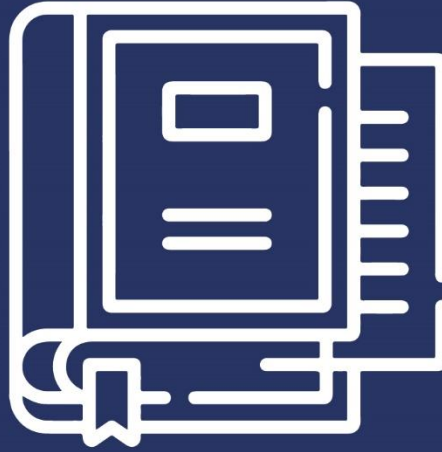


Address FOR FUTURE



WP3: Qualification

Result 2. Integration of Additive Manufacturing Technologies into University Curriculums

Leader of WP3. GAZI UNIVERSITESI (E10200512 – Türkiye)

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1. INTRODUCTION

There has been a growing recognition of the importance of additive manufacturing technologies in various industries, leading to an increased emphasis on integrating them into training curricula. In Europe, several universities have started incorporating additive manufacturing courses or modules into their engineering, design, or manufacturing programs. These courses typically cover topics such as the fundamentals of additive manufacturing, 3D printing technologies, material selection, design considerations, and post-processing techniques. Additionally, some universities offer specialized programs or degrees focused specifically on additive manufacturing.

Furthermore, partnerships between universities and industry stakeholders have been established to enhance additive manufacturing education. Collaborations with companies specializing in additive manufacturing technologies provide students with access to state-of-the-art equipment, industry-specific case studies, and real-world applications. This industry-academia collaboration helps bridge the gap between theoretical knowledge and practical skills required in additive manufacturing.

However, it is important to note that the specific extent of additive manufacturing integration into training curricula may vary across European countries and institutions. Some countries might have more developed and comprehensive additive manufacturing curricula compared to others, depending on factors such as industry demand, government initiatives, and research collaborations.

In addition to universities, there are also private education institutions that provide training and certification programs in additive manufacturing. These private institutions often offer more specialized and industry-focused training. Private education systems may also include smaller, specialized training providers that focus on specific aspects of additive manufacturing, such as design for additive manufacturing, materials, or process optimization.

ADDRESS for Future Project covers many aspects of activities including Identification and Analysis of AM in EU, Qualification, Skill Mapping, Training, Designing of Learning Tools, Forming Training Network and of course dissemination activities. Each of the activities has been designed to have action lists to be performed to reach the maximum efficiency and benefit at the end of the ADDRESS Project.

Previously, a general overview of AM in EU countries was formed using the data which were obtained by searching AM strategies of EU countries, company inventories and AM Survey.

This work package (WP) of the project namely WP3 aims to perform the Qualification of EU countries in terms of AM training curriculum and to propose a draft version of AM Curriculum to be adapted to E-learning platform for candidate AM trainees.

AM education curricula in different EU countries and different educational levels (such as technical schools, universities, and vocational schools etc.) should benefit the learners/students to gain the competencies of AM technologies by using both problem-based and project-based pedagogies. Currently, numerous AM curriculums are being taught in different education levels mostly in undergraduate and graduate levels.

However, the current AM curricula should be revised and improved based on AM industrial needs and technological developments since AM technologies are being evolved very quickly and teaching methods are being changed from conventional ways to digital tools. COVID pandemic has also promoted this educational transformation. Digital platforms and e-learning tools have become an alternative and efficient way of learning particularly for the persons who are suffering to reach highly technical trainings.

So, there is no holistic comparison of content (with different materials, design and production chapters) in this coverage. Access to curricula generally offered for a fee in private training companies or it is given in the universities for engineering students but with a limited coverage and with the needs analysis and developments. The curriculum to be created comparatively includes the scope of technical content and the practices of the production of direct industrial products, and the curriculum content will be presented as opensource, enabling all university educators, students, sector employees and anyone interested in AM throughout the EU to reach AM without geographical and economic obstacles. An inclusive comparison, in which general information is given in a field such as dynamics of production, material selection, design methods, more efficient designs with topological optimization, 3D printer types and working mechanisms, has not been established before.

Therefore, ADDRESS Project will facilitate the AM technical content which will be open to universities, technical schools, sector employees and anyone interested in AM throughout the EU to reach AM without geographical and economic obstacles.

2. SCOPE

This report is the output of the third work package (WP) of ADDRESS for Future Project. International comparative curriculum analysis in AM and integration of AM technologies into university curriculum are the two main activities of this WP of the project.

Main activities for this WP3. are;

1. AM courses and existing curriculums were searched in EU countries whether in universities, institutions, and colleges.
2. Collection of the curriculums and Course Identification Documents (CID) were used identify the current topics and focuses of AM courses.
3. Learning outcomes are the critical outputs of AM courses and learning outcomes are collected and extracted both from the AM strategy report and gap-fit-analysis.
4. Gap-fit-Analysis is a scientific method to compare the existing situation and the need to fill. This analysis was also performed in this WP by evaluating the AM strategy report and existing AM curriculums. The main output of the gap-fit-analysis is to determine what learning outcomes and AM Topics should be in the proposed AM Curriculum.
5. Target audience of this project WP is not only the university students but also NEETS (not in education, employment, or training) who are willing to be trained in AM and to get a chance to be employed in AM industry.

In addition to universities, there are several other beneficiaries who can benefit from the outputs of the ADDRESS for Future Project.

Vocational Training Institutions: Vocational training institutions focusing on technical and industrial skills development can utilize the AM curriculum and learning outcomes to enhance their training programs. By incorporating AM technologies and knowledge into their courses, they can provide their students with up-to-date skills and make them more employable in the AM industry.

Industries and Companies: Industries and companies involved in additive manufacturing can benefit from the project's outputs by gaining insights into the necessary skills and competencies required in the field. The project's curriculum analysis and identification of learning outcomes can help companies align their training programs and recruitment strategies with the desired skill sets.

NEETs (Not in Education, Employment, or Training): As mentioned earlier, NEETs are a specific target audience of the project. The project aims to provide training opportunities for NEETs in additive manufacturing, enabling them to acquire relevant skills and improve their employability. The developed curriculum and identified learning outcomes can serve as a valuable resource for NEETs seeking to enter the AM industry.

Policy Makers and Government Institutions: Policy makers and government institutions involved in shaping educational policies and workforce development initiatives can benefit from the project's findings. The curriculum analysis and identification of skill gaps can inform policy decisions and support the development of strategies to promote AM education and employment opportunities.

Educational Researchers and Scholars: Researchers and scholars in the field of education, particularly in the area of technical and vocational education, can utilize the project's outputs for further studies and analysis. The project's comparative curriculum analysis and gap-fit analysis provide valuable insights into the integration of AM technologies into educational systems.

Overall, the beneficiaries of the ADDRESS for Future Project extend beyond universities and encompass vocational training institutions, industries, NEETs, policy makers, government institutions, and educational researchers. The project's outputs aim to benefit various stakeholders by addressing the skill requirements and educational needs in the field of additive manufacturing.

3. AIM

Specializations working in AM technology today have created a strong demand that cannot be met by university graduates. According to the survey results conducted within the Address project, the investment category that received the highest percentage of votes, with 46%, for the question "What kind of investment will you make about AM?" was identified as training.

Additionally, for the question "What is the biggest challenge to implement AM technologies in your company?" the options "lack of qualified workers" and "lack of training" received the highest number of votes, ranking as the 2nd and 3rd choices, respectively.

The reason for this is that AM cannot be fully represented in training curricula, and in addition to this, the development of technology in the AM industry has not been able to respond to content that is extremely dynamic and requires a significant amount of new information every year.

Continuous, sustainable, and accessible training on AM has become particularly important for employed people. Creating this qualified education is only possible by determining the needs of the groups in this sector and creating contents that serve this purpose.

The aim of this study is to conduct an international comparative curriculum analysis focused on the integration of additive manufacturing technologies into training curricula. This research aims to explore the current state of additive manufacturing education across different training institutions in Europe, examining the courses, programs, and modules offered, as well as the learning outcomes and assessment methods employed.

By analyzing and comparing these curricular approaches, the study seeks to identify best practices, challenges, and gaps in additive manufacturing education, ultimately providing insights and recommendations for the effective integration of these technologies into training curricula.

4. METHODOLOGY

4.1. Current Additive Manufacturing Curriculum in EU Countries

The ADDRESS for Future project involves several partners from different countries, each contributing to the development of the Additive Manufacturing (AM) curriculum. Below list is the key information provided by the partners, in Appendix 3, all the detailed institution list has been given as well:

Gazi University from Türkiye: Gazi University has investigated 12 institutions and created 12 Course Identification Documents (CIDs) related to AM. Their efforts have mainly focused on institutions in Turkey, with one CID created for an institution in Serbia.

CEF from Türkiye: CEF has conducted investigations in 2 institutions and developed 2 CIDs. The institution in the United Kingdom has been the primary focus of their research and curriculum development.

EPMA from France: EPMA has examined 8 institutions and produced 11 CIDs. Their work has been concentrated in France, with 10 CIDs created for institutions in the country, and one CID for an institution in Belgium.

UNIBO from Italy: UNIBO has conducted investigations in 12 institutions and generated 19 CIDs. They have primarily focused on institutions in Italy, with 17 CIDs created for Italian institutions and one CID for an institution in Slovenia and one CID for an institution in Denmark.

UPM from Spain: UPM has investigated 6 institutions and developed 9 CIDs. Their efforts have been centered around institutions in Spain.

LOT from Bulgaria: LOT has conducted investigations in 28 institutions and created 34 CIDs. They have covered multiple countries, including Bulgaria, the Czech Republic, Estonia, Austria, and Germany.

In total, the project has involved investigations in 68 institutions and the creation of 87 Course Identification Documents across 14 different countries in the European Union. These efforts aim to contribute to the development of a comprehensive AM curriculum that can benefit learners and institutions across Europe.

Table 1 gives the details of the statistics of current curriculum numbers.

Table 1. Partners' contributions in terms of searched institutions and the numbers of AM Courses thought in EU Countries

Partners	Number of Investigated Institutions	Number of Created CIDs	Countries per CIDs
Gazi / Türkiye	12	12	Türkiye (11) Serbia (1)
CEF / Türkiye	2	2	UK (1) US (1)
EPMA / France	8	11	France (10) Belgium (1)
UNIBO /Italy	12	19	Italy (17) Slovenia (1), Denmark (1)
UPM / Spain	6	9	Spain (9)
LOT / Bulgaria	28	34	Bulgaria (10) Czech Republic (8) Estonia (5) Austria (3) Germany (8)
Total	68	87	14 Countries

This part of the report outlines the list of AM Courses and training courses in EU countries and existing curriculums. Collected curriculums are evaluated and classified based on focus area (i.e. process, design, material, application etc.)

AM courses can be grouped into different categories based on the topics which are thought.

- 1. Process:** This curriculum group focuses on the various AM processes, such as powder bed fusion, directed energy deposition, binder jetting, and material extrusion. It covers the principles, advantages, limitations, and applications of each process.
- 2. Design for AM:** This group emphasizes the design principles and considerations specific to additive manufacturing. It covers topics like design optimization, lattice structures, support structures, and design guidelines for achieving functional and efficient AM parts.
- 3. Materials:** This curriculum group delves into the materials used in additive manufacturing, including metals, polymers, ceramics, and composites. It explores material properties, selection criteria, processing parameters, and material testing for AM applications.
- 4. Applications:** This group focuses on the practical applications of additive manufacturing across various industries, such as aerospace, automotive, healthcare, and consumer goods. It covers case studies, industry-specific challenges, and the integration of AM into traditional manufacturing processes.
- 5. AM in Construction and Architecture (additive construction):** This specialized curriculum group concentrates on additive manufacturing techniques and applications in the construction industry. It covers topics like large-scale 3D printing, robotic construction, sustainable building practices, and architectural design using AM technologies.
- 6. Practical Skills for Operators:** This group provides hands-on training and practical skills development for AM machine operators. It includes topics like machine setup, maintenance, post-processing techniques, quality control, and safety protocols.

- 7. 3D Design and Manufacturing Technologies:** This group encompasses broader topics related to 3D design and digital manufacturing technologies. It may include CAD software training, computer-aided engineering, simulation, and digital workflow management.
- 8. MSc Program in Additive Manufacturing:** This curriculum group represents a comprehensive master's degree program dedicated to additive manufacturing. It covers a wide range of topics, including AM processes, materials, design, applications, research methods, and advanced concepts in AM.
- 9. Course of University Specialization in Additive Manufacturing:** This group refers to a focused curriculum offered by universities that provides in-depth knowledge and skills specific to additive manufacturing. It may include a combination of theory, practical exercises, and project work.
- 10. Professional Specialization Program in Additive Manufacturing:** This curriculum group caters to professionals and individuals seeking specialized training in additive manufacturing. It covers fundamental principles, practical applications, and industry-specific knowledge required for career advancement in the AM field.
- 11. EWF IAMQS Modular System:** The European Welding Federation (EWF) Integrated Additive Manufacturing Quality System (IAMQS) offers a modular curriculum system for AM education. It provides a structured pathway for acquiring skills and qualifications related to AM quality assurance, inspection, and certification.

These curriculum groups represent the diverse range of topics covered in AM courses, catering to different levels of expertise and specific application areas within additive manufacturing education.

4.2. Course Identification Document (CID)

A syllabus is a requisite document for teaching, and it delivers the outline and basic elements of the course. Course Identification Document (CID) covers syllabus and CID presents the way of teaching and all the necessary issues in teaching and assessment. A typical CID outlines the objective, scope, activities, teaching methods, assessment method, list of learning outcomes and weekly schedule.

In this project, 68 institutions where AM Courses are given, were searched among 14 Countries (Table 1). In total 87 CIDs were collected and examined the way of teaching and the elements of syllabus.

(Table 2) show the parts of a typical CID. Such document format will be helpful for trainers to give the courses in a systematic way.

Course Details	
Course Title	Master Sustainable Manufacturing and Advanced Technologies
Language of Instruction	French
Level of Course Unit	Master's Degree
Department / Program	Mechanical Engineering
Mode of Delivery	Face to Face

Type of Course Unit	Compulsory	
Objectives of the Course	Training future industry executives, researchers and teacher-researchers, with unique technical and scientific expertise but also integrating specialties to meet future challenges	
Course Content	Develop a practical sense by implementing a wide range of manufacturing processes and characterization techniques	
	Develop international/intercultural skills through mobility opportunities	
	Train in collaborative work and project management	
	Offer specializations centered on digital, smart processes, clean processes and the durability of components.	
Prerequisites and co-requisites	BAC+3 in engineering (Bachelor's degree)	
Course Coordinator		
Assistants		
Work Placement(s)	No	
Recommended or Required Reading		
Resources		
Course Category		
Mathematics and Basic Sciences	30%	
Engineering	30%	
Engineering Design	40%	
Social Sciences	0%	
Education	0%	
Science	0%	
Health	0%	
Field	0%	
Planned Learning Activities and Teaching Methods		
Activities are given in detail in the section of "Assessment Methods and Criteria" and "Workload Calculation"		
Assessment Methods and Criteria		
Mid-terms	1	% 30
Assigment	10	% 20
Practice	5	% 10
Projects	0	% 0
Final examination	1	% 40
ECTS Allocated Based on Student Workload		

Weekly Theoretical Course Hours	14	2
Weekly Tutorial Hours	14	1
Reading Tasks	14	2
Material Design and Implementation	11	4
Midterm Exam and Preperation for Midterm Exam	1	5
Final Exam and Preperation for Final Exam	1	5
Course Learning outcomes: Upon the successful completion of this course, students will be able to:		
1	Has a knowledge of advanced manufacturing processes	
2	Comprehends sustainability in these processes	
3	Develop international/intercultural skills through mobility opportunities	
4	Offer specializations centered on digital, smart processes, clean processes and the durability of components.	
Weekly Detailed Course Contents		
Week	Topics	
Semester 1	Fundamentals of manufacturing processes	
	Basics of production engineering	
	Metalworking processes	
	Additive-manufacturing	
	High temperature processes	
	Physical Measurement	
	Transversal project on manufacturing technologies	
	Research Methods	
Semester 2	Modern language	
	Materials: Correlation between microstructure and mechanical properties, Material selection, Thermodynamics and kinetics of materials	
	Characterisation: Modern Equipment and Techniques for Investigation of Structure and Properties of Metallic Alloys; Methods of Surfaces and Interfaces Investigation (OM, SEM, TEM, EBSD, XRD, AFM & others)	
	2 month internship	

Table 2. Typical Course Identification Document

4.3. Learning Outcomes and AM Topics in Curriculum

Learning outcomes are the list of achievements of the learners/students who take AM course. AM topics are the main areas and technological abilities where AM course should focus and thought in the AM course lectures. Learning output and AM topics were collected and extracted from AM Strategy and the current AM courses. (Table 3 shows an example list of learning outcomes and AM topics.)

Some of the learning outcomes are very basic needs in AM, however some of them are the up-to-date needs that an AM expert should have to be able to adapt the latest technological achievements. These learning outcomes also pointed out that different levels of technical qualifications should be given to AM trainers.

According to the results of the survey conducted by the ADDRESS project at the beginning of the project, highlighted the importance of training and personnel investment in the context of additive manufacturing (AM). Nearly %20 percent of the respondents stated "personnel investment" is the area with the most investment plans. This indicates that the qualification of individuals in the field of AM is critical.

AM STRATEGY AND SURVEY RESULTS BASED	
Learning Outcomes	AM Topics
Knows the basic principles of additive manufacturing technologies.	Fundamental principles of AM Technologies
Knows additive manufacturing methods, differences, usage areas and needed technologies.	General Additive Manufacturing Method/Process Cycle
Makes additive manufacturing process planning and applies design approaches for additive manufacturing.	Design for AM, Biomimetic Approach and Design Perspective and graphical tools
Knows the effects of manufacturing parameters changing according to additive manufacturing method on part quality.	Software and Hardware Tools in Additive Manufacturing
Learn the current AM technologies, their operating principles, and their characteristics	Metal, polymer, ceramic and composite-based materials used in additive manufacturing methods
Knows the post-processing methods, their application principles	Post-processing methods
Knows the selection of material to appropriate additive manufacturing method. Behaviour of the material in AM Process	Materials in AM
To learn the effects of manufacturing parameters that change according to the additive manufacturing method on part quality.	Industrial applications, innovations and developments of additive manufacturing methods
Able to model the AM processes and simulate using AM software	Bioprinting, micro-nano printing Methods
Able to design the factory/production line for AM	Process Simulations in AM
Knows the digital tools that can be used in AM	Industrial applications, innovations and developments of additive manufacturing methods
Able to check the quality of the AM parts	Production Planning in AM
Knows the standards of AM	Process Digitalization in AM
Able to make cost analysis of an AM parts	Quality Control
To have an awareness of environmental impact of AM Technologies	Standardization
	Cost-Analysis
	Environmental Impact of AM Methods

Table 3. The list of learning outcomes and AM topics

4.4. Gap-fit-Analysis

Gap-fit methodology is used to identify the areas where a planned system fits or does not fit according to the needs. Gap-fit-analysis starts with which topics should be evaluated in the analysis. Then, the current situation is examined, and the needs are listed based on the topics. Gaps are the missing points which should be filled and finally actions are assigned to each gap to fit. Curriculum highlights are the main AM topics that the AM curriculum should cover. Firstly, these curriculum highlights are evaluated whether the current curricula covers or not. Needs are the requirements of AM sector which are extracted from AM strategy report and Survey Results. Mostly these are the learning outcomes that AM users should have and most required abilities.

CURRICULUM HIGHLIGHTS	CURRENT CURRICULA	NEEDS AM Strategy Report & Survey Results	GAP	ACTIONS
Technology Awareness	Exists ISO/ASTM International Standard Technologies	- To know the AM technologies in detail, their differences, usage areas, and the related technologies	- Micro and nano scale additive manufacturing techniques are not included. - Bioprinting is not included enough - 4D Printing is not included	- Micro and nano scale manufacturing techniques should be included as a Topic. - Bioprinting and related materials should be included as a topic. - 4D printing and its materials should be included as a topic.
Design Perspective	Exists General DIAM rules	- Able to design the parts based on AM perspective, - to know the solid modelling, CAD formats	- Topology optimization ability - Generative design capability	- Optimization tools should be included - Topology optimization software should be thought - DIAM and generative design approach should be included
Material Knowledge	Exists Well-known materials	- To know materials used in AM, to choose appropriate materials for AM processes, - to know mechanical and metallurgical properties of the used materials, - to understand behavior of the material in processing	- micro and nano materials knowledge - bioprinting materials knowledge - Characterization of the AM materials - Heat treatment of the materials	- Materials and their metallurgy should be included as AM topic - Characterization of materials in AM processing should be thought - New and challenging materials should be thought
Materials Engineering	Partly Microstructure and mechanical properties, Material selection, Thermodynamics and kinetics of materials	- To know powder characterization methods and how to apply them in AM	- Terminology of Particle Size Distribution, powder density types, flow properties and how to measure.	- Should be included as a separate section
Process Developments	Exists Only popular AM methods	- To know the AM process parameters effects on part quality - Able to control the process parameters	- Process development stages - Intersection of process parameters	- Process development stages should be thought for each AM process
Process Simulations	Partly	- To simulate the AM process based on process parameters - Able to FEM Analysis - To analyze temperature distribution, thermal distortion, inherent strain - To simulate scan strategy - To determine support structure, density, type, and position. - To decide building direction and angle - To determine the feature orientation	- How to use AM simulation software and tools - How to use AM process planning tools and software	- One of the AM process simulation software should be included and practically thought in the course.
Post-Processing	Partly Very few methods: sand blasting, heat treatment etc.	- To determine proper post-processing method based on AM technology - to understand the effect of post-processing technique - To know surface treatment methods - To know heat treatment methods	- How to choose proper Post-processing technique - How to apply post-processing techniques	- Post-processing of AM parts should be included as separate AM topic - AM Specific Post-processing methods like HIP should be included as separate AM topic
Machine Operating	Not Exists Due to insufficient infrastructure	- Able to operate AM machine - Able to generate machine codes - Able to use the process control unit - Able to use control interface - Able to change the raw material - Able to change the necessary parts/accessories of AM Machine	- How to operate AM machine - How to use AM machine control unit	- Practical training should be given at least 20% of the training hour.
Machine Use and Maintenance	Not Exists Due to insufficient infrastructure	- Able to make daily and weekly maintenances - Able to change the necessary parts/accessories of AM Machine	- Maintenance of equipment (print head, oven, depowdering station, etc.)	- Practical training should be given
Factory Design for AM line production	Not Exists Future Trend Topic	- To know features and capabilities of AM equipment's - To know AM machine Technologies - To know job operation and job process proceeded sequentially - To know pre-production, production and post-production processes	- To understand and able to design an AM factory	- AM production planning topic should be given as a separate section
Process Digitalization	Not Exists Future Trend Topic			- Should be included in a separate chapter as Digitalization of AM
Process Control	Not Exists Future Trend Topic			
Artificial Intelligence Integration	Not Exists Future Trend Topic			
Data Processing and Security	Not Exists Future Trend Topic			
Quality Assurance	Not Exists Not Considered	- To know Tools and techniques to ensure that your 3D printed parts are manufactured to spec and perform as required - To know GD&T (Geometrical Dimensioning and Tolerances) measurement techniques	- To know GD&T tools and methods in AM	- Should be included as a separate Chapter as 'Quality Assurance in AM'
Standardization	Not Exists	- To know basic AM standards	- To know AM Standards	- Should be included in 'Quality Assurance in AM' Chapter
Cost Analysis	Not Exists Not Considered	- Able to consider cost units - To know the up-to-date costs (material, energy, operating etc.)	- Able to consider cost units - To know the up-to-date costs (material, energy, operating etc.)	- Should be thought included as a separate section in a chapter
Environmental Impact	Not Exists Not Considered	- To have an awareness of Environmental Impact of AM	- To have an awareness of Environmental Impact of AM	- Should be included as a separate section
Sustainability and Circularity	Partly Very few information on the sustainability in AM Future Trend Topic	- Assess the circularity and sustainability of AM processes.	- Lack of specific knowledge to assess the AM sustainability and Circularity	- Adding topics related to quantitative assessment of circularity and sustainability of AM using LCA and similar tools
Process Monitoring, In-line	Not Exists Future Trend Topic	- Able to control the process during the process: adaptive workflow	- Lack of specific knowledge about monitoring sensors applied to AM processes	- Adding topics related to technologies (imaging and thermal) and methods for in-line process monitoring
Process Monitoring, Post-process	Partly Future Trend Topic			- Adding topics related to technologies and methods for post-process monitoring
Software for design and optimization	Partly Software for optimization and conceptual design	- Able to develop optimization algorithms - Able to define the logistics of the production	- Lack of courses to learn software useful for path planning, optimization and logistic	- Adding the topics related to specific software for path planning and optimization and logistics
Practical skills for operators	Partly Very little knowledge about AM	- Operators able to manage the whole process. - Able to know materials, AM processes, Software for in-line and post-process monitoring	- Lack of specific contents devoted to practical skills for AM operators (apart the expensive courses of EWF)	- Adding topics related practical skills for AM operators

Table 4. Gap-fit-analysis of AM Courses and the needs-gaps-actions for the specified AM Topics

4.5. Modular AM Curriculum and CID Preparation

Additive manufacturing technologies have broad applications in different perspectives. Engineering and technology are the core in AM however cost analysis, design approach, critical thinking and risk analysis are also crucial and should be included in an AM syllabus. Therefore, there are plenty of learning outputs and topics that should be covered in AM Course and it would be practical and simple to give in a short term. Thus, a modular AM curriculum was proposed to include all the necessary topics of AM to be able to educate the persons in different background and knowledge level. It has been observed in the survey conducted at the beginning of the project that different sectors are engaged in additive manufacturing production using different materials and processes or planning new investments.

In the Address project, work package (WP) structures are frequently carried out simultaneously. The main reason for this is that the research outputs feed into sequentially designed work packages. WP3 and WP4 have been designed in this way. While examining the curricula across Europe, a simultaneous human resource skills mapping in different enterprises in different countries has also been initiated. Although the work conducted during this work package is presented in a separate report, one of its most valuable outputs is the need for talents to be involved at different levels.

Based on the outputs and knowledge areas mentioned, it is evident that there is a need to level the curricula in the field of additive manufacturing. The diverse range of topics covered, including understanding the physics of additive manufacturing processes, selecting suitable technologies, and mastering design principles, highlights the multidisciplinary nature of this field.

In addition to technical knowledge, the curricula should also emphasize the importance of sustainability and the reduction of environmental impact in additive manufacturing processes. Learners/Students should be encouraged to consider the durability of components, optimize designs for additive manufacturing, and explore clean processes that minimize carbon footprint and resource use.

Furthermore, the curricula should address the evolving nature of additive manufacturing technologies and the challenges associated with digital chaining, interoperability, and the integration of advanced manufacturing processes. By staying up to date with the latest advancements, learners/students can adapt to industry trends and contribute to the development of innovative solutions.

To enhance international collaboration and intercultural skills, curricula could incorporate mobility opportunities, enabling learners/students to gain exposure to additive manufacturing practices and perspectives from different regions and cultures. This global outlook will contribute to the overall competency and adaptability of graduates in the field.

Overall, leveling the curricula in additive manufacturing will enable learners/students to acquire a broad range of skills and knowledge necessary for success in this rapidly evolving field.

By incorporating these topics into the curricula and emphasizing interdisciplinary approaches, educational institutions can prepare learners/students to tackle the challenges and opportunities presented by additive manufacturing in various industries.

Additive manufacturing is a technology with immense potential for innovation and disruptive change across industries. By incorporating entrepreneurship training, learners/students can develop the mindset and skills necessary to identify market opportunities, transform ideas into viable products or services, and navigate the process of commercialization.

So, incorporating entrepreneurship training into the curricula for additive manufacturing can empower learners/students to become innovative, adaptable, and market-oriented professionals. By developing an entrepreneurial mindset, fostering interdisciplinary collaboration, and addressing market needs, learners/students will be better prepared to leverage the potential of additive manufacturing and contribute to its growth and impact in various industries.

At the end of all these research activities, partners were requested to extract the CIDs of their education models, learning outcomes, and the AM topics covered based on their research findings. To identify important and prioritized topics from the generated overall list, a decision matrix was implemented. Partners were asked to score and rank all topics based on Relevance (purpose to cover industry needs), Priority (priority to cover industry needs), and Applicability (easiness to implement to cover industry needs). The topics that received the highest scores were then ranked accordingly. In Appendix 4. Chosen Topics Relevance-Priority and Applicability Analysis can also be seen in detail.

Three levels are proposed for a comprehensive training in AM:

1. Beginner
2. Intermediate
3. Advanced

In Appendix 5. Course Identification Documents in Project Result Platform, the CID for all three recommended curricula has been made available for review. Beginner level encloses basic additive manufacturing technologies, design for AM approaches and fundamental process planning in AM. In Appendix 6. Curriculum Level Based Highlights Document also covers all additional topics for maximum learning outcomes compared with the existing curriculums reviewed.

Beginner Level

Table 5. shows the list of learning outcomes and weekly topics outlined in the CID prepared for Beginner Level AM Course. Additive manufacturing beginner level training targets a wide range of individuals, including unskilled, non-technical, and technical persons.

The goal is to provide knowledge and skills in additive manufacturing processes, technologies, and applications. Whether individuals have limited skills or technical expertise, the training aims to equip them with the necessary competencies to understand and utilize additive manufacturing techniques effectively.

By offering accessible and comprehensive training programs, unskilled, non-technical, and technical persons can enhance their capabilities and contribute to the growing field of additive manufacturing.

Course/Training Learning Outcomes: Upon the successful completion of this course/training, students/attendees will be able to:			
No	Learning Outcomes		
1	Know the basics of additive manufacturing, AM classification and know the differences between the conventional processes		
2	Know the polymer based additive manufacturing methods and their basic principles		
3	Know the metal based additive manufacturing methods and their basic principles		
4	Use CAD software and able to design parts for AM		
5	Know AM process planning, able to support generation and part orientation, related software issues and ready the part to be 3D printed		
Weekly Detailed Course/Training Contents			
Week	Topics (weekly times x hour)	Study Materials	Materials
1	Introduction to Additive Manufacturing: Overview on AM processes: classification of AM processes, The ASTM/ISO classification of Additive Manufacturing Technologies, main characteristics, advantages and manufacturing constraints. (1x4)	[Text 1, 2]	[Ref1], [Ref7]
2	Additive Manufacturing Methods-Polymers: Basic Principles, Material Knowledge, Constraints, Applications (3x3)	[Text 1, 2]	[Ref1]
3	Additive Manufacturing Methods-Metals: Basic Principles, Material Knowledge, Powder Metallurgy, Constraints, Applications (3x3)	[Text 1, 2]	
4	Design for Additive Manufacturing: Main concepts and objectives, basic tools for computer aided design (3D CAD modelling), shape complexity, DfAM Rules, Biomimetic Design Approach. (3x3)	[Text 1, 2]	[Ref1], [Ref5], [Ref 8]
5	Process Planning in Additive Manufacturing: Main concepts on the whole process planning chain (slicing, path-planning, platform optimization, support generation, machine code generation), Use of common AM Software (Cura, Magics, etc.) (3x3)	[Text 1, 2]	[Ref2], [Ref3], [Ref4]

Table 5. The list of learning outcomes and weekly topics of **Beginner Level AM Course**

Intermediate Level

Additive manufacturing technologies need engineering solutions and analytical approaches. Numerical implementations and solutions are having primary role in the design, processing, and applications. Therefore, intermediate level AM course is more engineering based and needs high level of theoretical engineering background and skills.

Design for AM is the mindset that each AM user should have, and it should be thought in a way. One key aspect that should be instilled in every additive manufacturing user is the "Design for AM" mindset.

This approach emphasizes designing products specifically tailored for additive manufacturing processes, considering the unique capabilities and limitations of the technology. It requires a deep understanding of the engineering principles and considerations involved in additive manufacturing.

To ensure the quality and functionality of additive manufacturing designs, various engineering analyses need to be conducted. These include thermal analysis to evaluate heat transfer and thermal management, structural analysis to assess mechanical strength and integrity, and modal analysis to

examine vibration and natural frequencies. These analyses are essential to justify or approve the performance, reliability, and safety of the additive manufacturing components or products.

Simulations play a critical role in reducing the overall cost and time. By incorporating these engineering analyses into the curriculum, the intermediate-level additive manufacturing course equips learners/students with the necessary knowledge and skills to effectively apply theoretical engineering concepts to real-world additive manufacturing scenarios. This enables them to optimize designs, troubleshoot potential issues, and ensure the overall quality and functionality of additive manufactured parts.

Finally, inspection and control finalize the produce parts and they need different testing methods such as mechanical metallurgical, and surface. Table 6 shows the proposed list of learning outcomes and AM topics for Intermediate Level AM Course.

Course/Training Learning Outcomes: Upon the successful completion of this course/training, students/attendees will be able to:			
No	Learning Outcomes		
1	Know deisgn for AM methods: generative design, topology optimisation and other design		
2	Perform optimisation design methods and perform computer engineering analysis		
3	Perform AM process development and knows the process parameters affects		
4	Perform thermal, mechanical and simulation analysis using AM software		
5	Know GD&T tools for AM, destrutice and non-destructive testing methods, surface		
Weekly Detailed Course/Training Contents			
Week	Topics (weekly times x hour)	Study Materials	Materials
1	Design for AM: Generative Design, Topology, shape and size Optimisation, lattice design, Reverse Engineering, Biomimetic design (3x3)	[Text1,2]	[Ref1], [Ref6], [Ref 8]
2	Design and Analysis: Mechanical and Thermal Anslsysis, Software implementations, Analysis of FEM results (3x3)	[Text1,2]	[Ref1], [Ref 8]
3	Process Development: Process Parameter Selection, part Orientation, support genaration, scanning strategies, path planning and process parameter Control (4x3)	[Text1,2]	
4	Process Simulation: Thermal Analysis, Distortion Analysis, strain analysis, support structure analysis, orientation analysis (3x3)	[Text1,2]	[Ref1], [Ref7]
5	Inspection and Quality Control: Non-destructive Testing Methods, Mechanical Testing methods, Microstructural Analysis, SEM, CT Analysis, Surface Topography Measurements Methods, Dimensional and tolerance measurements and analysis (2x3)	[Text1,2]	[Ref2], [Ref3], [Ref4]

Table 6. List of learning outcomes and AM topics for **Intermediate Level AM Course**

Advanced Level

Advanced level of AM Course implies post-processing and standardization, cost analysis and practical applications. Post-processing is a must in AM for most applications and parts. It needs theoretical knowledge and practice.

Standardization is not mature level in AM however there are huge attempts and effort how to standardize AM technologies, safety rules, testing, processes, post-processes etc. Cost analysis is the final job in AM process chain, but it could change all AM decisions. Therefore, AM users should have the ability to be able to know the parameters and expenses which affect the overall cost.

Practical application is a must and the core of AM training which may help to improve the abilities of end user and easy understand to how to design, implement and use.

Course/Training Learning Outcomes: Upon the successful completion of this course/training, students/attendees will be able to:			
No	Learning Outcomes		
1	Know post-processing methods and determine proper methods for AM technology		
2	Know AM standarts and able to perform cost-analysis considering cost units		
3	Know advance AM Techniques, materials, AI in AM and enviromental and social impacts		
4	Set-up AM machine, Plan AM production steps and prepare AM machine, control and perform whole sequence of production		
5	Perform part removal, support removal, sanding and necessary secondary operations		
Weekly Detailed Course/Training Contents			
Week	Topics (weekly times x hour)	Study Materials	Materials
1	Post-processing Methods: Surface enhancements methods, Heat Treatment, Support Reomoval, Finishing etc. (3x3)	[Text1,2]	[Ref1], [Ref6]
2	AM Standarts & Cost Analysis: Standardization and cost estimation (material, energy, operating etc.) (1x3)	[Text1,2]	[Ref1]
3	Advanced AM Techniques: AI in AM, Micro-Nonao Printing, Bioprinting, 4D Printing, Hybrid AM, FGM and Smart Matarials, enviromental and social implications (2x3)	[Text1,2]	[Ref7]
4	Practical Application 1: Production Planning & Preparation, industrial and business case models, Process Optimisation and Simulation, Machine Operation, raw material handling (loading and depowdering etc.) (5x6)	[Text1,2]	
5	Practical Application 2: Workshop Production, Post Processing, testing and Inspection, Maintenance of AM machine and its units (5x6)	[Text1,2]	

Table 6. List of learning outcomes and AM topics for **Advanced Level AM Course**

5. DISSEMINATION ACTIVITIES

In the 25th Welding and Joining Technologies seminar organized by the Spanish Welding Federation in Spain. An additive manufacturing workshop and conference were organized in Spain to facilitate knowledge sharing, collaboration, and networking among industry professionals, researchers, and stakeholders. This event aimed to disseminate the project's progress and create a platform for exchanging ideas and best practices. Additive manufacturing workshop and conference attendees were SMEs and other size company representatives, AM Professionals, Engineers, trainers.

CEF (Coşkunöz Education Foundation) Program Manager Vesile Bahtiyar and Gazi University Prof. Oğuzhan Yılmaz took part as a speaker. During the presentation, which focused on the developments in the Address for Future project, an EU initiative, insights and solutions regarding education, employment requirements, and the future of Additive Manufacturing as a sustainable production technology were shared. Within the scope of the project, the skill requirements of institutions working in the field of Additive Manufacturing and those interested in investing will be identified, an integrated educational curriculum will be designed, and the prepared curriculum will be made accessible to anyone interested in acquiring a profession in this field through an online platform.

The event, attended by approximately 200 people, 151 attendees in ADDRESS event but only 96 signatures could be taken. The event provided valuable feedback and input for the project. The survey results, the strategic framework report, and the gap between the current state and the expected state in education were presented to the participants, which received great interest from them.



Figure 1. Conference presentation as a Dissemination Activity

6. CONCLUSIONS

In conclusion, the third work package of the ADDRESS for Future Project focused on international comparative curriculum analysis in additive manufacturing (AM) and the integration of AM technologies into training curricula.

The aim was to address the strong demand for specialized professionals in the AM industry, which cannot be fully met by traditional university programs due to the dynamic nature of the field and the need for continuous updates.

The objective of this study was to conduct an international comparative curriculum analysis that focused on integrating AM technologies into training curricula. By examining AM courses, programs, and modules offered across different universities worldwide, the research aimed to identify best

practices, challenges, and gaps in AM education. This comprehensive analysis provides valuable insights and recommendations for effectively integrating AM technologies into training curricula.

Extensive research was conducted to search for AM courses and existing curriculums in EU countries, encompassing universities, institutions, and colleges. This collection of curriculums, along with the Course Identification Documents (CID) provided valuable insights into the current topics and focuses of AM courses.

The learning outcomes, crucial in AM education, were gathered from the AM strategy report and the gap-fit-analysis. This analysis aimed to compare the existing situation with the identified needs and determine the necessary learning outcomes and AM topics to be included in the proposed AM curriculum.

It's important to note that the target audience of this project's work package extended beyond university students to include NEETS (Not in Education, Employment, or Training) who were interested in receiving training in AM and obtaining employment opportunities in the industry. This highlights the project's commitment to making AM education accessible to a wider range of individuals.

The main outputs of this WP are as follows.

1. AM curriculums are searched and collected from universities, colleges and institutions among EU countries.
2. The collected AM curriculums are evaluated in terms of content, AM focus, technology focus and education levels.
3. To ensure consistency and compatibility, a Course Identification Document (CID) was prepared following the criteria outlined in EU universities' course catalogs, including factors such as ECTS, weekly schedules, assignments, and more. This document served as a framework for organizing and structuring the AM curriculums.
4. The learning outcomes and AM topics were extracted from the AM strategy report outputs and survey results. This comprehensive approach allowed for the identification of key areas to be covered in the curriculums.
5. A gap-fit-analysis, using a matrix approach, was carried out to assess the highlights, needs, gaps, and necessary actions within the AM curriculums. This analysis aimed to align the curriculums with the current state and future demands of the AM industry.
6. A modular CID is proposed which contains three levels of AM training: (1) Beginner, (2) Intermediate and (3) Advanced. This modular approach ensures a progressive learning experience for learners/students, allowing them to acquire the necessary knowledge and skills in a structured manner.

The outputs are presented in an international welding and joining conference special session named 'Additive Manufacturing'. More than 200 attendees listened to the session and the details were shared with the academics and industry representatives. The details and findings were also shared with academics and industry representatives, fostering collaboration, and promoting the integration of AM curriculums into educational institutions and industry practices.

Overall, this work package has played a significant role in advancing AM education by identifying current trends, addressing gaps, and providing guidance for the development of high-quality and up-to-date curricula. By aligning AM education with industry needs and ensuring continuous training opportunities, the project contributes to the growth and competitiveness of the AM industry, while also providing individuals with the skills necessary to thrive in this evolving field.

After the successful completion of the work package (WP) focusing on the evaluation and analysis of existing AM curriculums, the ADDRESS for Future project is moving forward to the next important stages. The upcoming work packages are Skill Mapping and Training Curriculum Designs, which aim to further enhance the development and implementation of the Additive Manufacturing (AM) curriculum.

Appendix 3: Institution List for AM Courses

Appendix 4. Chosen Topics Relevance-Priority and Applicability Analysis

Appendix 5. Course Identification Documents

Appendix 6. Curriculum Level Based Highlights



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