SING for GREEN

Needs Analysis Report

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Executive Summary

The Sing for Green project aims to develop a curriculum for AM designers that focuses on green transition, create Open Educational Resources, and test these green/sustainability curricula and resources. The first step in the project is to identify the knowledge and skill requirements of the AM industry. This report details the findings from efforts to determine the industry's and higher education's needs for sustainable product design in additive manufacturing were conducted during Work Package 2: Industry driven analysis for AM design and green skills of the Sing for Green project.

To conduct comprehensive needs analysis and gather information from various sources, the Sing for Green project partners implemented a broad desk research, interviews with experts from industry and higher education, and a focus group discussion with experts in AM and sustainability.

The needs analysis was carried out through a careful and rigorous process, meticulously planned by the project partners. First, desk research was conducted to identify key themes, such as knowledge and skills gaps in AM for sustainable design of designers. Based on these themes, interview questions for industry and higher education were developed. Following the interviews, a focus group was organized to verify the outcomes of the desk research and interviews and clarify points raised during these phases.

In summary, the report revealed several skills and knowledge gaps in additive manufacturing (AM) technologies and processes, materials knowledge, product life cycle and environmental impact, as well as the economic and marketing benefits of sustainability. These gaps will guide the Sing for Green project in developing a curriculum for AM designers.

1. Methodology

This report aims to process the information obtained and processed by SINGforGREEN project partners in previous stages of the project. In this regard, the processing of information from different sources has followed some general principles:

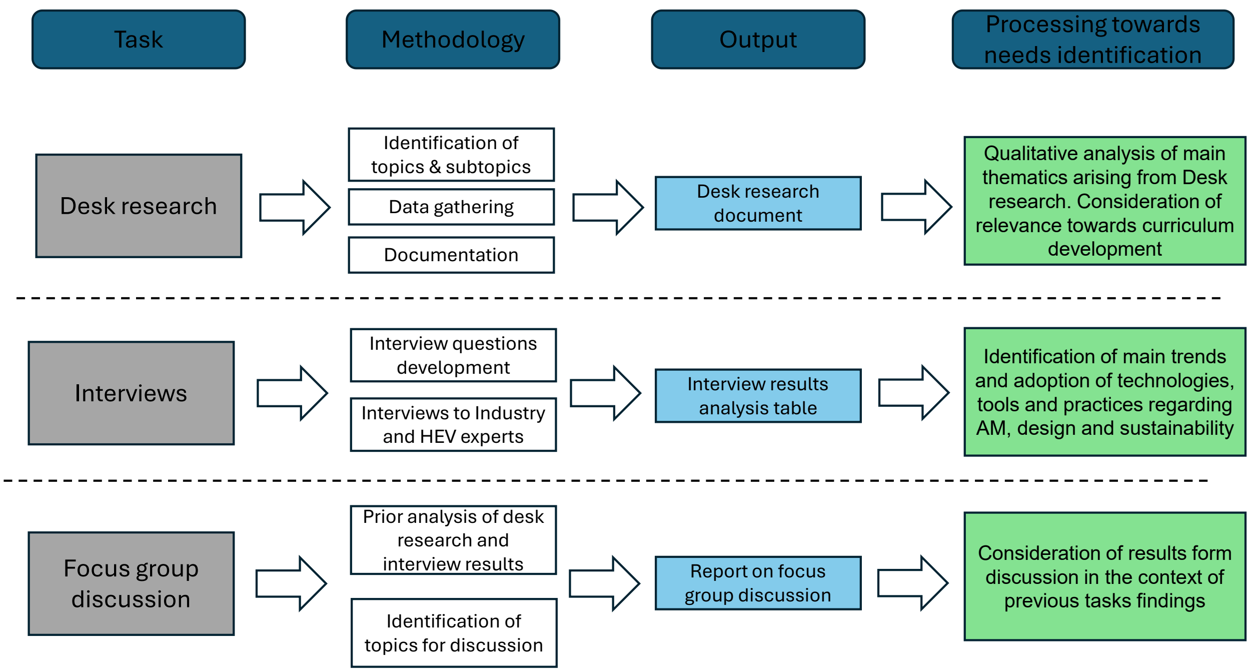

Figure 1: diagram showing main process followed for needs identification during SINGforGREEN project

- Desk research: This task involved the collection, review, and structured interpretation of a large amount of information related to the topics of interest, aiming to identify main themes or blocks of interest in the project's educational scope. The analysis applicable in this case was therefore qualitative, derived from contextualizing all the collected information, within a framework where project partners could apply the findings to form a general knowledge scheme supporting the sustainable use of additive manufacturing technologies.

  In this sense, once the work of collecting, structuring, and documenting the information was completed, it was possible to identify major blocks or themes with which most of the analysed and presented information correlated. These were then assessed to determine their relevance for transfer to the curriculum.

- Interviews with experts: For this task, lists of questions were prepared to serve as a basis for conducting interviews with experts (two lists, one for industry experts and another for HEV experts). The intended sample size was about 30 people (with a 50% distribution between the groups), so the basic method of processing the information was oriented towards identifying the main trends (e.g., in the selection of specific AM technologies) and dominant perceptions among the interviewees. In this sense, the analysis and detection of these trends were possible thanks to the consolidation of all the responses obtained for each of the different questions (using Excel tools), their analysis, and the consequent extraction of the main data.

- Focus group discussion: This task was carried out when the previous tasks were already well advanced, so one of its main functions was to discuss the main themes of interest that had already been identified in the previous tasks. This task took the form of a meeting where the discussion was based on four questions related to the previous findings, serving to qualitatively gather additional information that would support or influence the consideration of all the collected information and findings throughout the process.

The identified tasks began in a sequential scheme, starting with the desk research activities. Once this was initiated, the initial definition of topics and subtopics developed allowed for the establishment of the basis for defining the questions for the interviews. Finally, the progress in the previous two tasks provided an overall view of the topics and subtopics addressed and the perception of them by the respondents. This combined effort enabled the focus group discussion, a task that ultimately served to gather additional perceptions on the main aspects identified.

Thus, the general approach to interpreting the information and identifying findings related to the project's objectives followed an incremental approach. In the end, the members of the SINGforGREEN project were able to reach a final assessment and identify potential needs for the development of a curriculum for Sustainable Additive Manufacturing design.

2. Desk Research

The desk research was the first step in the needs analysis process. This research aimed to understand the scientific literature on additive manufacturing (AM) and sustainable design. Initially, the partners searched for keywords such as "additive manufacturing," "sustainability," "designers," and "sustainability in AM" using Google Scholar and other scientific databases.

The selected scientific papers were shared in a common file management tool, SharePoint, to analyze and identify themes and group the papers according to common topics. At the end of the analysis, the identified eight themes are listed below:

- Sustainability (general concepts + context)
- Additive Manufacturing (process perspective)
- Additive Manufacturing Materials
- Advanced designing tools
- Designers - Sustainable design
- Sustainable production
- Learning techniques
- Sustainability integration into AM designers training programs

These main themes were further divided into subthemes and distributed among the partners, who wrote detailed reports on the current status of each theme. At the end of the writing process, the project partners developed comprehensive material explaining the current situation of sustainable design in AM based on the latest scientific studies. The state-of-the-artwork resulted in the following findings:

Thematic	Conclusions	Curricular relevance
Overall concept of the product life cycle	The product life cycle is very important for the designer to acquire a point of view that is not only limited to his or her work or its connotations in terms of subsequent manufacturing.	Very High: should be addressed in great detail
Knowledge of design techniques in additive manufacturing technologies	The combination between advanced design methodologies and additive manufacturing is perhaps one of the "strong points" since only additive manufacturing has the capacity to take maximum advantage of techniques and tools such as topological optimisation, generative	Very High: should be addressed in great detail, providing illustrative examples of at least a couple

Thematic	Conclusions	Curricular relevance
	design, lattice structure design, minimisation of the number of components in a product, etc.. It is therefore obvious that this set of issues is of critical importance for a future curriculum in the fields of interest.	of optimised design technicians.
Relationship in the selection of an additive manufacturing technology and the modification of "upstream" and "downstream" processes	The relevance of the choice of additive manufacturing technology and how this can change not only manufacturing, but all upstream and downstream processes, including logistics, has been highlighted. Its potential relevance for inclusion in a curriculum is high. It should be part of the designer's body of knowledge, even if starting from the general principle of additive manufacturing (layer by layer), without taking a specific technology as a reference.	High: should be developed in some detail
Differentiation between additive manufacturing technologies	Even though they share a basic concept, additive manufacturing technologies differ greatly from each other, with differences that do not only cover the materials or the nature of the processes themselves, but also the associated design "rules". These aspects are key in each technology, or at least in the most widespread ones, when it comes to increasing the potential of each one of them to minimise material consumption, manufacturing times, post-processes, etc., and are therefore very relevant from the point of view of sustainability. It is therefore highly relevant for a curriculum that aims to illustrate the possibilities of combining design methodologies, additive manufacturing technology and the potential improvements in sustainability of the different alternatives.	High: should be developed in some detail, taking at least into account the most important technologies from an industrial point of view (PBF, FDM, SLA, WAAM, etc.).

Thematic	Conclusions	Curricular relevance
Knowledge of raw materials for additive manufacturing	As in any other field related to design, a thorough knowledge of the materials that can be used is a basic aspect in order to propose a design capable of responding to the requirements in the most efficient way possible. In this sense, the choice of some materials over others can be a key aspect of the sustainability of a product, which is why its importance cannot be overlooked in a future curriculum. It is also a complementary theme to different technologies and post-processes are often linked to different materials.	High: should be developed in some detail, in line with the technologies covered in some depth in the previous theme.
Knowledge of techniques for identifying and accounting for impacts	Concepts such as Life Cycle assessment are not easy to approach, as they require a body of knowledge that, depending on the scope, may require a complete knowledge of the process upstream and downstream of the design process. It is therefore complicated for a non-specific training in the subject to create a complete capacity in a potential student, but techniques such as the one mentioned above are tools that allow the identification, accounting and comparison of impacts between different alternatives, and so to speak, "not measuring" implies not knowing whether the measures implemented with the awareness that they reduce the impact of a product are effective or not. Thus, while perhaps in full detail, a future curriculum around design, additive manufacturing and sustainability cannot avoid addressing these issues in as much detail as possible.	High: should be developed in some detail, with a thorough approach to the full methodology, and if possible, a simple case study as an example.

Thematic	Conclusions	Curricular relevance
Specific knowledge of the development cycle associated with additive manufacturing.	The cycle associated with additive manufacturing has been set out simply but clearly. It is extremely important for the designer to be aware of it, in order to understand how the different stages modify what can be a traditional product design and development process. It is understood in any case that the concept can be basic for anyone minimally familiar with additive manufacturing, so assuming that this knowledge will already exist in the designer, or that it will be accessible through non-specific training, its valuation is lower than in previous cases.	Medium: can be approached from a conceptual point of view, examples in specific technologies are employable.
More general sustainability knowledge	It is necessary to bear in mind that sustainability is, before being a set of tools or knowledge, a "philosophy", which is based on the awareness that it is possible to maintain or improve the well-being of individuals based on the application of a series of fundamental precepts. Although this is not technical knowledge, it should be included in a curriculum in the areas to be addressed, perhaps as a necessary introduction to other knowledge.	Medium: it can be approached from a conceptual point of view.

According to the desk research, we concluded that product life cycle and knowledge of design techniques in additive manufacturing technologies were identified as very high important themes of the sustainable design in AM. The differentiation between additive manufacturing technologies, knowledge of raw materials for additive manufacturing themes were identified as high level importance according to the desk research. Finally, “general sustainability knowledge” was identified as medium critical topic for the sustainable design in AM.

3. Interview

To develop a contextual understanding of the requirements and current situation of sustainable design in additive manufacturing (AM) and to address the gap through training during the Sing for Green project, the project partners conducted interviews.

First, the interview questions were developed collaboratively by the project partners. Each partner provided feedback on the questions, and several iterations were made until consensus was reached. The semi-structured question sets were developed separately for industry and higher education. Both questionnaires began with warm-up questions, such as asking for the interviewee's name, the company they work for, and their years of experience. The industry interview protocol included 12 questions (see Annex 1 for the full interview protocol), while the higher education interview protocol included 11 questions (see Annex 2 for the full interview protocol).

Once the question sets were finalized, the partners invited experts from industry and higher education via email and scheduled appointments to ask the prepared questions. The interviews were conducted both online and in person with 18 experts from higher education and 17 from industry. The interviewees' answers were recorded during the interviews or through online meeting recordings, which were then transcribed.

These interview notes were saved in a shared file for each partner. Subsequently, content analysis was performed by quantifying specific words and codes within this file. The findings of the content analysis are outlined below.

3.1. Industry Interviews Findings

We asked industry experts about the AM equipment they use, the design processes they follow, and the design and slicing tools they utilize. This information is crucial for the project as it helps us understand which AM equipment is currently in use, how the design process is conducted in the industry, and which design and slicing tools are most commonly used. These insights provide evidence for us to investigate the current situation in AM.

3.1.1.AM Equipment:

The participants' responses regarding AM equipment usage were analyzed and are presented in Table 1. The results indicate that Fused Filament Fabrication (FFF) / plastic material extrusion is the most widely adopted technology, with almost three-quarters of the participants mentioning its use. In contrast, metal 3D printing technologies are less common. Nearly half of the respondents reported using metal AM, predominantly Powder Bed Fusion (PBF) technologies.

Both metal and polymer 3D printing involve other technologies as well. In plastic fabrication, photopolymerization technologies for resins are frequently mentioned, along with occasional use of Binder Jetting and PBF-polymer. In metal fabrication, PBF remains dominant, but there are instances of high-volume deposition technologies (DED) and Laminated Object Manufacturing (LOM).

Regarding materials, commonly used plastics include PLA, ABS, and PETG (FFF), with occasional use of reinforced fibers (FFF) and resins (VAT photopolymerization). Among metals, frequently used materials include various aluminum, titanium, and steel alloys.

Table 1: AM Technologies and Materials Analysis

Technology	Adoption Rate
Fused Filament Fabrication (FFF) / plastic material extrusion	Most widely adopted (~75%)
Photopolymerization technologies for resins	Frequently mentioned
Binder Jetting	Occasional use
PBF-polymer	Occasional use
Powder Bed Fusion (PBF)	Dominant (~50%)
High-volume deposition technologies (DED)	Instances
Laminated Object Manufacturing (LOM)	Instances

3.1.2. Design Process:

We asked interview experts if they conduct design in AM and how do they conduct this design process. We found that 16 of the 17 interviewees are involved at some level in designing parts for 3D printing.

The majority of interviewees are optimizing parts already created by customers using standard/conventional modeling techniques. When implementing optimization changes into the design, they mainly try to minimize part weight and 3D printing time. By making design changes that reduce the need for support structures they reduce waste.

When developing a new part design for 3D printing, they mainly use general knowledge of the capabilities and design constraints of specific 3D printing technologies and in-house know-how → experience and proven design solutions. Only 2 of the interviewees implement modern, innovative design methods Topology Optimization and Generative Design into the component design development process in order to improve the weight/strength ratio of the component.

The interviewees primarily use 3D printing for prototype production in order to verify the correctness of the component shape or the correct functioning of the mechanism. Secondarily, they use 3D printing to produce final and functional components and mechanisms:

- functional components for engineering and automotive

- sheet metal bending tools

- components for production lines and automatization

- measuring, assembly and welding jigs

3.1.3. Design and Slicing Software

We asked our experts which design and slicing tools they are using. The results are summarized in Table 2.

Table 2. Design and Slicing Software Frequency Analysis

Software Type	Frequency
PrusaSlicer	6
Bambu Studio/Lab	6
CATIA V5/3DExperience	5
SolidWorks	4
Materialise Magics	3
Autodesk Inventor	3
Cura	3
Creo	2
Autodesk Fusion 360	2

3.1.4. Participation in Training on Sustainability in AM

The majority of respondents mentioned that they have not received any formal education or training specifically related to integrating sustainability principles into designing for AM processes.

Some interviewees acknowledged participating in various training programs related to AM technologies, such as deep dive training and courses on specific AM processes or tools. **However, they expressed a lack of formal education or training specifically focused on sustainability principles in AM**.

Several interviewees mentioned that their knowledge in AM and related practices, including sustainability considerations, was primarily gained through self-teaching and hands-on experience.

In conclusion, the responses reflect a general lack of formal education or training specifically focused on integrating sustainability principles into designing for AM processes.

The Barriers and Limitations of Implementation of Sustainability in AM

The barriers and limitation industry faces to implement sustainable design in AM were examined and the findings were summarized in Table 3. The most common answer, and by a large margin, is the cost of materials, software and overall practices of sustainability. The second most common problem is material limitations, and lack of education on sustainable practices and similar topics followed by lack of material availability.

Table 3. Barriers and limitations description of implementation of Sustainability in AM

Barriers and Limitations Description	Frequency
Cost of materials, software, and sustainability practices	12
Material limitations (properties don't satisfy)	4
Lack of education on sustainable practices and similar topics	4
Lack of material availability	2
Recycling and sustainability practices are still in development	2
Government incompetence to improve and enforce sustainable practices	1
No problems encountered	1

3.1.5. Specific Knowledge and Skills for Designers in Sustainable Design

The most common answer to this question is the need for designers to understand how a certain technology works. Knowledge of materials (its properties, uses etc.) is the second common answer. The interviewees thirdly stated that it is important for designers to understand product lifecycle and be aware how certain technologies, materials and processes influence the environment. Following these statements, two interviewees mentioned it is important for designers to know about topology optimisation, design constraints, DfAM principles and basic mechanics. One interviewee mentioned principles of recycling and circular economy. One mentioned the need for knowledge on product post processing and interviewee said that adaptability is important while other stated that a good designer must be able to think outside the box. One interviewee stated that the educational system needs to modernize, while one says that designers need to know not only how to produce a part but also how to repair it (extend its lifecycle).

Table 4: Key Knowledge Areas for Sustainable Design and Their Frequency of Mention by Interviewees

Knowledge Area	Frequency
Understanding how a certain technology works	7
Knowledge of materials (properties, uses, etc.)	7
Understanding product lifecycle and environmental impact	5
Knowledge of product post-processing	2
Knowledge of topology optimization, design constraints, DfAM principles, and basic mechanics	2
Principles of recycling and circular economy	1
Post processing	1
Knowledge of how to repair and extend the lifecycle of a part	1

3.1.6. The Preferred Type of Training on Sustainable Desing for Designers

Diverse Training Methods: The responses suggest a preference for a diverse range of training methods, including traditional in-person training, online courses, workshops, and practical hands-on experiences.

Practical Implementation: A recurring theme across several responses is the importance of practical implementation of taught skills and knowledge. Designers seem to value opportunities to apply sustainable design principles in real-world scenarios, whether through hands-on projects, design challenges, or practical sessions.

Individualized and Small Group Learning: There's an emphasis on individualized learning experiences and small group settings, where attendees can engage in open discussions, ask questions, and receive personalized attention.

Combining Theory with Application: Effective training methods should strike a balance between theoretical knowledge and practical application. While theoretical understanding is essential, it's equally crucial for designers to learn how to apply sustainable design principles in their work and understand the practical implications of their decisions.

In conclusion, effective training methods for equipping designers with knowledge and skills for sustainable design should be diverse, practical, and engaging, incorporating a balance of theory and application. Individualized learning experiences, small group settings, and opportunities for interaction and collaboration are essential to achieve meaningful learning outcomes.

3.1.7. The Preferred Topic of Sustainable Desing in AM Training

Based on the responses gathered, the preferred training topics among the respondents are as follows:

-There is a significant emphasis on understanding different materials used in Additive Manufacturing (AM), particularly metal printing technologies.

-Training in topology optimization, generative design, and component design constraints specific to AM was highlighted.

-Respondents expressed a need for training in various software tools used in AM, as well as post-processing techniques.

-Understanding the broader context and applications of AM technologies was mentioned as important.

-Sustainability topics were deemed essential, including understanding the environmental impact of AM, life cycle assessment (LCA), and carbon footprint analysis.

-Health and safety concerns related to metal materials and safe post-processing methods were also emphasized.

These topics reflect the diverse and critical areas of knowledge that stakeholders in higher education believe are crucial for training AM designers on sustainable design principles.

3.2. Higher Education Interviews Findings

In order to understand the context of higher education institutions regarding sustainable design in AM, particularly in current courses, and to identify requirements for improving existing courses or creating new ones to meet industry's sustainable design needs in AM, interviews were primarily conducted with professors at universities in partner countries. The findings of the interviews are presented below.

3.2.1.AM Equipment:

The overall results indicate a diverse range of technologies and training capabilities. Among the surveyed participants, plastic 3D printing technologies, particularly Fused Filament Fabrication (FFF) or plastic material extrusion, were predominant, mentioned by three-quarters of the respondents in most cases. Photopolymerization technologies within polymer 3D printing also showed significant presence, though slightly less common compared to FFF, with approximately 50% of respondents using them.

In contrast, metallic 3D printing technologies had considerably lower implementation rates, with only around a quarter of respondents reporting their use. This category included Powder Bed Fusion (PBF), Directed Energy Deposition (DED), and sporadic mentions of metal filament printing technologies.

3.2.2.Training Courses on Design Activities and AM Equipment of Higher Education

A total of 18 responses were gathered, with 13 respondents answering "Yes," 4 responding "No," and 1 indicating "Not applicable." The courses primarily incorporating these contents are at the master's degree level, including programs such as MSc in Engineering for Product Design, MSc in Engineering for Direct Digital Manufacturing, and MSc in Mechanical Engineering. The course content covers a wide range of topics, including Ecodesign, Grasshopper for generative design, Life Cycle Assessments (LCAs) using software like SimaPro, material properties characterization, and testing parts using additive manufacturing (AM). Additional subjects include mechanics in design, a design software called ProTOp for topology optimization, digital technologies for product development, principles and application of AM, material design, mechanical design, a French certification in Design for Additive Manufacturing (DfAM), design considerations such as defects, supports, and geometry, and manufacturing/production processes design for AM. One participant emphasized that the design of AM is critical for successful product design and production. Moreover, training courses and materials related to design activities are connected with products and equipment, integrating manufacturing and post-processing technologies.

3.2.3.Training Courses on Design in AM

The analysis of responses shows that while some organizations provide specific courses and materials in Design for AM (DFAM), others do not. A total of 8 participants said their organization provided specific courses in DFAM; 5 said their organization did not provide such courses; and 2 were unsure. The offered courses cover a broad range of topics related to AM and DFAM, including generative design, industrial design applications, and practical aspects of AM processes. The training curriculum emphasizes both theoretical knowledge and practical application, with a focus on design principles, optimization, and real-world case studies. The responses indicate a mixed approach to DFAM education, with some institutions offering tailored programs and others integrating DFAM concepts into broader AM courses. The summary of the responses is presented in Table 5.

Table 5. List of DFAM Courses

Generative Design courses (Fusion360, Apex, NX Siemens, nTopology)
3D modeling and printing for validation
Principles and applications of AM and DFAM
Design rules, function integration, part consolidation
Lattice and gyroid structures
Print process (slicing, orientation, supporting, nesting, printing parameters, simulation)
Using industry case studies

3.2.4.Sustainability Subject in AM Training

Eighteen interviewees responded to the question about providing specific courses or materials in the field of Design for Additive Manufacturing (DFAM). Out of these, three participants did not provide any answer. Eight respondents indicated that their organizations offer training on sustainable design, while seven mentioned that they do not offer any courses on the topic.

The majority of the responses highlighted that "Elements of Sustainability" are either currently delivered or suggested to be delivered as a training course. This is intended to help designers integrate sustainability into additive manufacturing (AM) design.

Table 6. Delivered and/or suggested courses for Sustainable Desing in AM

Courses	Frequency
Elements of Sustainability	3
Life Cycle Assessment (LCA)	2
Generative Design and Topology Optimization	2
Material Recycling and Resource Efficiency	2
Energy Conservation	2
Sustainable Materials and Processes	2
Economic and Marketing Benefits of Sustainability	2
Environmental Impact Assessment	1

3.2.5.Barriers and Limitations that Designers Face on Sustainable Design

Designers face several significant sustainability challenges, including overlooking product end-of-life considerations and neglecting eco-design principles. Sustainability improvements often encounter economic challenges as they can impact the overall cost. Many compare AM with traditional methods without acknowledging AM's unique sustainability benefits and challenges, such as material recyclability and process costs.

There are misunderstandings about AM's potential and material properties, coupled with a lack of specialized courses. For true sustainability, designers need to consider the entire product lifecycle. There is a need for greater awareness and education in this area. Achieving a comprehensive vision of how the entire process changes when incorporating sustainability is difficult. Additionally, the high cost of software and a lack of understanding of post-processing steps are significant barriers.

3.2.6.Specific Knowledge and Skills for Sustainable Design in AM

This question directly addresses the required skills for AM designers to design in a sustainable way. The summary of the findings is presented in Table 7.

Among the 18 respondents, the majority, with 11 responses, highlighted that material knowledge should be known by AM designers for sustainable designs. Nine of them stated that understanding AM technologies and processes is essential, so a basic understanding of AM should be taught to AM designers. “Design for AM principles” was repeated by six respondents. Life cycle assessment was mentioned by five respondents. Generative design and topology optimization was also suggested by the respondents.

Finally, sustainability principles and awareness as well as practical applications like case studies or best practices are recommended to be integrated into designers' training about sustainable design.

Table 7. The required skills of Designers for Sustainable Design in AM

Required Skills	Frequency
Material knowledge	11
Understanding AM technologies and processes	9
Design for AM principles	6
Life cycle assessment	5
Generative design and topology optimization	4
Sustainability principles and awareness	2
Practical applications (case studies or best practices)	2

3.2.7.The Benefits of Sustainable Desing in AM on Higher Education Institutions

In a total of 18 answers, 17 organizations mentioned that their organization could provide and benefit from sustainability in AM. They indicated these benefits as follows: cost estimation methods to determine the payback on AM tools; Life Cycle Assessment (LCA) evaluation on the recycling of AM products; development/circularity of new AM materials from recycled materials; use of build simulation tools to prevent bad decisions; optimization of energy consumption; optimization of different technologies (AM and non-AM); prototyping and industrial design; construction and design in general; basic knowledge on design, technologies, and materials in general; investment in repositories and platforms in native languages; standardization; environmental footprint of a product, process, or material; matching requirements; Azure manufacturing; types of technologies, design, and post-processing of 3D printed parts; parameters optimization to minimize waste and energy consumption; topology optimization, generative design, lattice structures; materials recycling; and good practices in industry.

3.2.8.Preferred Type of Training Methods in Sustainable Design in AM

The question aimed to gather insights from higher education stakeholders about training delivery for AM designers focusing on sustainable design topics. The findings were summarized in Table 8. A notable finding was that none of the interviewees favored exclusively online learning. Instead, the majority, six respondents, expressed a preference for a "blended learning" approach. They suggested that online learning could serve for introductory purposes but emphasized that nearly 70% of the course content should be delivered face-to-face and in close proximity to AM equipment. Four respondents specifically favoured face-to-face training. Practical exercises such as case studies and regular workshops were highlighted by four participants as beneficial components of the training. Furthermore, one respondent proposed delivering hands-on training through digital twins of AM equipment or VR technologies.

Table 8. Training Delivery Preferences

Training Delivery Method	Frequency
Blended learning	6
Face-to-face training	4
Practical Exercise (case studies, workshop)	4
Hands-on training	2
VR technologies	1

Both industrial and higher education stakeholders emphasize the importance of hands-on, practical training in sustainable design for AM. While industry focuses on optimizing existing designs and prototype production, higher education institutions provide a broad curriculum that integrates sustainability principles. However, there is a general lack of formal education specifically targeting sustainability in AM, highlighting the need for more structured and comprehensive training programs. Addressing barriers such as material costs, education gaps, and technological understanding will be crucial for advancing sustainable design practices in AM. The findings suggest a strong preference for blended learning methods, combining theoretical knowledge with practical application, to effectively equip designers with the necessary skills for sustainable AM.

4. Focus Group

The focus group was conducted with 17 experts from industry and higher education, including professors, researchers, engineers, and chief technologists. Three of them are already members of the IAMQS sustainability working group and the Metal AM design working group. The preparation for the focus group discussion was carefully designed to gather detailed and valuable information to validate the outcomes of the desk research and interview results, identifying gaps in additive manufacturing (AM) that the Sing for Green project curriculum and training aim to address. To this end, the partners held several preparatory meetings to decide on the agenda, presentation content, and questions to be raised during the focus group meeting.

The focus group event began with a presentation on the background of the Sing for Green project and an overview of some desk research outcomes. Following this, participants were divided into two groups to allow for more in-depth discussion. Each group addressed four open-ended questions, such as "Do you see additive manufacturing as a tool to develop more sustainable products?" and "Do you perceive barriers/limitations to implementing sustainability?

These questions guided the discussions in the breakout rooms, leading to productive exchanges. The experts' responses were recorded during the discussions and validated by the experts after each question. As the meetings were recorded, the project partners reviewed the recordings to thoroughly analyse the experts' opinions on sustainability in AM. The outcomes are presented below.

Sustainable Product Development: Experts debated the role of AM in sustainable product development, emphasizing its context and case-dependent nature. Examples included leveraging digital warehouses for spare parts beyond manufacturing. Additionally, they discussed the potential of AM in sustainable product development under the condition of economic sustainability and benefit to the business. Considerations included the balance between production aspects and sustainable practices.

Barriers/Challenges: Discussions highlighted limitations in implementing sustainability, such as the lack of comprehensive lifecycle information and challenges with material recyclability, emphasizing the need for a holistic approach.

Training Topics: Preferred training topics included design principles, materials development, and quality/certifications. As well as, the experts highlighted the topics components not typically printed, functionality, material selection, technical standards, and awareness of regulations' compliance specific to AM. Emphasis was placed on understanding the distinction between AM and other technologies.

Training Methods: Participants favoured training methods such as videos, theoretical principles, and software interaction. While blended modalities were deemed less effective, the importance of physicality and audience-specific considerations were highlighted. Additionally, "hands-on", "learning by doing," and direct exposure, with considerations for online training based on the topic complexity and audience preferences methods favoured.

The Focus Group discussions outlined the multifaceted considerations when integrating sustainability practices in AM training. Areas of focus included the holistic approach to sustainability, overcoming barriers, aligning training topics with industry needs, and selecting suitable training methods to enhance understanding and application.

5. Final Conclusion:

As previously described, the nature of the main tasks developed during Work Package WP2 and their sequentiality leads to an incremental assessment of those aspects that could be of high relevance for the short- and medium-term development of a curriculum capable of implementing a sustainability approach to the activities of a designer making good use of additive manufacturing technologies. Thus, in view of the main results and conclusions that have emerged throughout the process, it is now clear that there are a number of blocks or themes around which potential needs can be identified for the development of such a curriculum. These are outlined below::

- **AM Technologies and Processes**. The tasks carried out have led to a series of fundamental findings:

  - Under the concept of additive manufacturing, the state of the art shows that there are several technologies, which present very marked differences, insofar as knowledge of one technology (in the field of design and manufacturing) does not imply knowledge of the others.

  - Regarding the adoption and knowledge of the various technologies by experts in industrial and educational fields, there is currently a great disparity in their adoption, with a primary tendency to adopt one or two technologies (mainly powder bed fusion and material extrusion, VAT photopolymerization in some cases) and a much lesser approach to the other technologies.

  - It is necessary to consider that even if we compare the most widely adopted technologies, there are very marked differences between their technical capabilities, the available materials, the applicable design methodologies, and the criteria for sustainable manufacturing.

  - When we talk about processes, design for AM must also be included, as some of the potential advantages in terms of sustainability (lightweighting of parts, reduction of manufacturing times, etc.) are achieved much more easily if designers are well-versed in design techniques that are highly applicable to AM, such as topological optimization or generative design.

  Thus, a profound understanding of various AM technologies and their respective processes is crucial. Designers must be well-versed in specific AM methods.

- **Materials Knowledge**. The differences between technologies and processes are somewhat transferred to this theme, as it is found that:

    - Material selection is a critical aspect for product design (meeting technical requirements), as well as for assessing aspects related to manufacturability, cost, and potential recyclability. A significant aspect is the material's capability to be reused or disposed of in more sustainable conditions.

    - Nowadays, the selection of a manufacturing technology is an important determinant for access to various materials, as each AM technology demands materials of different natures and in specific formats. This implies that when an organization focuses on using only one AM technology, it misses the opportunity to know and access the materials available for another, which is a significant design limitation.

  Based on the above, and from the perspective of a designer, comprehensive knowledge about materials, including their properties and applications in AM, is essential. This includes understanding the sustainability aspects of different materials and their lifecycle impacts.

- **Product Lifecycle and Environmental Impact**. The tasks carried out show very clearly that, although there have been tools for qualitative and quantitative assessment of environmental impacts associated with manufacturing processes for years, the experiences among the experts consulted are still scarce, with very low penetration in the industrial field.

  This is a significant handicap for any product design and development process that aims to increase the sustainability of industrial activity, as any assertion not based on recognizable estimation methods lacks validity. In this sense, d.designers need to grasp the entire product lifecycle, from conception to disposal, to minimize environmental impacts. This includes life cycle assessment (LCA) and sustainability principles.

- **Economic and Marketing Benefits of Sustainability.** A large proportion of the interviews conducted establish an association between greater sustainability and higher costs, which can be a generalization that can only be assessed in light of analysis frameworks in which a product designed and manufactured using additive manufacturing technologies can be adequately evaluated in a complete techno-economic context. Thus, understanding the economic and marketing advantages of sustainable practices can help designers justify and implement sustainable designs despite potential cost barriers.

In the light of the information, the curriculum should cover critical areas such as advanced designing tools, sustainability integration into AM design, knowledge of AM materials, and techniques for identifying and accounting for environmental impacts. It also should include specific modules on eco-design, recycling, resource efficiency, and energy conservation. Practical examples and case studies should illustrate these concepts.

6. Annexes

Annex I- Interview Protocol of Higher Education

”Warm up”
It is suggested to start the interview with some previous conversation, in order to obtain some contextual data form the interviewee, as for example: - Name: - School/Institution: - Department: - Occupation: - Previous experience

Questions
1. AM: **Can you summarize the AM technologies and the related capabilites in which your organization is providing or can provide training activities?**
2. Design: **Does your organization provide training courses or materials related to design activities**?
3. Design for AM: **Does your organization provide specific courses or materials in the field of DFAM (Design for Additive Manufacturing)?**

4. Design for AM: **If the answer to question 3 is yes, can you summarize your training curriculum/programmes/courses/seminars, etc. offer?**
5. Sustainability: **Have you received any formal education or training on integrating sustainability principles into *DfAM* processes? Which?**
6. Sustainability and AM: **Does your organization have previous experience on implementing some specific methods, techniques, practices, or software for making AM related activities more sustainable (or more sustainable than other manufacturing options)?**

7. Sustainability and AM: **Do you see sustainiability as a training topic? Is it currently integrated in your AM training offer? An in the context of other manufacturing technologies? If the answer is yes, how?**
8. Sustainability and AM: **What do you see as the most important sustainability issues designers face nowadays?**

9. Sustainability and AM: **What specific knowledge and skills do you think are essential for designers to effectively implement sustainable design principles and practices in their work?**
10. Sustainability and AM: **Do you think that your organization could improve its current level of skills and Knowledge regarding AM-design-sustainability? If the answer is yes, in what areas?**
11. Sustainability and AM: **What types of training methods and platforms do you believe would be most effective in equipping designers with the necessary knowledge and skills for sustainable design?**

Conclusion	Yes	No
Are you interested in a free training of employees in your organisation focused on	☐	☐

sustainability context of AM technologies in design activities?		
What would be your prefeered topics for the training?		

Annex 2- Interview Protocol of Industry

"Warm up"
It is suggested to start the interview with some previous conversation, in order to obtain some contextual data form the interviewee, as for example: - Name: - Company: - Department: - Occupation: - Previous experience

Questions
1. AM: **Can you summarize the AM technologies/capabilites that are available in your organization as well as the available manufacturing materials?**
12. Design: **Does your organization carry out the design tasks for all the additive manufacturing works? If the answer is yes, could you please explain what is your typical design process for AM?**
13. Design for AM: **What design and slicing tools does your organization use?**

14. Design for AM: **Do you know about the term DfAM (Design for Additive Manufacturing)? Do you associate it with some specific methods, techniques, practices, or software? Which ones?**
15. Sustainability: **How does your organisation understand and implement sustainability in its industrial activity? Can you provide an successful example/case study?**
16. Sustainability and AM: **What kind of formal education or training on integrating sustainability principles into designing for AM processes have you received so far?**

17. Sustainability and AM: **Does your organization implement some specific methods, techniques, practices, or software for making AM related activities more sustainable (or more sustainable than other manufacturing options)?**
18. Sustainability and AM: **What existing sustainability initiatives or practices would you like to implement in the future?**
19. Sustainability and AM: **What barriers or limitations do you encounter when implementing sustainable practices?**

20. Sustainability and AM: **What specific knowledge and skills do you think are essential for designers to effectively implement sustainable design principles and practices in their work?**
21. Sustainability and AM: **What types of training methods or platforms do you believe would be most effective in equipping designers with the necessary knowledge and skills for sustainable design?**

22.	Is there anything you want to add?

Conclusion	Yes	No
Are you interested in a free training of employees in your organisation focused on sustainability context of AM technologies in design activities?	☐	☐
What would be your preferred topics for the training?		

