Skills Requirements for the 4th Industrial Revolution: The Additive Manufacturing case

Panagiotis Stavropoulos[1,*], *Andreas K.* Lianos[1], *Harry* Bikas[1], *Dimitris* Mourtzis[1]

[1]Laboratory for Manufacturing Systems & Automation, Department of Mechanical Engineering and Aeronautics, University of Patras, Patras 26504, Greece

Abstract. This work analyses the required expertise knowledge for the European workforce under the implementation spectrum of the technologies from Industry4.0. The advancement of the conventional manufacturing technologies with complementary monitoring and control systems combined with the rapid growth of unconventional manufacturing technologies, calls for the equivalent advancement in the workforce's expertise. The Industry's 4.0 skills are mapped and categorized based on the knowledge requirements derived from the major technologies involved. The competences' categorization is what further determines the Professional Profiles and skills requirements for the Industry4.0. As Additive Manufacturing is one of the most significant manufacturing technologies implemented from Industry4.0 a case study for the required AM skills is performed. The outcome of this work indicates that the AM Professional Profile is a multi-dimensional quantity with multiple competence units that require validation and further evaluation in order to meet the skills requirements imposed by the industry.

Terminology

Digital Complementary Technologies	All secondary technologies that: are aiding an existing and integral technology of the overall product development, the part manufacturing processes or are introduced as a separate stage in the production in order to increase the overall performance. The complementary technologies can be subtracted without effecting the production's ability to be completed. The "digital" complementary technologies are mainly related to computational means for automation, AI and cloud-based technologies.
Competence/ Competency	Competence: refers to a specific function and its effective accomplishment. It is based on the outcome-based approach that screens the individual skills and knowledge as the required foundation. Competency: Refers to the sum of behaviors and traits that are required to perform a function These two terms both appear in the literature and are used interchangeably to describe traits under the scheme of the Professional Profiles. It can be derived that the term competence is used for specific technical skills whereas the term competency for general in nature soft skills. In this paper the term competence is exclusively used.
Competence Model	The result of a competence identification which is a description of competences for an identifiable group and its key characteristics [1].
Competence Unit	Competence units are the smallest modules that shape the model. They are extracted from different types of analysis including occupational analysis, value chain analysis, functional analysis, and proficiency level analysis. Often, only one of the analysis methods is dominant considering the nature of the industry [2].
Competence Standards	They document the expected performance for the competence units and are used for qualification procedures at both the early stages of the Professional Profiles definition and at the later training or the workforce.

*Corresponding author: pstavr@lms.mech.upatras.gr

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Competence Level	Is a quantified metric that screens the educational level of the Professional Profile. The existing classification has six levels of competence levels form graduate diploma to generic certificate [2].

1 Introduction: Industry 4.0 and Professional Competences

Along the lines of Industry 4.0 paradigm for the manufacturing industries, a series of competence units, requirements and new skills have been introduced. The Professional Profiles of the dominant industries are being redefined as the mechanisms of how the progress and tasks are being released is radically changing compared to the status quo of no more than 20 years ago [3,4]. This initial approach referred to all-rounded abilities a worker/engineer should master, and included all technical, leadership and social skills.

The above professional competences status and requirements have been extensively described and reviewed from a soft-skills prism for Industry 4.0 [5]. That is, the current state of the manufacturing industry, considering the uptake of advanced manufacturing technologies, requires a further definition of the Professional Profiles in terms of technical/hard skills from technician certificates to graduate diplomas [6,7]. This created a need for establishing training and educational mechanism. This applies for both products and services as the mentality of how they are perceived, designed, made and finally validated and monitored is changing due to the innovative outcomes of Industry 4.0. The decomposition of a Professional profile to its characteristic subsets is shown in Fig. 1.

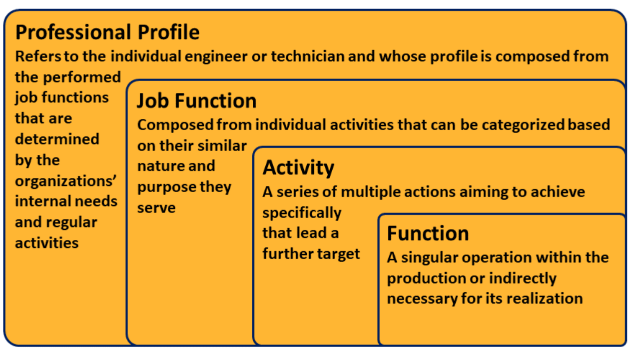

Fig. 1. The Professional Profile's sub elements

2 The Shift of the Professional Profiles

Although the nature of the manufacturing and its processes remain the same at their core, the involvement of digital complementary technologies targets these exact stages in order to effectively optimize their performance and reduce costs [8]. The above advancements are driven from four main factors that are sorted based on the frame in Fig. 2. The introduction of a new technology has two implications; it creates an additional production step in the production chain and it also increases the demand for expertise linked to this technology. This work's main thematic axis is focused on the Advanced Manufacturing technology of Additive Manufacturing. That is, the framework and the technological drivers of Industry 4.0 that are used to establish the main aspects that are causing Professional Profiles' shift can be extrapolated to the rest of the technologies.

The current skills' gap is traced back to the misalignment of the AM industry with the knowledge and training providers that is further increased with the introduction or advancement of new complementary technologies and materials [9]. For instance, a machine operator for a DED AM process, apart from the generic expertise for robot and AM head operation, is now required to operate in-line monitoring and control equipment which have increased the Competence Units for their Competence Level. The high growth rate of the AM industry cultivates an equally high demand for skilled AM workers and engineers which combined with the limited in number and capacity training and education institutions specialized in AM, results in the current insufficient status of the AM workforce and expertise.

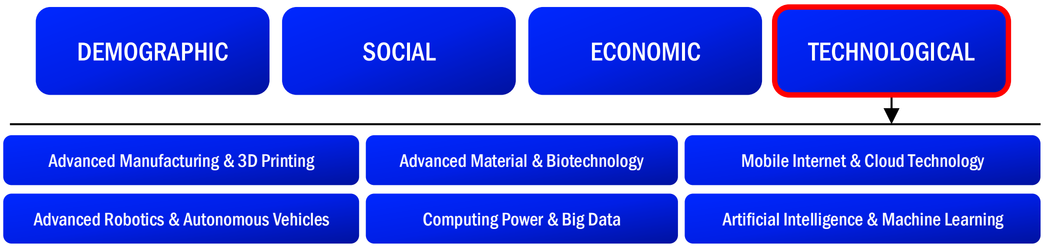

Fig. 2. Categorized Drivers of Industry 4.0 that effect the Professional Profiles

3 Establishing the Professional Profiles for Additive Manufacturing

The method presented below, to establish the AM Professional Profiles, is derived from the process-driven modelling approach [10] and the Organization Strategy and Objectives Model [11]. The combined methods are to best serve the AM current state and nature for the AM sectorial skills. The method can be separated to two stages:

1. Initiation from the objectives of the end user and the required operations that are gathered form specific activities. In the case of AM, the objectives are to realize product development and part manufacturing.
2. These activities are delegated to the people within the organization and further grouped to form a job function and finally a Professional Profile.

Determining the Professional Profiles for AM and the blocks of knowledge, expertise and skills for these Competences Units will define the required educational and training content for the upcoming AM workforce. This will additionally set the requirements for the Competence Standards and qualifications of the AM engineers and technicians.

The different stages of the overall AM production impose activities and operations that must be carried on by the equivalent experts. This creates specific roles within the whole product development and production chain as shown in Fig. 3. The definition of the above functions and activities for the Professional Profiles is a task being undertaken by major AM European players to further expand the use of AM in production applications.

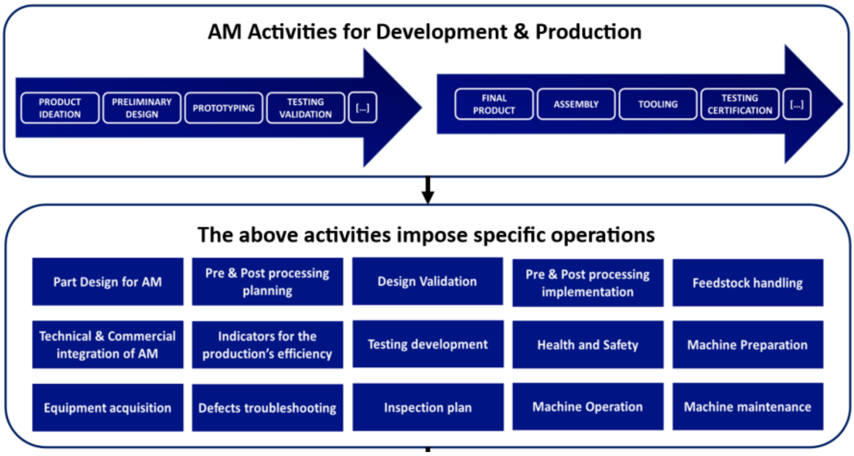

Fig. 3. AM Activities from the product development to the final manufacturing of the product.

The Professional Profiles and the specific functions each person perform within the AM design and production stages have been defined as shown in Fig. 4.

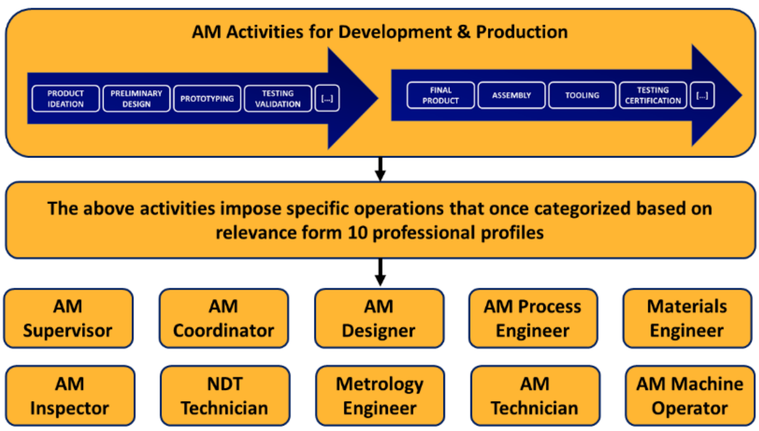

Fig. 4. The generation of the AM Professional Profiles

The Professional Profiles' descriptions are presented in Table 1:

Table 1. AM Professional Profiles' descriptions

PROFILE	DESCRIPTION
1. AM SUPERVISOR	Supervises the AM production on shop floor ensuring quality and HSE procedures.
2. AM COORDINATOR	Evaluates manufacturing suitability for end-use customers' requests defining which AM and post processes are fit for the request. Coordinate the work within the AM team.
3. AM DESIGNER	Designs optimized parts for function and cost, ensuring that the buildability constrains are secured and validating that parts can be produced cost-effectively and efficiently; Validates specific AM process design projects by verifying requirements with production engineer.
4. AM PROCESS ENGINEER	Creates the AM manufacturing process for the efficient production planning of additively manufactured parts including post-processing. They also carry the responsibility of the final design validation and tasks coordination between the operators according to the work planning.
5. MATERIALS ENGINEER	Specifies the optimal material to meet the functional and manufacturing requirements of the part and implement material handling processes for the entire material life cycle. They also provide insight for part failure troubleshooting that is traced back to material properties.

6. AM INSPECTOR	Carries out the inspection of the parts after their manufacturing and during the post -processing stages to the specified requirements and quality assessment.
7. NDT TECHNICIAN	Carries out the safe and reliable non-destructive testing of complex geometry additively manufactured parts.
8. METROLOGY ENGINEER	Specifies the optimal measurement method to meet the functional and manufacturing requirements of the part.
9. AM TECHNICIAN	Carries out the safe and reliable non-destructive testing of complex geometry additively manufactured parts.
10. AM MACHINE OPERATOR	Professionals that perform reliable production based on standardized procedures including post-processing, fitting and setting up AM printers, maintenance and machine repairs.

This is to identify the current knowledge gaps in terms of technical competences for AM technologies under the umbrella of Industry 4.0. The initiative of the training and educational European institutions aims to determining the content of their future programs which makes this process of establishing the AM Professional Profiles highly critical.

4 Conclusion and Discussion

The current and near future of AM workforce faces a shortcoming of specialized people having the expertise to perform AM engineering and AM machine operation. That is, the Industry 4.0 future AM workforce framework is to be based on the established Professional Profiles and Competence Units for both the processes of educating and certifying in the AM world. This is to be realized via three main channels:

1. Educational institutions. This channel involves the early education of pupils and students and is undertaken by organizations in education (e.g. universities, schools, online course providers). The Teaching Factory initiative was found to the best educational approach, as it effectively creates a communication channel, connecting an industrial AM entity with the undergraduate engineers [12].
2. Training Centers. For certified technicians and high Competency Level diplomas the existing European organizations, legislated for providing training courses, are to establish and validate the content for the AM Professional Profiles. This content will be commercialized by their programs or shared within their networks.
3. Internal company trainings. For the most cases the end-users of AM engineers and technical personnel, are organizations (e.g. R&D departments, part or equipment manufacturers) that utilize an AM technology in one of their productive stages. The current status sees most of these organizations with their own internal educating and training system that is based on their specific needs and AM activities in present time. Once the Professional Profiles are established with the modular fashion of the proposed method, these organizations will have the ability to recruit AM personnel based on the Job Functions they are performing and the Competence Standards of the training and certification centers.

The process described above calls for a close contact between the training and educational institutions with the AM industry. This is due to the fact that the constant shift of needs and operations withing Industry 4.0 calls for the equivalent adaptation of the training and educational context via periodic redefinition: every two years for rapidly changing industries and every 5-10 years for conservative industries. Furthermore, the validation and publication of the skills mapping is to be established by standardization organizations to be aligned with the European Qualifications Framework (EQF).

The continuation of the initial determination of the Professional Profiles with the proposed method is their validation and then their periodic re-evaluation. This requires a two-side party cooperation. The first party is the standardization organization with universal acceptance and legal presence that validates and publishes the Professional Profiles based on the Competence Standard for the Competence Level it provides. The second end of the two-side party is a panel of key-actors in the AM field, that performs the initial evaluate and then the update of the competence units for the Professional Profiles. The current expertise demand appointed by the industrial actors combined with the foresight of the training and educational organizations acts as input for the Job Functions' complementary definition.

The long-term sustainable mechanism to meet the everchanging skills requirements is Education 4.0 where the AM competences are fully developed. This aims to create technical learning outcome for the future engineers in order for them to fully exploit the freeform advantageous nature of Additive Manufacturing [13].

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