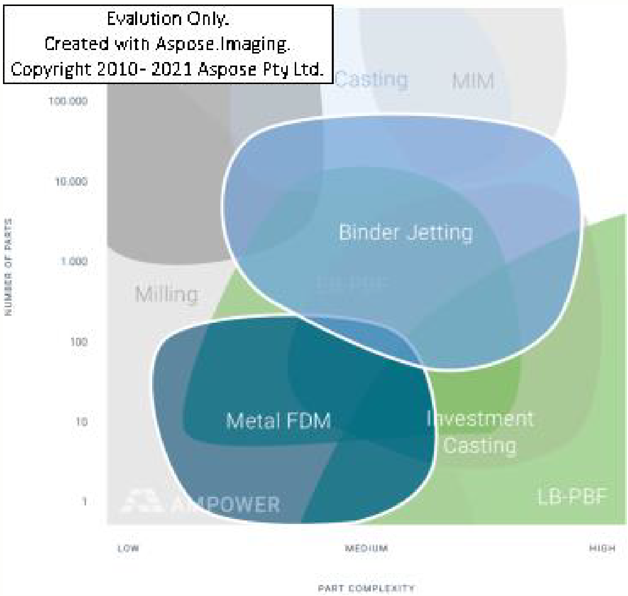


Figure 3: Technology impact in terms of production volume and part complexity (Image source: AMPower [2])

On the other hand, MBJ has a number of limitations, such as:

- The decoupling of printing and densification results in a multi-stage process (printing, drying, debinding and sintering), which is typically longer and more laborious than conventional AM and requires careful control of every stage.
- Sintered parts typically have a level of porosity, which for some applications would require post processing, e.g. HIP (Hot Isostatic Pressing) , to reach full density.
- Like all sinter-based technologies, design options for MBJ are limited by factors related to sintering challenges, such as non-uniform shrinkage and deformation of unsupported features. This in turn puts limitations on part design, such as overall size and wall thickness.
- The use of relatively fine powders in MBJ poses technical challenges (e.g. layer deposition), health and safety challenges (e.g. handling and storage) and cost challenges.

4. Recent Developments in MBJ

In order to overcome challenges that hamper the industrial adoption of MBJ, developments have focused on three primary areas: widening material options, enhancing part quality and increasing process throughput.

With regards to materials, a range of alloys have been successfully printed using MBJ in industry and academia, such as stainless steel 316L [3,4], stainless steel 420 [5,6], copper [7,8,9], Inconel 625 [10,11], Inconel 718 [12,13], titanium [14], Invar36 [15] and shape memory alloys [16]. Beyond metals, binder-jetting has also been used to 3D-print ceramics, polymers and biomaterials [17]. Machine producers keep certifying new materials for their specific systems, and recently more 'open' systems have been made commercially available, which would accelerate the development of new materials.
With regards to enhancing part quality, developments have focused on enabling consistent and defect-free parts. This includes improving powder properties (e.g., size distribution, flowability and wettability), improving binder properties (e.g., saturation) and controlling key process variable (KPV's), such as layer thickness, orientation, and droplet generation [18]. In addition to reducing defects and improving process fidelity, these improvements have also led to parts with higher dimensional accuracy and surface finish. Benchmarking studies have shown that MBJ could produce parts with linear features down to 150μm and surface finish down to 10μm (Sa) [19], making it suitable for applications that require high accuracy and excellent surface properties.

The third area of technical development is increasing process throughput. As discussed earlier, SBAM technologies are inherently suited for batch production due to the decoupling of printing and densification. However, relatively slow printing speeds and limited build volumes have been a significant limitation on process throughput and, hence, the full potential of productionising has not been exploited. Recent developments have focused on increasing process throughput by increasing build volume and build rate. Table 1 lists examples of some MBJ systems and their capacities.

Provider	System	Build Volume	Maximum Build Rate [cm^3/hr]	Minimum Layer Thickness [μm]	Ref
Desktop Metal	P-50	490x380x260 mm (48 Lt)	12,000	30	[20]
Desktop Metal	X160 Pro	800x500x400 mm (160 Lt)	3,120	30	[21]
Digital Metal	DMP/PRO	250×217×186 mm (10 Lt)	1,000	35	[22]
GE Additive	Series 3	500x500x500 mm (125 Lt)	n/a	n/a	[23]
HP	HP Metal Jet	400x320x200 mm (25 Lt)	n/a	50	[24]

Table 1: Examples of MBJ systems and their specifications

Across all the areas of development, modelling and simulation have been key enablers to overcome process challenges. This includes simulating aspects of both the printing (including binder droplet impact and penetration [25,26]) and sintering process (including shrinkage and deformation [27,28]).

Automation is another development area that is gaining increasing priority due to the laborious nature of the process. Digital Metal, for example, has worked on an automated system for de-powdering MBJ build boxes, which is currently a bottleneck in the process [29].

5. Market Trends and Commercial Uptake

The rapid developments in MBJ have brought the technology closer to commercialisation. Figure 4 shows the 2020 Maturity Matrix of Additive Manufacturing developed by AMPower, where MBJ was forecast to reach industrialisation in less than 2 years [30].

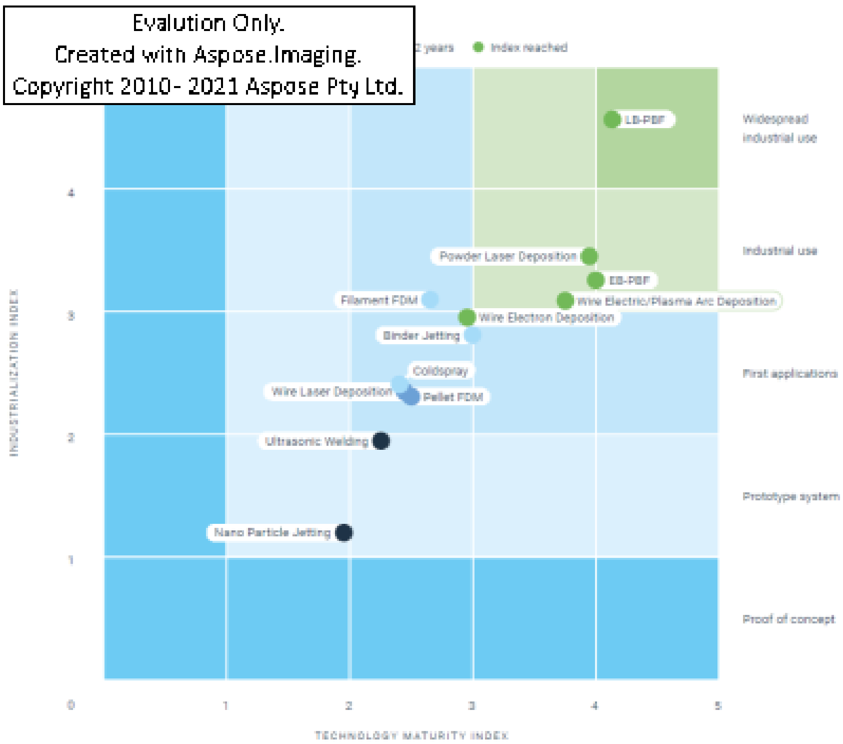


Figure 4: Maturity Index 2020 for Additive Manufacturing (Image source: AMPower [30])

In terms of market penetration, like many emerging technologies MBJ has had a relatively slow start, where at the end of 2020 the number of installed MBJ machines was 275 (compared to 10,600 beam-based systems) according to AMPower. In 2020, MBJ accounted for 3% of metal AM machines in terms of sales revenues (equivalent to ~€27Mil.). Despite this relatively small market share, AMPower forecasts that sales revenues will reach 8% of the total metal AM machines market by 2025 (equivalent to ~€225Mil.) at a CAGR of 53.1% (over double the 20% CAGR forecast for beam-based technologies) [23].

In terms of MBJ companies, there are not many manufacturers out there, and their numbers have recently decreased due to acquisitions. The key players in this market with fully commercial systems are currently Desktop Metal (based in USA and has recently acquired ExOne and MetaAdditive) and Markforged (based in USA and has recently acquired Digital Metal from Höganäs). Other key players with systems that are not commercially available yet include HP, GE Additive and Ricoh.

The commercial uptake of MBJ has notably increased in recent years, with partnerships between technology developers and industrial end-users accelerating adoption across several sectors. For example, in 2019, Cummins Inc. announced a partnership with GE Additive to develop MBJ for production [31] and in 2021, they announced finalising their first production part, the lance tip adapter, which is a critical emissions component in Cummins engines (Figure 5).

Figure 5: An image of the lance tip adapter developed by MBJ using the GE Additive System (Image source: Cummins [32]).

In 2021, Volkswagen, in collaboration with HP and Siemens, announced that it will integrate MBJ into vehicle production [33] for making automotive components (Figure 6).

Figure 6: An example of an automotive component produced by MBJ (Image source: HP [34]).

The growth is also driven by the traditional metal-injection moulding (MIM) industry, where MIM producers have seen an opportunity in MBJ for making small batches or prototypes to avoid tooling cost and lead time. For example, in 2019, Indo-MIM, one of the world largest producers of MIM parts for aerospace, automotive and other industries, has entered a partnership with Desktop Metal to integrate MBJ into production [35].

It is expected that MBJ will quickly find more applications in a range of sectors, such as medical parts like bone implants and scaffolds [36-38], fuel cells [7], aerospace components [37], energy and automotive [38].

6. The Role of Awareness and Training in Accelerating Adoption of MBJ

A key challenge to the wider industrial adoption of MBJ is that each stage of the process needs to be optimised in order for the final part to be successful. Unlike conventional AM processes, the printing stage of MBJ is not the most technically challenging aspect of the process. It is rather the downstream processes, especially sintering, that dictates the final quality of the part. It has been noted that knowledge in sintering technologies, both theoretical and practical, is not widely available and is not easily learned [23]. This is primarily because of the complexity of the process and the number of variables that need to be optimised to achieve successful sintering. Although the principles of sintering are relatively available in public domain, the practical aspects that are typically gained via years of experience are not as widely accessible. This relatively lack of knowledge extends to other relevant aspects of the process such as design rules for sintering, achievable surface properties, quality assessment, standards, etc.

These challenges were taken into consideration when the SAM training programme for MBJ was put together. The training was jointly organised and delivered by the MTC and Politecnico di Milano between 28th and 30th of March, 2022. It was aimed at delivering a comprehensive programme that combined both theoretical and practical aspects of MBJ. The programme also included subjects that were designed for both engineers and operators. Topics covered included an overview of the MBJ process, material selection and characterisation, key process variables, design rules for MBJ, sintering theory and practices and industrialisation of MBJ. Attendees gained a broad knowledge of MBJ technology, hardware and process capability, as well as more detailed understanding of the effect of processing parameters, advanced sintering principles, and when to use the process and the benefits its brings.

The training, which was attended by ~30 participants, was followed by an assessment, which was prepared by Istituto Italiano Saldatura, the Italian ANB (Authorised Nominate Body), and performed on site at Politecnico di Milano, with support from the UK's National Centre for Additive Manufacturing at the MTC in Coventry, UK.

The participants were asked to assess the pilot course and provide feedback on the learning experience. As shown in Figure 7, the majority of participants were satisfied or highly satisfied with the content, especially for knowledge and skills acquired [39].

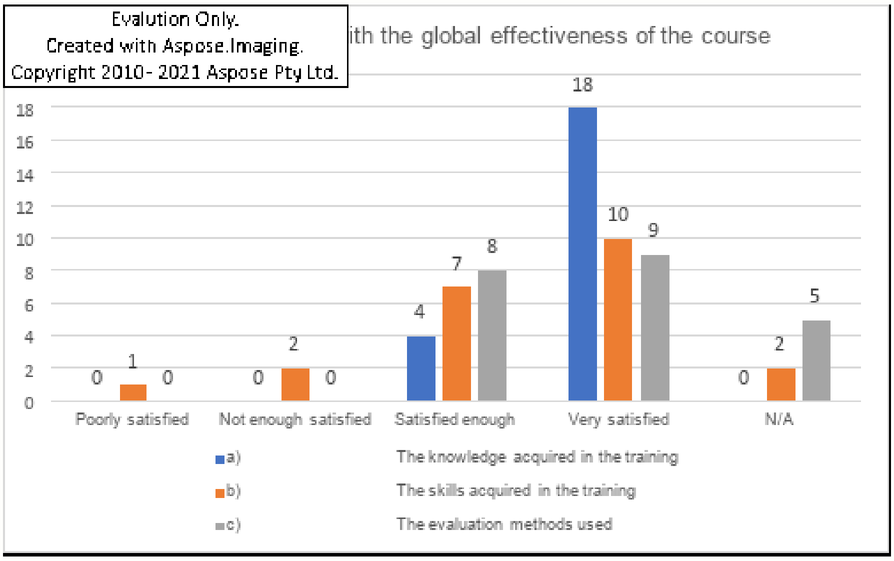


Figure 7: Assessment results for the pilot MBJ training

In their written feedback, the participants highlighted a number of positive aspects about the course, such as:

- The comprehensive content and coverage of different aspects of MBJ
- The expertise and knowledge of the trainers.
- The clear and well-organised structure and delivery.
- The combination of theoretical and practical aspects of the process
- The practical angles of the courses, such as process applications and industrialisation.

The participants also highlighted potential areas of improvement. Such as:

- The need for hands-on aspects, which was missing in the on-line delivery.
- The content was relatively dense compared to the duration of the course, which makes it challenging to comprehend all the delivered content.
- More focus is required on successful applications and case studies.

7. Conclusions

Metal binder jetting is the fastest growing SBAM technology today and the closest to commercialisation. The rapid adoption of the technology by industry is driven by the batch-production capabilities of the process combined with design freedom, high dimensional accuracy, and good surface finish. A key challenge that hampers faster uptake by industry is lack of awareness and knowledge about the process in general and about the downstream stages in particular. Therefore, developing dedicated training on MBJ is a key enabler for faster industrialisation, until now this training was not available. The SAM MBJ training is aimed at bridging this gap by creating a Europe-wide comprehensive theoretical and practical training offering. As mentioned, this was piloted in March 2022 and has been favourably received by participants. The next stage would be to follow up with the participant, in order to assess the impact of training on their current activities, as well as to take their feedback onboard in the next iterations of the training and make the course available as a regular offering to the wider industrial community in Europe, through its integration in the International Metal AM Coordinator Qualification or as separated training within the IAMQS.

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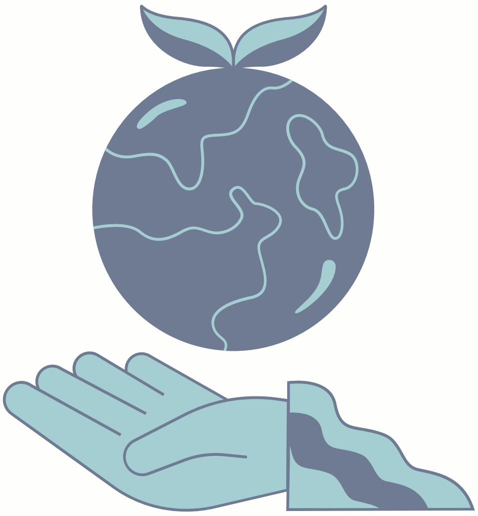
ADDITIVE MANUFACTURING FOR A SUSTAINABLE INDUSTRY OF THE FUTURE

Eva Sanchis, Lara Escudero & Berta Gonzalvo - AITIIP Centro Tecnológico, 2022



1. Future of Industry and Additive Manufacturing

Additive Manufacturing, commonly known as 3D printing technology, is more than 40 years old and has been blocked for years mainly by patents, which are now extinct. Today the growth of applications, technologies and materials is predicted to be continuous and unstoppable. New materials and technologies and advances as Zero-defects manufacturing systems or real time control / monitoring systems are being developed and appears as the trends to implement in the following years. These will change conventional design and manufacturing concepts and processes as well as new businesses, companies and jobs around the world.

Additive manufacturing (AM) has become one of the key strategies towards the transition to a digital and green Europe. It has already changed our lives and will continue to do so in the future. From the point of view of product development, it is allowing us to conceive single piece products that traditionally were a set of parts to achieve the same function. It also allows the reduction of launching times, as well as the versatility and customisation of products dedicated to a final function.

In general, for industry, it means a revolution that perfectly connects digitalisation and the optimisation of the consumption of raw materials. As far as people are concerned, it represents an opportunity to improve the quality of life both in its application in external medical uses (e.g.,splints, prostheses, utensils and tools for operations and cell cultures, protective elements such as helmets, safety and ergonomics such as exoskeletons) and in internal uses (e.g.,mainly prostheses and organs, etc.), as well as in their daily lives (e.g.,cars, sports equipment, fashion, etc.) or by becoming creators of their own objects.

Automation and robotics are key technologies for industry in order to regain manufacturing hegemony. The democratisation of robotic applications is one of the priorities, which includes the training of personnel and the promotion of more accessible technologies. Particularly important is the integration of additive manufacturing processes with robotics, to develop, for example, metal and polymer AM systems for the manufacture of large parts, covering applications that were until now unattainable, such as: demonstrators in transport, aerospace and equipment sectors, as well as in the manufacture of machines and tooling.

When analysing the job market for additive manufacturing, it can be seen that in 2021 there were 30% more job vacancies in the AM industry in same specialized websites. In Spain alone, more than 500 companies are looking for professionals with the skills to work with 4.0 technologies. Undoubtedly, one of the challenges these companies face is finding trained and experienced professionals in additive technologies; hence the importance of having a solid training based on practice. The enormous growth of AM will continue to require specialised training to fill the positions that this emerging industry will need in the future.

It is very important to train different types of profiles to apply AM in their field of work. They need to be aware of the possibilities of these technologies to be able to apply a strategy in their company that will enable them to differentiate themselves in an increasingly competitive market, which is why training must include everything from design to manufacturing and to start from a basic level, which allows workers familiarize themselves with the technologies and learn about their possibilities up to a more specialized level, focused directly on the needs that each company wants to solve through AM.

Training activities are still very focused on traditional manufacturing methods. Additive manufacturing breaks with traditional processes and many of the traditional subjects, such as design or calculation, are not prepared yet for AM manufacturing. To solve this, a basic training is needed, but currently itis not being provided by traditional training courses. Hence the importance of good initial training, with practical content in alignment with a market demand of increasingly qualified professionals. In the long term, it is also essential to broaden the perspective and influence the need for training in AM from the early educational stages, from infants and primary schools to later progress to vocational training centers and universities, as well as to professionals. Actions of this raise awareness type, focused on various audiences, are carried out in reference projects such as SAM.

In this context, it is essential to propose new sustainable developments and advanced digital processes, so that they are transferable to national and European level and above all, that it favours their incorporation in SMEs. The main objective must be to modernise and adjust the industrial network to the needs of the future. Adequate training is essential for this.

RELEVANCE OF THE SAM PROJECT FOR K-12 EDUCATION

Begum Canaslan Akyar - FAN3D, 2023

Additive Manufacturing (AM), commonly known as 3D printing, has emerged as a cutting-edge technology that revolutionizes physical object creation. By layering materials to build component parts, AM provides infinite design freedom, material versatility, and a streamlined production process [1]. While its applications in various technical fields are well-known, 3D printing is also making significant inroads as an educational tool in K-12[1] settings. By enabling the production of tangible objects that facilitate learning, 3D printing holds the potential to enhance comprehension and engagement across various school subjects, such as: chemistry, mathematics, sports and others. [12]. Additionally, it helps to facilitate learning and recall by addressing multiple senses [13], for example a study shows that using 3D printing activates the sense of touch via producing materials and makes abstract concepts more concrete [15]. For this reason, 3D printing provides advantages to support learning in subjects like mathematics [4], science [5], engineering [6], and social studies [7]. It also supports learning with a new approach to teaching complex subjects [6], harmonizes multiple curriculums, and enhances students' higher-order thinking and learning skills [8].

When compared to the traditional didactic approach, 3D printing offers revolutionary and innovative methods of learning and understanding complex subjects [6] by visualizing theoretical concepts [2], as well as improving students' higher-order thinking and learning skills [8] by integrating theoretical and practical knowledge [2]. The major benefits of using 3D printing in education can be sorted as (1) creating excitement among students by allowing them to involve in the study and design phase of the models, (2) preventing students from being passive in the learning process instead of consuming information they can actively involve in the creation of objects related to the subject topic, (3) providing new learning possibilities to students by visualizing the topic learned, (4) promoting students' problem-solving skills due to printing objects correctly they will have to learn to face and solve prac ing can be used as a s

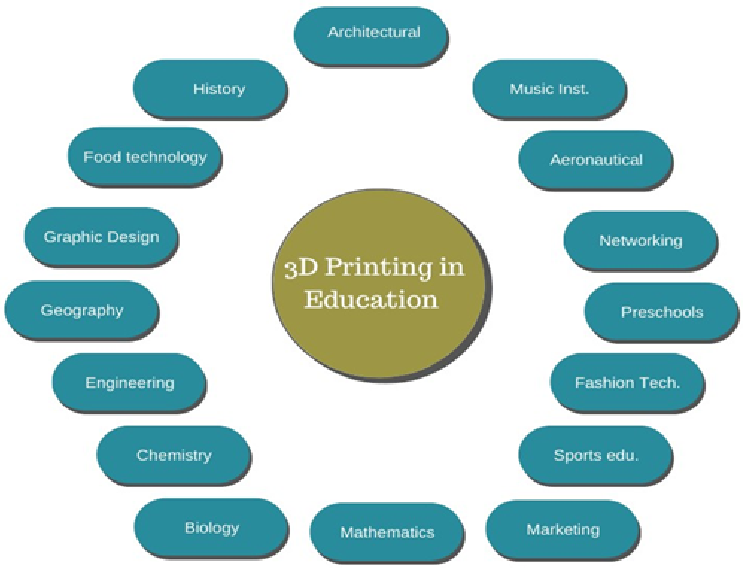


Figure 1: Aspects of where 3D printing can be used in education [12]

Despite 3D printing having advantages, meaningful integration is still very limited [9]. Even though some schools have 3D printing equipment, a high percentage of schools still do not fully utilize these technologies for education [10]. This is because most teachers have limited knowledge and experience of the benefits of 3D printing and the use of the equipment [11]. Studies show that teachers get frustrated with the use of 3D printing software and hardware. They also have trouble understanding 3D file types, and some technical aspects such as printer calibration, modelling, and design [11]. When knowledge, support and resources are made accessible to teachers, they are more likely to engage in the use of 3D printing [14]. Therefore, training for teachers will be beneficial to have positive attitudes toward using 3D printing in education and reduce their resistance to integrating this technology into education [11].

Perception of teachers about SAM TECH4KIDS activities

Over the course of the project lifecycle, SAM project partners conducted a systemic raise awareness campaign involving the planning and implementation of dedicated activities with schools from early childhood to high school levels. . These activities were conducted under the Tech4Kids framework that includes developing educational materials, such as: comic series, videos, banners, quizzes, and an 3D printing kit for teachers to implement 3D printing activities. Tech4kids activities were carried out in Germany, UK, Spain, France, Ireland, Italy, and Portugal.

The awareness campaign has been launched to attract young people to the 3D Printing industry. To achieve this goal, SAM focused on students and teachers in K-12 education. Since teachers are one of the main actors in designing the learning process, if they are aware of the AM technology use and benefits, they can encourage students' learning as well, thus ensuring a multiplier effect. in terms of impact with K-12 target group, the SAM project approached 86 different schools and involved nearly 3400 children and youngsters. Among the great number of participants, this paper will focus on the results achieved with two specific activities conducted in Portugal. The first activity aimed to engage a wide range of students, from early childhood to high school grades, over a period of five full days. Customized materials developed in the Tech4kids program were utilized for each grade level. For example, one activity designed for early childhood grades involved a recycling game where children matched 3D-printed materials with the correct recycle bin. Following the game, the children were introduced to the 3D printed materials and machine, and a discussion was held to explore their benefits for sustainability.

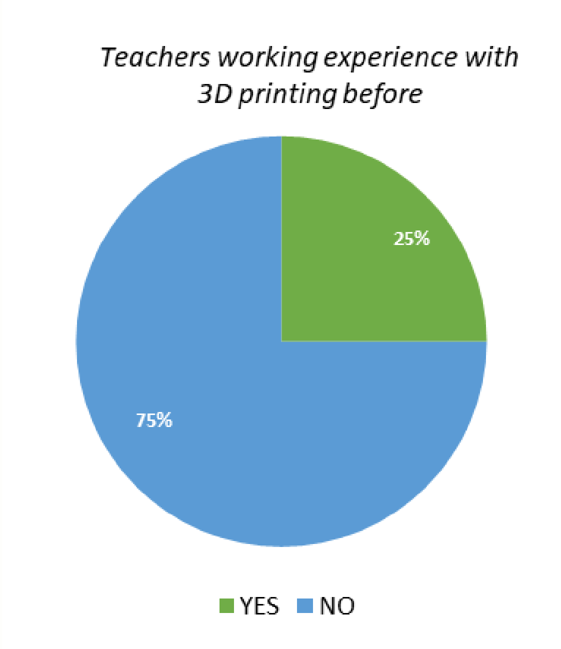
For primary school students, a comic series was presented, followed by the SAM Basic quiz. They also had the opportunity to participate in the recycling game and learn about 3D printers and shredder machines. A discussion on sustainability and 3D printing concluded the session.

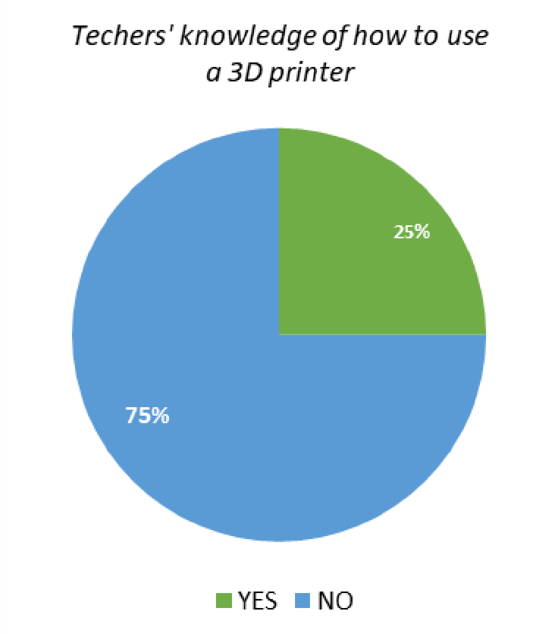
Secondary school students were exposed to a presentation on 3D printing and its application areas. They enrolled in a hands-on experience investigating 3D printers and shredder machines. A recycling game was incorporated into their session as well, followed by a discussion on the relationship between 3D printing and recycling.

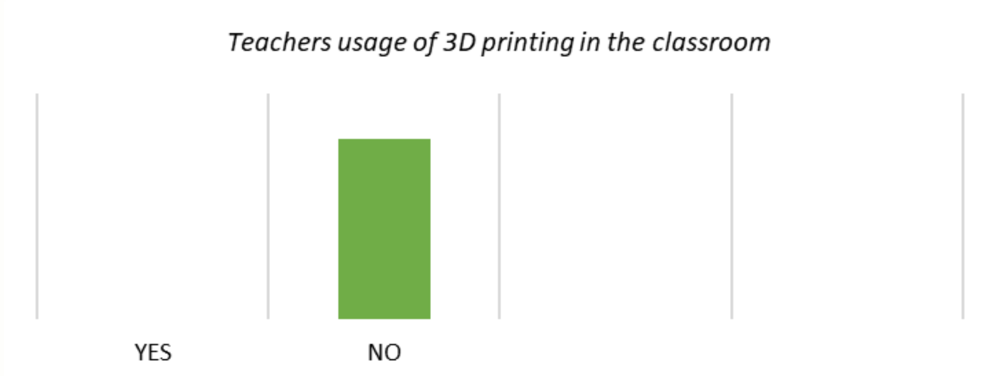
In the second activity, the target audience consisted of high school students. They were presented with information about 3D printing technologies and potential career opportunities in AM. The focus was to educate and inspire the students about the possibilities offered by 3D printing and its relevance in various industries.

Throughout these activities, teachers were also encouraged to attend the sessions. This allowed for a collaborative learning environment where both students and teachers could engage in the activities and discussions, fostering a deeper understanding of 3D printing and its connection to sustainability.

At the end of both activities, the views of the teachers were sought. Four teachers voluntarily filled out a feedback questionnaire. The teachers' names were kept anonymous and referred to as T1, T2, T3, and T4. The background of these teachers with 3D printing is shown below.







In conclusion, we can say that most of the teachers have not had knowledge and experience with 3D printing before the Tech4Kids activity.

In response to the question of the type of 3D printing activities they would like to apply in their classes. They responded as:

- "It does not apply to the subject I teach." (T1)
- "Production of 3D models for Natural Sciences, Physics, Chemistry, Mathematics, Geography, Visual Education (etc.)." (T2)
- "Presentations, prototypes." (T3)
- "Prototyping characters or interfaces." (T4)

In general, and despite non-prior knowledge about the technology, teachers are interested in using 3D printing for prototyping and visualizing concepts.

Another question was asked about the necessary teaching resources and support to integrate 3D printing into school projects or classroom settings. Their responses were:

- "Training, appropriate technology." (T1)
- "Experiences." (T2)
- "Funding." (T3)"3D scanner and printer." (T4)

Teachers indicated that they need to access the printer first and then get training and experience to use these technologies. Then, their opinion about the benefits of 3D printing in education was asked.

They answered that:
- "Making learning more hands-on in science." (T1)
- "The participation of students and the production of unique pieces or models in the most scientific areas." (T2)
- "Creativity." (T3)
- "A fast relationship as a prototype. Connecting the virtual to the real.
- Connecting the digital to the analogue." (T4)

According to their response, it can be concluded that 3D printing in education has the potential to increase interaction in the classroom and bring innovation to education. This is done by visualizing materials and increasing hands-on learning opportunities. In addition, it provides examples that illustrate the use of digital technology in real-life situations. When they were asked what the less positive side is of using 3D printing in education, they replied that;

- "It cannot be used in quantity and is a time-consuming process." (T1)
- "Cost, investment." (T3)
- "Costs." (T4)

Their responses reveal that the cost of equipment is one of the barriers in applying 3D printing technology within the different school education levels. Additionally, it is a time-consuming process and challenging to integrate into limited class time. This answer might be linked to their lack or limited background knowledge regarding 3D printing. Finally, we asked teachers from the Teach4Kids activity whether they were enlightened about how to implement 3D printing in the classroom context. All of them responded with "yes".

Conclusion

The integration of 3D printing in education has the potential to revolutionize the learning experience by providing tangible and interactive tools for K-12 students. The benefits of 3D printing, such as enhanced engagement, visualization of concepts, and the development of problem-solving skills, make it a valuable addition to classrooms across various subjects. However, the limited integration of 3D printing in education highlights the need for accessible training, appropriate technology, and support for teachers. Overcoming these challenges will pave the way for a more widespread adoption of 3D printing in educational settings. Through the experience and opinions of some of the teachers involved in the SAM project, it becomes evident that 3D printing has the potential and capability to enrich education and empower students as active participants in the learning process. The desire of teachers to incorporate 3D printing in producing prototypes, visualizing concepts, and fostering creativity underscores the potential impact of this technology in the classroom. While cost and time constraints remain as challenges, advancements in technology and increased availability of resources are expected to mitigate these limitations over time.

As the benefits of 3D printing in education become more evident, it is crucial to invest in teacher training programs and provide the necessary infrastructure to support the integration of this innovative technology. To meet these needs, the SAM project developed Tech4Kids interactive education materials addressing early childhood to high school education. Additionally, a free and open-access 3D printing kit for teachers was developed to support and guide teachers in integrating 3D printing into their education environments (https://skills4am.eu/3dprintteacher.html).

In conclusion, 3D printing holds great promise for transforming education by facilitating hands-on learning, visualization of abstract concepts, and the development of critical skills. Despite the lack of knowledge about 3D printing and the constraints in accessing a 3D printer. The SAM project has contributed to increase teachers' awareness of 3D printing and its applications. As well as created the necessary resources to support the teachers in future activities. As found in the study, before the Tech4Kids activity, most of the teachers had not contact with 3D printing. However, now they have a new vision and also supporting guidance materials to facilitate 3D printing in their educational environment.

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