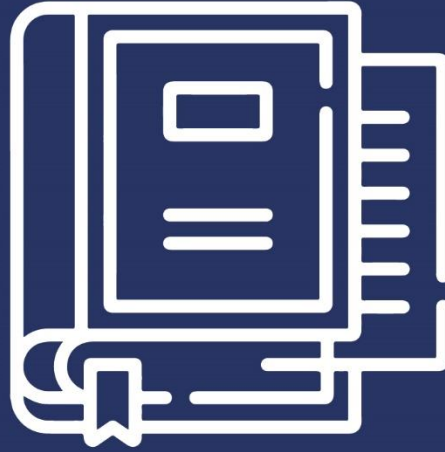


ADress

F O R F U T U R E



Appendix 8:

Matching of Critical Skills to IAMQS Outcomes

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MATCHING OF CRITICAL SKILLS TO IAMQS OUTCOMES

SAM (2019-2022) is Erasmus+ Project about Sector Skills Strategy in Additive Manufacturing which aims to tackle the current European need for developing an effective system to identify and anticipate the right skills for the Additive Manufacturing (AM) sector demands in response to the increasing labour market needs, thus, contributing for the smart, sustainable and inclusive growth of the AM sector.

And output of this project, The International AM Qualification System is composed by a set of qualifications for different proficiency levels in the field of AM technologies, grounded in industry requirements and validated by experts. The AM Qualification System covers Metal AM Qualifications for Operators, Technicians, Designers, Supervisor, Inspector, Coordinator and Engineers, as well one Polymer AM Qualification for Designers. The management of the International AM Qualification System is done by EWF.

AM competencies within the scope of the SAM project, that was made as a complimentary impact, used as a benchmark in ADDRESS project and the basic set of criteria taken.

The topic headings that emerged within the scope of the skill map work package were compared with the requirements for IAMQS.

By comparing the identified topic headings in the skill map with the IAMQS requirements for operators, designers, and engineers, a comprehensive understanding of the necessary competencies and qualifications can be obtained. This helps in aligning skill development initiatives with the industry standards and ensuring a well-rounded skill set among professionals in additive manufacturing.

As a first step, the key 13 general and process knowledge competences resulting from the survey conducted among AM intensive companies are mapped against the general and process knowledge learning outcomes of the three most representative IAMQS levels (in turn listed for representative technologies below) and, in a final attempt, the collection of key qualitative skills resulting from the study are again mapped face to the general contents, philosophy and aims of the IAMQS as a whole.

Mapping of key competences against representative IAMQS modules

Overall, the EWF Education, Training, and Qualification System for Additive Manufacturing Personnel, in alignment with the IAMQS, provides a structured approach to develop skilled professionals who can effectively leverage additive manufacturing technologies in industrial settings. It promotes a standardized framework for competence, quality, and continuous improvement in the AM industry, contributing to its growth and success.

	Required competency	IAMQS Operator	IAMQS Designer	IAMQS Engineer
General Skills	AM Process Overview	X	X	X
	Conventional manufacturing technologies	X	X	
	AM fundamentals	X	X	X
	Material Knowledge		X	X
	AM Manufacturing Technologies	X	X	X
	Computer aided design (CAD)		X	X
	Computer aided manufacturing (CAM)			
	Computer aided engineering (CAE)		X	X
	AM international quality standarts			X
	Sustainability in AM			
	Maintanance (TPM)			
	Post process skills			
	Safety knowledge			
Process based skills	Design for related process (relevant principles)		X	X
	Design software (solidworks, fusion 360, catia etc.)		X	
	Engineering analysis principles for related proces		X	X
	Analyses software		X	X
	Production of related process			X
	Quality testing and evaluation methods			

Mapping Methodical and Behavioral Skills to IAMQS contents, philosophy and aims

Required competency		IAMQS Operator	IAMQS Designer	IAMQS Engineer
Methodical & Behavioral Skills	Design Thinking			
	Process control and quality assurance methods			
	Production economics and business economics			
	Project management methods			
	Critical thinking	X	X	X
	Curiosity	X	X	X
	Eagerness to learn	X	X	X
	Creative thinking (out of box thinking)			
	Initiative (risk taking and decision making)			
	Teamwork	X	X	X

According to these results, it can be appropriately concluded that the IAMQS provides an appropriate training frame from the point of view of AM intensive companies.

However, ADDRESS is conceived as a Project aiming to provide an advanced step for the profitability of companies employing operators, designers and engineers aiming to collect all the required skills at each level with the more up-to-date disciplines shaping the way of implementation of emerging technologies.

Both projects have their own merits and relevance within the context of additive manufacturing education. The first project, SAM Project, ensures alignment with industry standards and requirements, which is crucial for professionals seeking recognition and employability within the field. The second project, with its beginner, intermediate, and advanced stages, addresses the need for comprehensive curricula that accommodate learners at different skill levels and support their progression within additive manufacturing.

SUMMARY OF TECHNICAL LEARNING OUTCOMES OF SELECTED LEVELS OF THE IAMQS FOR REPRESENTATIVE AM TECHNOLOGIES

1. EUR./INT. METAL AM OPERATOR: POWDER BED FUSION – LASER BEAM

LEARNING OUTCOMES	
COMPETENCE UNIT	SKILLS
CU 00: Additive Manufacturing Processes Overview	- Distinguish parts produced by different AM processes - Recognise the advantages and limitations of AM processes from a manufacturing process chain point of view - Identify the applicability of different AM processes, according to the characteristics of each process
CU 15: PBF-LB Process	- Describe the PBF-LB systems, including the components and their functions - Recognise the characteristics of the PBF-LB build platform, feedstock and other consumables - Recognise the PBF-LB parameters and the influence of their adjustment on the as built part - Recognise the interaction of the process heat source with the feedstock - Identify the problems associated with inadequate preparation and setup of the build platform, handling and storage of feed-stock and application of the gases used in PBF-LB
CU 16: Quality Assurance (QA) in PBF-LB	- Recognise the broader use of QA within engineering - Recognise the scope of the PBF-LB operator qualification within the AM industry - Support the qualification and requalification procedures of PBF-LB equipment - Identify the main procedures, equipment and their role - Prepare test reports based on the requirements specified by the manufacturer - Read a manufacturing plan - Compare geometry and dimensions specified in the technical drawings with the as built parts - Use simple measurement devices and techniques to carry out a basic visual inspection of the as built part - Identify problems in the as built parts distinguishing between imperfections and defects - Report defects suggesting either their removal with post processing operations, further inspection or part disposal
CU 17: Health, Safety and Environment (HSE) in PBF-LB	- Identify the main hazards and safety measures associated with PBF-LB systems

LEARNING OUTCOMES	
COMPETENCE UNIT	SKILLS
CU 18: Hardware, software and build file set-up for PBF-LB	- Prepare the machine for operation, according to the AM procedure specification - Prepare the feedstock, build platform and the machine in accordance to the material being used - Verify if the PBF-LB machine complies with the machine manufacturer and/or internal specifications - Load files to PBF-LB machines - Verify if the PBF-LB machines are working in accordance with the job specification, in terms of process parameters - Comply with HSE procedures associated to PBF-LB machines - Interpret technical information related to the PBF-LB process and machines
CU 19: Monitoring and managing the manufacturing of the PBF-LB parts	- Load powder following mandatory safety procedures - Apply HSE procedures when manufacturing parts - Interpret technical documentation related to the requirements of the as built parts - Identify the main reasons for failure during the manufacturing process - Prepare reports on the manufacturing process, including identified issues
CU 20: Post processing of PBF-LB parts	- Remove the as build parts and base plates from the machine applying the necessary HSE procedures - Carry out simple manual preparation of the as built part for different post-processing methods - Remove powder from the powder bed and parts following mandatory safety procedures - Separate the as built parts from base plates distinguishing the base plate from the part based on the technical drawing and specifications using simple manual processes
CU 21: Maintenance of PBF-LB systems	- Change protective lens and clean the nozzle - Assess the need to perform maintenance operations in PBF-LB system - Perform maintenance operations in PBF-LB system - Identify the consumables for the different machine parts - Report the need to execute specific maintenance - Support other technicians during system maintenance - Verify the cleanliness of the optic system - Verify if the optical system is working correctly - Monitoring and calibration status - Verify the level of wear of a mechanical component - Verify the system gas flow - Adequate maintenance routines to the material type - Verify the condition and make use of the personal protective equipment

LEARNING OUTCOMES	
COMPETENCE UNIT	SKILLS
CU 48: Powder Handling	- Complete technical documentation related to powders for metal AM - Characterise powders according to instructions from the engineer - Ensure powder conditioning according to the AM Procedure Specification - Control the reusability of powders - Handle powders according to HSE procedures
CU 49: Laser Beam Characterisation	- Safely carry out power measurements including power stability - Safely carry out beam profiling in different areas of the build platform - Use other measurement equipment to determine other Laser beam properties - Carry out measurement in accordance with existing standards and/or internal specifications

2. EUR./INT. METAL AM METAL AM DESIGNER FOR POWDER BED FUSION PROCESSES

LEARNING OUTCOMES	
COMPETENCE UNIT	SKILLS
CU 00: Additive Manufacturing Processes Overview	- Distinguish parts produced by different AM processes - Recognise the advantages and limitations of AM processes from a manufacturing process chain point of view - Identify the applicability of different AM processes, according to the characteristics of each process
CU 25: Post Processing	- Discuss methods to reduce distortion, using different post processes, for a variety of part geometries and AM processes. - Explain the applicable post processing methods to several AM processes as built parts - Describe the effect of different heat treatments on microstructure, mechanical properties, residual stress and defects - Explain the requirements that the as built part needs to have/comply according to each post process
CU 59: Relevant principles of PBF Processes for Design	- Associate the degrees of freedom of a PBF machine to the possibilities in terms of design - Relate the capabilities and limitations of PBF to design considerations - Determine dimensional constraints and geometric tolerances required for PBF parts design - Provide solution-based approaches to redefine design problems (Design thinking) within PBF processes and parts

LEARNING OUTCOMES	
COMPETENCE UNIT	SKILLS
CU 60: Design Metal AM parts for PBF Processes	- Verify and analyse requirements for production providing initial propositions and constraints - Analyse relevant costs considering the requirements, materials, machine hour rate and manual preparations to ensure the most efficient design - Test additively manufactured parts to assess the need for redesign (for example, when the part design is completed, and its performance needs to be tested. If it fails, some redesign may be needed.) - Carry out reengineering design using metal AM to design parts previously produced by conventional processes/methods - Ensure liaison with other technical areas (process, production, etc.) - Sign off (ESO) drawings (STL/AMF files included)
CU 61: Simulation Analysis	- Verify compliance between part requirements and simulation results - Run topology optimization considering part requirements interpretation in terms of in-service conditions - Define part design improvements based on simulation results - Elaborate simulation analysis reports proposing production strategies
CU 62: Hardware, software and build file set-up for PBF-LB	- Choose appropriate CAD file extension to export geometry to the FEA software workspace - Judge the type of Simulation Analysis (e.g. Structural, CFD, etc.) according to the problem characteristics - Assign physical properties (e.g. material, Boundary conditions, etc) to the geometry to reproduce the in- service solicitations - Select proper element type, size, solver and time step to generate a computationally time effective mesh - Appraise the quality of the model by comparing physical aspects between the simulation and reality - Perform an analysis to assess the converging characteristics of the model - Elaborate simulation reports specifying part geometry, boundary conditions, mesh characteristics, material model

3. EUR./INT. METAL AM PROCESS ENGINEER: DIRECTED ENERGY DEPOSITION – LASER BEAM

LEARNING OUTCOMES	
COMPETENCE UNIT	SKILLS
CU 00: Additive Manufacturing Processes Overview	- Distinguish parts produced by different AM processes - Recognise the advantages and limitations of AM processes from a manufacturing process chain point of view - Identify the applicability of different AM processes, according to the characteristics of each process
CU 08: DED-LB Process	- Describe the DED-LB systems, including the components and their functions - Distinguish different types of feedstock - Associate the interaction of the process heat source with the feedstock - Recognise the DED-LB parameters and the influence of their adjustment on the as built part (e.g. deformation) - Recognise the characteristics of the DED-LB build platform, feedstock and other consumables - Identify the problems associated with inadequate preparation and set-up of the build platform, handling and storage of feedstock and application of the gases used in DED-LB - Recognise the basic principles of 3D CAD systems and machine control software - Explain how the DED-LB process works - Explain the influence of modifying process parameters on the as built part - Discuss the influence of build platform, feedstock and other consumables characteristics on part manufacturing - Identify areas that will need thermal compensation - Identify the cause of defects and propose methods for their mitigation - Discuss the adequacy of selected equipment and accessories on the part manufacturing - Distinguish the different regimes and processes of failure and describe the factors controlling them and the boundaries and limits between them - Select specific materials for different applications to meet part requirements - Identify specific metallurgical aspects of DED-LB parts - Identify the variables used to define the DED-LB manufacturing strategy

LEARNING OUTCOMES	
COMPETENCE UNIT	SKILLS
CU 25: Post Processing	- Discuss methods to reduce distortion, using different post processes, for a variety of part geometries and AM processes. - Explain the applicable post processing methods to several AM processes as built parts - Describe the effect of different heat treatments on microstructure, mechanical properties, residual stress and defects - Explain the requirements that the as built part needs to have/comply according to each post process
CU 26: Introduction to materials	- Describe the structures of pure metals and alloys. - Explain, in detail, the principles of transformation and conditions of structure under which it occurs. - Interpret in detail the phase diagrams information and apply phase diagrams to define microstructures, mechanical properties and alloys. - Realise the mechanical properties of metallic materials according to their structures. - Describe the differences between elastic, plastic, cold and hot deformation that can occur in metals. - Explain the advantages and disadvantages of metals recrystallization, work hardening and strain ageing. - Interpret crystalline lattice distortion from given alloying elements and subsequent structural changes. - Compare the mechanisms of precipitation, types of precipitates and their location within the microstructure. - Explain the effect of loading conditions and temperature on the mechanical properties of metallic materials. - Explain in detail the differences between cracks and fractures comparing the mechanisms of different types of failures. Assess types of failures.
CU 27: AM with Steels feedstock (excluding Stainless Steel)	Describe the theory, principles and applicability of steels: - Describe processability with AM, including obtained properties and their relation with process parameters - Describe main causes of cracking and how to avoid - Identify possible imperfections, including metallurgical imperfections, and how to avoid - Select types of heat treatments when necessary For the following types of steels: low alloy, Cr-Mo, maraging and high strength steels: - Explain in detail the effects of micro-alloying, relating grain refinement to mechanical properties. - Discuss the AM conditions for a certain part taking into account the material ability for AM - Discuss carbon equivalent (CE), $t_{8/5}$ concept and preheating temperature - Discuss hardenability and maximum cooling rate - Identify the type of heat treatments requirements for a certain part, inferring the heat treatment conditions (depending of the shape and size of the part, the application and the code).

LEARNING OUTCOMES	
COMPETENCE UNIT	SKILLS
CU 28: AM with Stainless Steel feedstock	- Identify stainless steels type: austenitic, ferritic, martensitic, precipitation hardened, duplex and its ability to be processed by AM in all processes with different feedstock - Identify main problems for each Stainless Steel when AM processed by different AM processes and feedstock - Identify the material processability with AM, the type of heat source and feedstock - Discuss and predict how to prevent major cracking phenomena - Decide the type of post treatment required for a certain part (according to the type of stainless steel, the shape and size of the part, the application and any relevant documentation)
CU 29: AM with Aluminium feedstock	For the following metal and alloys – Aluminium: - Interpret the processability with AM for each alloy with different AM processes and feedstock - Discuss the applications, recommending processing parameters and shielding gases to achieve quality requirements for a specific part - Distinguish heat treatable and non-heat treatable alloys and problems in AM - Recommend methods to avoid cracking phenomena and solid-state micro fissures, providing alternatives where necessary.
CU 30: AM with Nickel feedstock	For the following metal and alloys – Nickel: - Interpret the processability with AM for each alloy with different AM processes and feedstock - Discuss the applications, recommending processing parameters and shielding gases to achieve quality requirements for a specific part - Recommend methods to avoid cracking phenomena and solid-state micro fissures, providing alternatives where necessary.
CU 31: AM with Titanium feedstock	Describe in detail the theory, principles and applicability of: - Titanium processability with AM - Main causes of cracking and how to avoid - Heat treatments- types and techniques For the following metal and alloys – Titanium: - Interpret the processability with AM - Discuss the applications, recommending heat input, shielding gases to achieve quality requirements for a specific part - Recommend methods to avoid cracking phenomena and solid-state micro cracks, providing alternatives where necessary.
CU 32: AM with Tungsten feedstock	For Tungsten: - Interpret the processability of W with different AM processes and feedstock - Discuss the applications, recommending processing parameters and shielding gases to achieve quality requirements for a specific part

LEARNING OUTCOMES	
COMPETENCE UNIT	SKILLS
CU 33: Biomedical metallic materials	Describe in detail the theory, principles and applicability of - Biomedical metallic materials processability with AM - Main causes of cracking and how to avoid - Heat treatments- types and techniques For the Biomedical metallic materials - Interpret the processability with AM - Discuss the applications, recommending heat input, shielding gases to achieve quality requirements for a specific part - Recommend methods to avoid cracking phenomena and solid-state micro cracks, providing alternatives where necessary.
CU 35: Metal AM integration	- Analyse all the manufacturing processes existing in the company comparing AM with other manufacturing processes - Design AM cells including selection of AM machine and methods to manipulate the part, fixturing and sensing of the part, equipment for loading and unloading. - Design a factory layout that incorporates all required manufacturing operations - Provide inputs for a factory layout design that incorporates all required manufacturing operations - Recommend procedures for integration of AM processes within the company's manufacturing chain - Discuss the commercial aspects related to the integration of AM fostering the involvement of internal and external stakeholders in the adoption of AM
CU 36: Coordination activities	- Manage communications across all actors involved in the AM manufacturing chain - Establish procedures for information control and traceability - Control all the information generated within a given AM
CU 40: Production of DED-LB parts	- Discuss Design for AM features with other AM staff. - Adapt CAD files to build files (e.g. toolpath) - Interpret reports of finite element analysis and numerical modelling to AM (e.g. topology optimisation, distortion, residual stresses) - Apply workflows for virtual pre-processing (e.g. part orientation) - Demonstrate competency in working with toolpath creation software - Select specific materials for different applications to meet part requirements - Propose a suitable toolpath for a given part and identify the areas that will need thermal compensation. - Propose methods to reduce distortion for a variety of part geometries and processes. - Identify the cause of defects and propose methods for their mitigation. - Identify the most suitable post processing technique for a specific AM process and application - Create a DED-LB AMPS - Produce work instructions for the DED-LB Operator

LEARNING OUTCOMES	
COMPETENCE UNIT	SKILLS
CU 41: Conformity of DED-LB parts	- Apply the principles of quality management to process and part qualification - Evaluate feedstock characteristics required to qualify a part - Develop AM procedures according to appropriate standards and other documentation - Select Non-Destructive Testing and Destructive Testing methods to characterise a part - Interpret Destructive and Non-Destructive Testing reports - Adapt AMPS based on results from testing results - Integrate troubleshooting techniques in manufacturing process chain - Propose methods to perform the repair and re-certification of a damaged DED-LB part - Guarantee process conformity to client's requests, standards and other requirements - Define the manufacturing and approval of test artefacts - Interpret inline control and monitoring systems data and define correction strategies
CU 42: Conformity of facilities featuring DED-LB	- Explain in detail the health and safety hazards associated with Laser, electricity, gases, fumes, fire, radiation and noise, grinding, spatter, flame, fire, combustion. - Predict the hazards, defining the health and safety requirements and working procedures, including the definition of the necessary PPE. - Recommend healthy and safe workplace practices to be implemented in a manufacturing plant.