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Impact of Additive Manufacturing towards the Environmental Sustainability

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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.

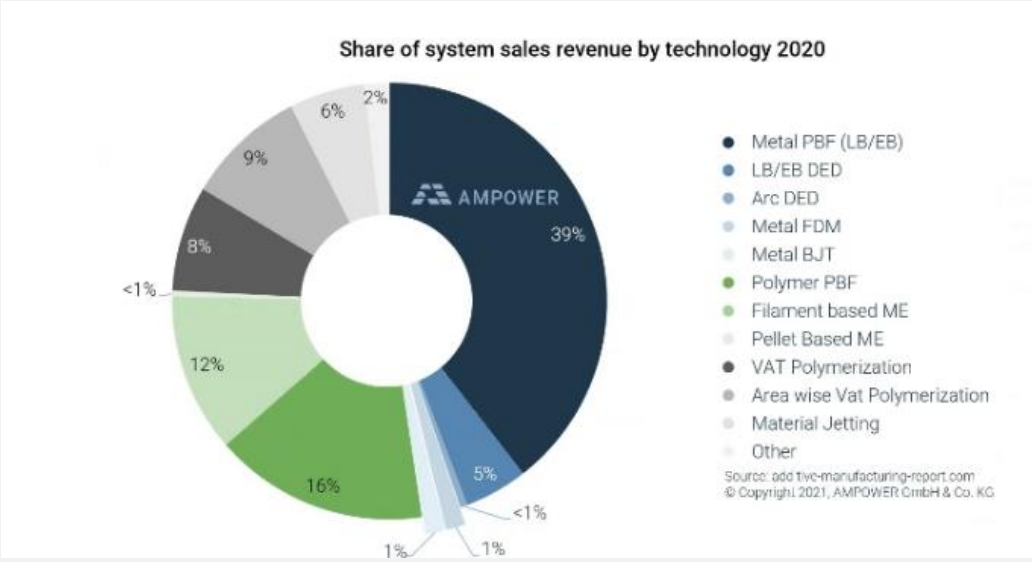

Figure 1 - Overview of System Sales in AM for the Year 2020 (copyright: AMPower 2021)

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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, 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 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.

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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).

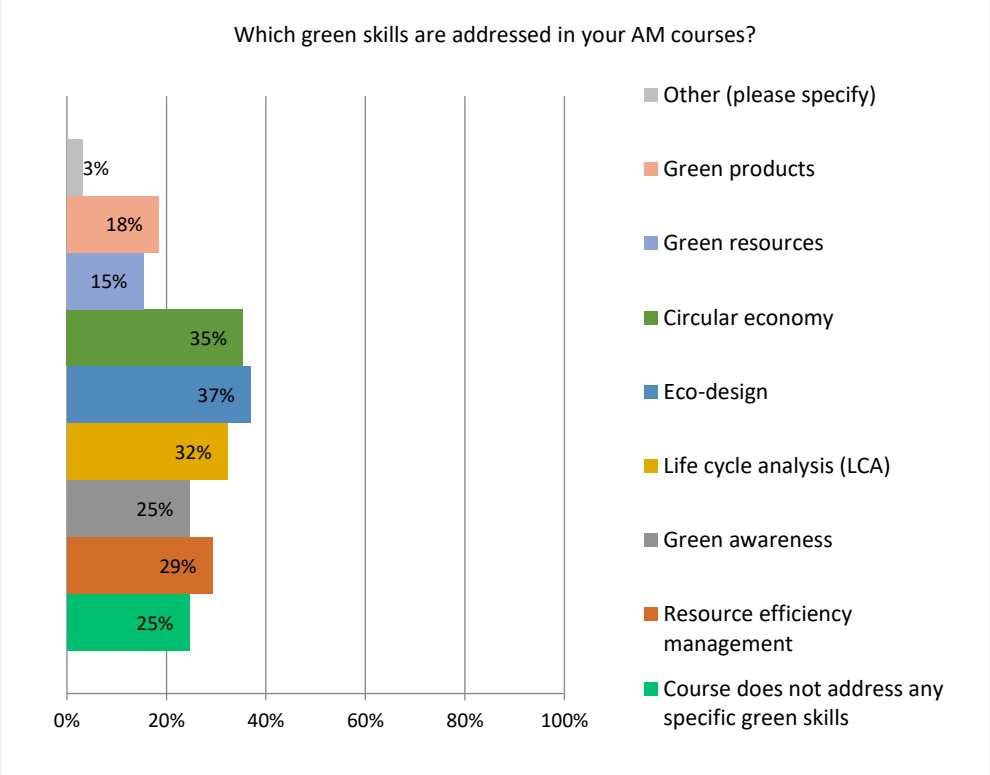

Figure 2 - Green Skills covered in AM Training Courses

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).

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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).

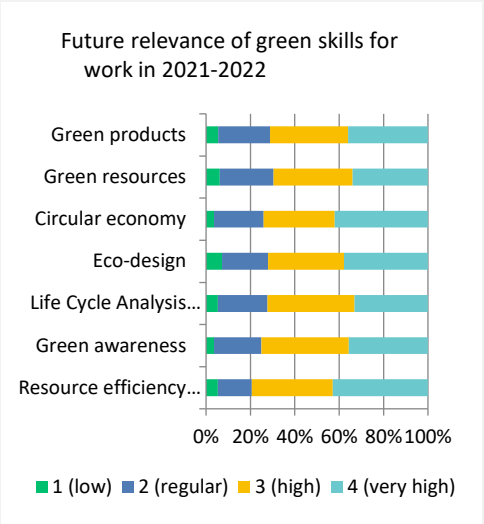

Figure 3 - Relevance of green skills for workers

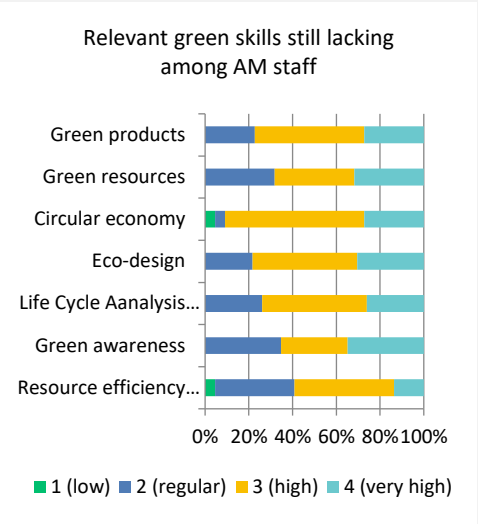

Figure 4 - Current Relevance of green skills according Companies

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.

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

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

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 c*ase studies* and *on-site* v*isits* (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 t*hesis writing* (Figure 6). Common tools, such as p*roblem-based learning* and l*aboratory practices* were not gaining much attention.

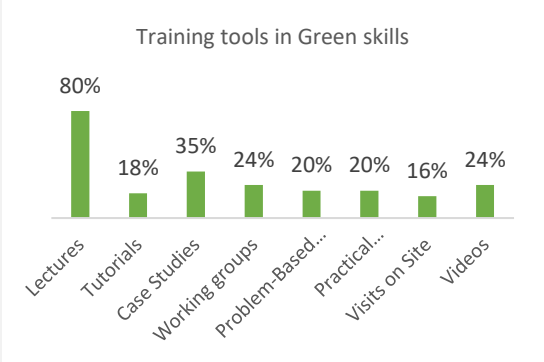

Figure 5 - Training Approach for Green Skills

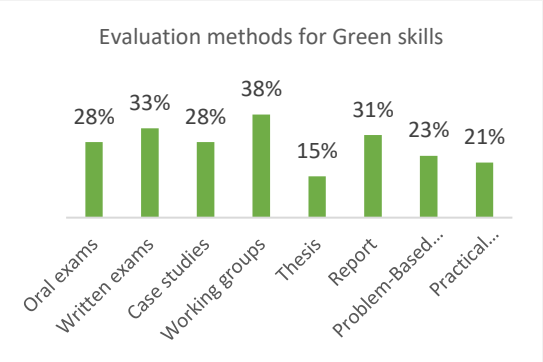

Figure 6 -Evaluation method for green skills

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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Get involved

If you are interested in learning more or engaging in developing skills in AM, get in contact with us through the SAM website: http://skills4am.eu/contactus.html

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More information on SAM project

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