Competencies to Address the Industrial Additive Manufacturing Towards Sustainable Production

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Abstract. Since the North Rhine-Westphalia (NRW) region is currently undergoing a structural change towards a CO2 neutral energy supply, the use of additive manufacturing (AM) can offer great potential to produce in a more sustainable way. AM can also offer opportunities for industry with regard to other aspects, since production complexity can also be reduced, and time-to-market shortened at the same time. Against this background of increasing importance of AM, this study has the focus to find out what competencies an employee in AM should have in order to establish him/herself in this area in the future and successfully use AM in the industry. For this purpose, problem-centered and guided expert interviews were conducted with 19 experts from different industries. The interviews were then transcribed and evaluated using Mayring's content analysis. A key finding of this work is that knowledge of technology and materials, the ability to part identification, and a basic understanding of the process chain in AM are among the most important hard skills for a future employee in AM. Regarding soft skills, the willingness to openly exchange ideas, the ability to work in a team in conjunction with good communication skills, a conscientious approach to work and the right mindset are emphasized. In conclusion, regarding structural change in NRW, it is clear from the interviews that the experts particularly suggest opportunities in the area of sustainability, but also greater collaboration within companies and universities involved in AM.

Keywords: Additive Manufacturing · Sustainable production · Competencies · Upskilling and Reskilling

1 Introduction

Additive manufacturing (AM) is now used in many industrial manufacturing processes. It is seen as a key technology for the current industrial structural change and many companies are intensively dealing with the different printing processes, materials and economic use [1]. To do this, employees in the respective industries must learn new

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skills and also already have knowledge from their university or school education. The aim of this work is to find out which competencies, that comprise knowledge, skills and attitudes, are of essential importance in this context. Furthermore, the study deals with the question of which technologies and materials are preferably used in additive manufacturing, especially in the NRW region, and which of these could become relevant in the future [2].

This paper first explains the theoretical basis of additive manufacturing in current industrial applications, the technology maturity of individual printing processes and materials, and the existing and lacking knowledge of AM workers. Afterwards, the procedure of the qualitative content analysis is explained. The preparation and follow-up of the conducted problem-centered and guideline-based expert interviews, as well as the result evaluation and analysis are also presented. Finally, the results are discussed, taking into account possible limitations and the actual derivation of recommendations for industry, trainers and universities.

2 State of the Art

2.1 Additive Manufacturing

Additive manufacturing - often also called 3D printing or rapid prototyping - belongs to the industrial manufacturing processes. It represents a new category in manufacturing technology in addition to classical processes. A distinction is made between subtractive manufacturing processes, such as machining, milling or turning, and formative manufacturing processes, such as casting or forging. Additive manufacturing is a layer-based automated manufacturing process of physical objects based on three-dimensional computer aided design (CAD) files [3]. All additive manufacturing methods in the printing process do not require an object-dependent tool. However, the entire process chain is counted as additive manufacturing. This includes the design, the selection of the appropriate technology and materials, the parameter settings or calibration of the printer, the monitoring of the printing process and the post-processing. Without a series of post-processing steps, the components are often not usable in the industries under consideration, automotive, aerospace and energy [4].

Manufacturing with AM therefore requires expertise in the different process steps of the AM process chain and also the linking of the steps for a smooth flow of the entire AM process chain.

2.2 Typical Areas of Application

To apply additive manufacturing, it is worth looking at the advantages over traditional manufacturing technologies. One advantage is weight reduction through intelligent design, where material is only added where forces need to be absorbed. This saves both material and fuel, helping to improve resource efficiency and reduce emissions. Some components whose conventional design is already complex can be improved to any degree of complexity through additive manufacturing [5]. For example, channels for flow control were applied to an impeller with additively manufactured blades.

Additive manufacturing can also combine new materials, such as certain high-strength, temperature-resistant, weather- and moisture-resistant metal alloys or polymers, whose use was not previously possible due to the material properties at room temperature or slow cooling rates of traditional manufacturing techniques. A common application of AM is prototyping, which contributes greatly to developing new innovations, merging multiple components, or redesigning. It can also be applied to the production of low volume parts, e.g. spare parts or the aftermarket of discontinued models or the customizing of cars or consumer goods [6].

3 Methodology

Our exploratory study to identify what competencies are required of employees in additive manufacturing consists of 19 problem-centered expert interviews [7]. We selected experts based on multi-year experience in application of additive manufacturing technologies in the field and recruited them via the platform LinkedIn. Industries in which our experts are active include aerospace, automotive, energy among others. The interviews lasted from 40 to 90 min. For the interviews, we designed a semi-structured interview guideline that consisted of four main parts that investigated the AM-technology applied by experts and questions on skill requirements of employees (Green skills, digital skills, hard and soft skills). All interviews were audio-recorded and then transcribed. All 291 pages of transcript were subjected to thematic analysis according to Mayring [8] using the software MAXQDA. Codes were developed by iteratively moving through the data in multiple cycles and subsequently developing categories in an inductive approach. Coding categories emerged in a step-by-step process from open-ended observations of the researchers and were merged to a final set of themes [9]. A total of eight categories with an average of five subcategories were discovered.

4 Results

One of the questions of this study deals with finding out which skills are necessary for the future AM employee to establish himself in this field in the future. In addition to the hard skills, the questionnaire also addresses the soft skills that future employees need, as mentioned by the participants. In addition to the "hard" and "soft", it is also important to know how these can best be taught in the future. Therefore, direct implications to educational content were identified via the interviews. The second part of the research questions deals, among other things, with which technologies, materials, applications and trends could be specifically relevant for the NRW region in the future. The main findings are presented in short in the Table 1 and discussed in depth in the following subchapters.

4.1 Hard Skills

Among many skills mentioned, the focus is on process-related AM knowledge, material knowledge, quality management and part screening, which are discussed in depth as follows.

Table 1. Key findings from 19 interviews related to hard and soft skills, educational and regional implications

Category	Development/Conclusions
Hard skills	• Process-related AM knowledge, material knowledge, quality management and part screening
Soft skills	• Open for innovation, way of working, ability to work in a team, way of thinking
Educational implications	• Theoretical AM knowledge, dual study for practice knowledge, material science, technology potential related to use case, teaching based on standards, use of enabling technologies
Regional implications	• Sustainability and sustainable production, open source, great potential to SMEs, digital warehouse for storage of spare parts

Process-related AM knowledge was mentioned by 17 out of 19 participants in this study as an important "hard skill" that future employees in the AM area should have. This is about developing a basic understanding of all processes within the process chain and not just being a specialist in one area. The participants emphasize the advantage that future employees could draw from such a skill. These are, for example, possibilities of scaling, faster problem solving, but also the understanding of what limitations there are in 3D printing.

> *"Every additive process has different sizes that it can scale. […]. And for that it's no enough to know how I design what, you have to understand the technology. Not in detail, but you need to understand how the process is, what constraints and function it has." (IP14, lines 170–177)*

The experts also see material knowledge as an important hard skill in additive manufacturing. The participants emphasize that in AM the challenge often lies in knowing which material is suitable for which product and what possibilities the materials give you in the first place when it comes to printing products. This is because the participants emphasize that materials have special properties that should be known in order to achieve the best possible component. Therefore, they see knowledge in the field of materials science as mandatory for AM.

As with all manufacturing processes, the quality of the component also plays a major role in AM, as several experts note in the interviews. Therefore, knowledge in this area is also crucial for the future AM employee. For example, one should know how to deal with standards and where to find them. The experts are concerned to show that the AM engineer has a certain understanding of quality assurance in AM and also deals with it.

The experts increasingly note in the interviews that it is crucial for companies to filter which parts are to be produced by 3D printing in the first place. Therefore, they see part screening, known as well as part identification, as an important "hard skill". It is about identifying which parts are suitable for AM and then creating a business case for the company. One could see this skill as an initiator to enable an AM process and to optimize it in the further course.

"That will really depend on the component, in order to find out the component, one goes through screenings, i.e. small numbers of parts, and then looks at what properties the component must have" (IP5, line 172–174).

With regard to other technological competencies, it is emphasized that it is important not only to specialize in a single process, but to acquire knowledge of all current processes. The participants also note that basic economic knowledge is also useful. This is important in order to establish the technology, because positive financial results and the correct calculation of costs, even the best process has no chance in industry. Furthermore, the experts emphasize that certain IT competencies is always important because one comes into contact with a lot of software and data in the field of AM. In addition, it is often mentioned that knowledge of CAD and Python would be an advantage for future employees. Regarding sustainability expertise in AM, participants state that a common and logical sense is important in this context, but also awareness and understanding of the product life cycle, i.e. from its creation, though material procurement to the finished product.

4.2 Soft Skills

The interviewees mentioned various personal and social qualities, which are summarized in the following subcategories: Open for innovation, way of working, ability to work in a team, way of thinking.

From the interview material, various characteristics can be summarized under the term "open for innovation". The majority of respondents mentioned the aspect of open exchange with different networks or other sectors. Particularly with regard to innovation, since AM is evolving rapidly, the willingness to engage in open exchange and good communication skills are advantageous in order to learn from the experiences of others and to obtain new inspiration and ideas and thus drive innovation forward.

"It's a field where you really rely on innovation and you learn a lot through network in the end too [...]" (IP9, lines 306–309)

Furthermore, the interview participants named various characteristics that can be summarized in the subcategory "way of working". Particularly regarding the protection of intellectual property, a conscientious way of working is considered important by the experts. In addition to working with Non-Disclosure Agreement, which are particularly relevant in the area of research and development and thus also in many AM areas, several participants also mentioned the responsible handling of IT data and the conscientious implementation of their own company security guidelines. As additive manufacturing consists of many different subject areas, the participants emphasize that the ability to work in a team and, as a result, good communication skills are advantageous. In particular, when determining in which areas or for which components 3D printing can be used, it would be necessary to work in interdisciplinary teams. But good communication is also necessary within the process chain in additive manufacturing so that, for example, components can be optimized through adapted CAD models.

The subcategory "way of thinking" is mainly composed of two soft skills that are mentioned by the interviewees: Interdisciplinary Thinking and Mindset. As already mentioned, AM is composed of different topics in the process chain. The participants state that a holistic view in connection with a linked way of thinking is relevant. It is very important to understand the connections and interactions between processes and to have interdisciplinary knowledge.

> *"Employees are very successful when they keep their eyes on the big picture. [...] A more global approach, don't just have the skills in one area." (IP10, lines 245–249)*

Another soft skill mentioned by the participants in the context of way of thinking is mindset. On the one hand, this refers to the fascination with technology, whereby the employee has a high willingness to learn and is also motivated to advance and develop the technology. On the other hand, the interviewees mention that it is important to break away from conventional manufacturing processes and to think in terms of AM structures in order to check the possibility of additive manufacturing directly during product development.

4.3 Educational Implications

Based on the interviews, it can be seen that it is particularly important to the participants to convey sufficient theoretical AM knowledge in teaching or training. Universities in particular are cited here as a crucial instrument whose task it is to implement this. The participants made it clear that there should be a stronger focus on theoretical AM knowledge at universities, as this is often not sufficiently covered in the degree courses. The experts feel that there is a lack of depth and comprehensiveness with regard to the teaching of theoretical AM knowledge.

In addition to the theoretical AM knowledge that should be taught, the study also suggests that the application of theoretical knowledge is often missing in teaching. In the interviews, the experts convey the impression that this aspect in particular should not be neglected in teaching. The combination of practice and theory in a kind of dual course of study is also suggested, among other things.

> *"[...] I need theory modules, but I also need practice, so of course you could have a kind of dual course of study where you are perhaps in the company, but also parallel somewhere at the university" (IP4, lines 543–545).*

In addition to practice, the experts also attach great importance to the topic of materials science. They explain that knowledge of materials in AM plays an essential role in being able to develop the potential of the technology. This is because it is possible to assess the requirements of the materials and what is possible with them. Therefore, they see it as the duty of teaching not to neglect this in studies or training.

These are two subcategories which were mentioned sporadically by experts and offer an interesting educational approach: "technology potential meets use case & teaching based on standards". The screening of business cases is, as already mentioned in the "hard skills", an important skill in AM. It would therefore be good to include in teaching which technologies fit which type of use case. The subcategory teaching based on standards also provides an exciting aspect for a possible approach to "new" learning methods.

Standards play a major role in AM and can be found practically throughout the process chain. On the basis of these, a kind of basic study could be derived, which covers a large part of the competencies required in AM.

Regarding trends and future development of AM, the participants state that they do not see a breakthrough of the technology in the future, but rather that there will be a gradual improvement and thus industrialization of AM technology, so that the market of AM will grow and more companies will take up additive manufacturing processes to take advantage of AM in the development process. In addition, several participants see that due to industrialization, the technology is increasingly used in series production. In addition to the future development of AM technologies and their materials, several interviewees also discuss various technologies that are summarized in the category "enabling technologies". These include all technologies that can be used in addition to the actual AM manufacturing processes. Several interview participants mention virtual or augmented reality (VR/AR) from teaching, through AM product design until live assistance during AM production and quality assurance.

4.4 Regional Implications

The experts see the first opportunity for NRW in the area of sustainability. Particularly when it comes to creating closed resource cycles or producing more sustainably, they see potential in the area of AM that could be exploited in NRW. In addition to sustainability, the idea of collaboration or "open source" is also suggested. The experts note that open exchange between a wide range of bodies could represent an opportunity for NRW and is often given little or no consideration. In addition, the interview partners mention isolated aspects that represent exciting opportunities for NRW. The two most interesting mentioned ones are the great opportunity for SMEs to benefit from AM and a project in the context of the storage of spare parts in NRW. The experts outlined the options available to companies, since AM is not widespread in many sectors and it is precisely here that funding projects could help to drive forward structural change in NRW with regard to AM. Projects from the federal government and the EU are mentioned frequently.

5 Conclusions

The aim of this study is to show which skills future employees will need in the field of AM. In addition, a relationship between additive manufacturing and structural change in NRW is to be presented. The focus here is on determining which of the processes are currently relevant and which opportunities AM offers for NRW. Among the hard skills were emphasized on process-related AM knowledge, material knowledge, quality management and part screening. As soft skills, the interviewees mentioned as the most relevant the open for innovation, way of working, ability to work in a team, way of thinking. In addition to the "hard" and "soft" skills, direct implications to educational content were identified. The present study provides exciting new insights in the area of learning methods. For example, it highlights the possibility of standards-based teaching and emphasizes the importance of hands-on experiences during training. Moreover, AR/VR were mentioned as new trend to be considered in this educational field of AM. Lastly, the research dealt, among other things, with which technologies, materials, applications and trends which could be specifically relevant for the NRW region in the future.

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