TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 67, Issue Special I, February, 2024

EXPERTS' PERSPECTIVES ON THE ADOPTION OF ADDITIVE MANUFACTURING IN THE INDUSTRY AND ITS INTERRELATED IMPLICATIONS IN PRODUCTION STRUCTURES

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Abstract: *Additive Manufacturing (AM) is a topic that is becoming more relevant to many companies globally. With AM's progressive development and use for series production, integrating the technology into existing production structures is becoming an important criterion for businesses. This study qualitatively examines the actual state and different perspectives on the integration of AM in production structures. Seven semi-structured interviews were conducted and analyzed. The interview partners were high-level experts in Additive Manufacturing and production systems from industry and science. Four main themes were identified. Key findings are the far-reaching interrelationships and implications of AM within production structures. Specific AM-related aspects were identified. Those can be used to increase the knowledge and practical application of the technology in the industry and as a foundation for economic considerations.*

Key words: *Additive manufacturing, production systems, manufacturing management, interviews, thematic analysis, AM implementation*

1. INTRODUCTION

Additive Manufacturing (AM) processes mark the transition of manufacturing technologies to produce large series of the same part to the serial production of different parts (with possible and economic batch-size-1 production). Rapid availability of complex shapes and prototypes, increased quality, customized designs, functional and module integration into a component, and a wide range of materials are just a few advantages of AM technology. However, companies today face the strategic and operational challenges of AM in the interface area with their production systems. This applies in particular to production planning and control, process planning, and strategic planning of the production system. [1–5]

To benefit from the named advantages, however, AM needs to be situated and assessed holistically in production systems. But the focus in the past has been merely on the technical aspects of AM, such as improving process parameters and machine technology and cost models related to a specific AM process [5]. In this regard, KORNER et al. explicitly suggest in their paper the need to integrate AM (and related models) into the whole production system [6].

The missing literature on research assessing and situating AM in production systems and structures constitutes a research gap that serves as a basis for the motivation of the paper.

Furthermore, in the practical use of AM in the industry, very tangible challenges arise from implementing AM. Missing work safety regulations and quality assurance processes, high material and machine costs, long throughput times that do not meet the standards of conventional systems, and at times extensive post-processing can be named. Also, the qualification of components is often a showstopper for companies. Other reasons are that a consistent integration of AM into the overall production system and consistent process automation is not yet possible. [7–12]

The overall objective of the interview study is a differentiated analysis of the understanding and status of AM in production systems.

Therefore, possible chances and risks of the implementation of AM in the practical field are analyzed qualitatively. Also, interrelated implications of AM in different areas of the production systems are evaluated. Finally, future perspectives and needs for AM in the industry are analyzed. This also leads to the question of what the gained results open up for further research needs.

2. MATERIALS & METHODS

Seven semi-structured interviews have been conducted, following a qualitative approach. In this form of interview, a list of questions guiding the conversation is used to structure the interviews in contrast to a fixed questionnaire. The interviews have been done as expert interviews, an extensively discussed methodology in literature (cf. e.g., [16–18]). Bogner et al. [19] define an expert as a person who ”…has a technical, process, and interpretive knowledge that relates to a specific field of action in which he acts in a relevant way (such as in a specific organizational or his professional field of activity)”. According to the authors, technical knowledge can be further defined as specialist knowledge or competencies, process knowledge as, e.g., practical experience from daily work, and interpretive knowledge as ideas, ideologies, and interpretations, all related to the particular field of action. The latter is an explicit characteristic of the theory-generating interview. In alignment with this, the interviews were guided by the ideas of the theory-generating expert interview, according to which an expert interview can vary depending on the research question and interest [20]. The authors chose the methodology due to its utility in understanding the industry's real needs and supporting the integration of practical experiences into science and new solutions. The selected type of semi-structured interviews allows for researching specific and defined topics while keeping a partial openness for the experts to share their knowledge and expertise in the research field.

2.1 Sampling and procedure during survey and analysis

Following the above methods and explanations, the criteria to be included as a relevant participant for the study on hand was interdisciplinary knowledge in both Additive Manufacturing and production systems with conventional production resources (in contrast to additive production resources), respectively planning and operation of these very in the industrial environment. Some participants had a main work focus on Additive Manufacturing with complementary experience in production systems. In contrast, others had their main focus on conventional production systems plus additional sound knowledge in AM. This cross-cutting experience was important to reflect on the interrelationships between different technologies and the structure and management of production systems. These valuable multi-dimensional perspectives contribute meaningful insights, opinions, and transfer skills in the interdisciplinary research field. In general, all participants had clear expertise in the field of investigation with 10+ years of experience. The different job positions among the participants, situated in the industrial environment, consulting, and/or science, aim to capture a holistic picture of the topic with broad perspectives and knowledge and a high degree of interdisciplinary thinking. The sample for the study is represented in Table 1.

Table 1

Study sample

Partici-pant (P)	Company/ Institute	Position	Years of Expe-perience
P 1	University	Professor, Consultant	>10
P 2	Manufacturing Company A	CEO	>20
P 3	Manufacturing Company B	CEO, (former scientist)	>10
P 4	Manufacturing Company C	Advanced Specialist	>20
P 5	Consulting Company D	CEO	>10
P 6	Manufacturing Company E	Managing Director, (former scientist)	>10
P 7	University	Professor, Consultant	>15

Before the interviews, the decisive thematic areas and content were structured, and a thematical interview guideline was created from this, which was reviewed by two experts in the research field. The interview guidelines developed ensured that all relevant questions were addressed in each interview. The flexible approach of semi-structured interviews [21] also allowed for the individual amplification of pertinent subjects and the discussion of the questions in light of the expert's unique frame of reference. As recommended in methodological texts, a pilot test was carried out upfront with a sample size of two experts to ensures and increase the research quality, and better prepare the interviewer [22].

The interviews were conducted between November 2020 and February 2022. The period for each interview ranged from 60 to 90 minutes. The sample size for the study was seven. The participants were recruited from business networks and contacted via e-mail with information about the purpose of arranging a meeting. The interview template was sent with the meeting invitation as preliminary information. All interviews were held in German, the interviewees' mother tongue. Choosing the native language is recommended in literature and allows participants to be more thorough, which results in quality data [23].

Four of the seven interviews took place offline, with two offering a company tour. The other three happened online using the Zoom platform to prevent face-to-face contact due to the COVID-19 pandemic at the time and to honor the interviewees' limited time resources. Whereas face-to-face interviews were the standard in the past, during the pandemic, virtual interviewing gained importance and has been increasingly adopted in qualitative research [24].

The answers and generated information were captured during the interview via simultaneous protocolling as a history log [25, 26]. The logged statements and contributions were communicatively validated for the first time during the interview. At the end of the meeting, the participants were encouraged to share any missing details they may have overlooked or wanted to address [16].

The analysis procedure, in addition to the described documentation and validation by the interviewees, consisted of verification of transcriptions where tape recordings were available. Following, qualitative content analysis, according to Glaeser and Laudel [16], was used to analyze each interview. The individual findings were aggregated in the first phase. Then, the extracted information was assigned to categories of previously defined analysis areas before further processing, which is reflected in the Results section (Ch. 3) [16].

2.2 Addressed topics

The interviews were divided into six parts. The first set of questions asked general questions about the current state of additive technologies and production systems in the individual's context. Participants were then asked about the opportunities and challenges they see and experience with AM in production systems. In the third part, the focus was on dependencies and interactions of AM in the production system. In this regard, also the topic of production/ AM key figures was addressed.

One section dealt with the procedure of how companies select parts for manufacturing them additively. The last section, section six, was the closing questions. The purpose was to conclude the interview and allow the interviewees to add missing information and their future vision. Four main themes could be extracted and analyzed from the interview sections, presented in the next Chapter.

3. RESULTS

A. Challenges and chances of AM integration in practice

Looking back on the personal experiences the experts had with integrating and using Additive Manufacturing in practice, various challenges and chances were communicated. Most participants have had positive experiences with the introduction and use of AM. In particular, filigree and complex applications/ components were mentioned as positive application examples for AM in this context. Furthermore, additional functional possibilities in the component due to geometry freedom (keyword features, design freedom), flexibility, the flexibilization of production batches, individual mass production, customer-oriented solutions, as well as more complex and better components were indicated by the participants as opportunities for AM in the company. Also, it was stated that one does not have to be an expert for the AM machine operation and that the printer can operate without a machine operator while processing the part.

However, the existing challenges concerning the implementation and practicability of the technology were also clearly highlighted in this context. In order to exploit the potential offered by AM, it is often necessary to completely re-design components, for which appropriately trained and "out-of-the-box" thinking engineers are required. Moreover, from an economic point of view, the added value of a new geometry must also be quantified (in terms of cost). In other words, it is not simply a matter of substituting a conventional part and process chain with an additive one. In this context, it was said that there is currently too much focus on printing rather than on the design of additive components.

When experts were further asked about the technology's practicability, the need for post-processing for AM parts was also named, which may be excessive and problematic. A consideration was that post-processing of parts in-house can be uneconomic and may be outsourced. Also, the qualification of parts was mentioned. Missing the part qualification and quality assurance standards leads to using AM currently only for internal use (such as tools or devices). Furthermore, some experts stated that practicability generally depends extremely on the application and the know-how in the company. Currently, the knowledge resides only with the AM experts.

Various points were addressed according to economic efficiency. Most experts agree that economic efficiency is essential for using any technology in a production system and that the decision for or against AM comes down “ultimately always as a cost issue”. In this regard, it was stated that it is about putting a "price tag" on the industrial application of AM. Specific points addressed were that the benefit of individuality needs to be given in contrast to purely mass production (which is an argument for possible lot-size-1 production). The slow process speed of the printers as well as high machine and software investments were aspects seen as critical in terms of cost. However, it was stated that not only a pure unit cost view should be considered. In addition, further economic reasons for application may include, e.g., customer satisfaction and retention or increasing flexibility.

B. Interrelated implications of AM in (existing) production structures

With the given interdisciplinary expertise of the experts in both (conventional) production systems and Additive Manufacturing, a special focus of the interviews was gaining insights into the dependencies of AM in relation to the overall production system.

When the experts were asked to estimate the implications and dependencies of AM as a supplementary production resource on the overall production system, they mostly agreed that AM's impact depends greatly on the company, strategic goals, and specific production structures. The suggestion was to look at answers with a certain range when asking about the impact of specific implications in the production system.

Points of reference in the discussion have been today's sophisticated conventional production systems that combine, e.g., process-thinking, constant measuring of production key figures (such as throughput time, work in progress (WIP), Overall Equipment Efficiency (OEE), stock levels and many more), and production planning and optimization. In this regard, experts claimed that key figures (KPIs) for AM are still far too little used or not at all and that KPIs are not adjusted to the AM technology. When the participants were asked if KPIs for conventional and additive production resources are comparable, answers ranged from very little comparability over that different conditions must be considered to mostly comparable. When asked which key figures should be measured for AM in production systems consisting of AM and conventional resources in order to capture interrelated implications, the following KPIs were named multiple times as a starting point: throughput times, order times, machine hourly rates, process costs (in comparison to conventional process costs), machine capacity utilization.

The impacts on the different production key figures (e.g., the impact of AM on throughput times or setup times) were regarded very heterogeneously by the participants. The experts agreed that it cannot be stated generally that AM has a positive or negative impact on a certain production key figure, but positive as well as negative effects appear and thus must be quantified. Impacts on key figures are case-sensitive, part-dependent, and dependent on the existing production structures. However, mostly the interviewees concluded that production structures change when implementing AM. The reasons are the specifics of the technology in contrast to conventional manufacturing resources. Structures may also change because AM can create new, alternative, or combined process chains. Shorter process chains arise; for example, certain manufacturing steps can become obsolete through possible function integration. Also, the IT landscape changes with AM integration since a new infrastructure, new software systems, and the integration of printers in the workflow are needed. Further aspects to consider within the changing production structures are also work safety (e.g., handling and supplying raw material in powder form or its storage under inert gas), the impact on competence profiles of the company staff (e.g., regarding the design process in engineering, skills of machine operators), special AM process characteristics, and the increasing managing efforts of the dependencies and integrating a different production resource into the system.

C. Identification of components for AM

The discussions on identifying parts were motivated by the fact that while various methods are proposed in the literature, no standard process is available [27]. The interviewee's responses supported this. When the experts were asked how they pick resp. identify components for AM, the consensus opinion was that there does not exist a standardized system for the identification of parts. The aggregated responses show that the companies and institutes of the interview partners look at the suitability of the AM component from different angles. These are, e.g., material and, from there, the selection of the specific AM technology/process, the complexity of the component, the component size that determines the needed size of the printer's build chamber, the desired batch size (with a focus on small batch sizes for AM applications). It was often pointed out that, generally, the decision to use additive manufacturing must be made based on the final added value and the economic efficiency compared to conventional manufacturing.

D. Future perspectives and needs of AM in the industry

Experts predict that there will be more additive systems in production systems in the future. This development should be seen as an extension, not a displacement of conventional resources. I.e., AM can establish itself as one manufacturing resource among many. It thus provides great opportunities to initiate new manufacturing possibilities. Most experts think that today's technological challenges will be solved in the future.

It was claimed essential to approach AM more from a process view with upstream and downstream steps. An end-to-end view of the entire value chain is needed, which is currently missing. Also, operational production planning, as known from conventional production systems, falls too short. In this regard, unknown risks, such as material supply, must be assessed.

Furthermore, standards and guidelines must be implemented in the industrial production context. Otherwise, the application possibilities for sales products are limited. Some participants indicated the need for industrial controllability of AM technology. It was stated that lots of people recognize the benefits of AM. However, methods are missing to use the advantages of AM in the production area; "the devil is in the details".

4. DISCUSSION

A variety of research disciplines approach Additive Manufacturing and production systems from different angles. However, a holistic and interdisciplinary AM analysis in production systems consisting of conventional production resources is missing as already discussed in the Introduction. Also, the needs of manufacturing companies that want to integrate AM into industrial series production need to be reflected more in ongoing research. This qualitative interview study examined the integration of AM in production structures. The goal was to capture on-hand insights from experts that work in the interdisciplinary field of AM and production system layout and investigate practical experiences with AM in production systems.

The experts were chosen to have in-depth knowledge of production systems and AM expertise to draw a realistic picture.

The methodology of semi-structured interviews was well suited for initial exploration and qualitative analysis of the study goal. In further research, quantitative methods should build on and deepen the results gained from the interviews.

It can be said that the comparison of conventional manufacturing processes and AM is not possible one-to-one. Many dependencies and process specifics must be considered. Also, an application must always be tested on a case-by-case basis. This aligns with the arguments found in the literature (cf. Ch. 1). Also, about the cost-effectiveness of AM, participants emphasized that a one-to-one substitution of conventional methods with AM is not possible and that a pure unit cost approach is not sufficient. Factors such as customer benefit/satisfaction or flexibility may also be considered. This already indicates multifactorial correlations. "One-dimensional" quantification methods that only consider certain aspects of AM thus quickly reach their limits. However, cost, in general, is mostly the decisive factor for companies to decide on the use of any technology and is thus a crucial factor.

Moreover, the interviews made it clear that even the questions were understood and interpreted individually. The subjective understanding was particularly attributable to whether the interview partner was primarily an AM expert or an expert in production systems and planning. The effects of AM on, e.g., production key figures and structures were also perceived and evaluated very differently depending on personal (job) experience.

These requirements and experts' suggestions finally lead to the question of creating foundations and methods for evaluating AM more holistically in a production context.

Limitations of the study may apply regarding the small sample size of the study of seven participants. The experiences and knowledge acquired through the interviews may not represent the understanding of AM in production structures. Also, an unconscious bias may appear since all participants were male. Even though the research field is male dominated, the genders should be well-balanced in further studies. Additionally, the protocolling and theme analysis methodologies may have added researcher bias into the process of data analysis. Future research should verify the gained knowledge and further investigate the discussed results.

Nevertheless, since there are no other qualitative interview studies to be found on the topic (to the best knowledge of the author), this study makes a meaningful contribution in highlighting current needs and practical insights of manufacturing companies in combination with the perspectives of experts from sciences and consulting businesses when it comes to situating AM interdependently in production structures.

5. CONCLUSION

The paper investigated the implementation of AM into existing (conventional) production systems and its interrelated implications on different areas of the system. Therefore, an introduction presented related research regarding the implementation of AM. A research gap in assessing AM from a holistic production system view was further identified, which led to the study's motivation.

In Chapter 2, the description of the research method is followed. Seven semi-structured interviews with high-ranking experts in AM and production systems were conducted. The results show the far-reaching interrelationships and implications of AM within production structures. Those include but are not limited to effects on employees, existing and newly emerging process chains, needed development and adjustment of production key figures, the re-thinking of design engineering, and adjusting IT systems. Furthermore, as an initial step, the decision of which components can be reasonably manufactured with AM has to be made.

The gained results can be used by companies that (wish to) implement AM. The clustered and analyzed results of the study increase the knowledge for practical implementation of the technology in the field of tension of AM in production systems. The expert experiences and insights can be used as a discussion foundation to elaborate further on the specific chances and challenges as well as potential impacts of AM on their production structures as well as economic considerations.

As suggested by the experts, future research is needed to develop methods to apply the benefits of AM in the industry. Therefore, standards also need to be developed and implemented regarding, e.g., key figures, part identification, and capturing the entire value chain of AM.

The focus here should be on the practical applicability of the methods for companies. At the same time, the same (high) standards must be strived for that are already achieved in conventional production. For this, the authors recommend interdisciplinary research teams consisting of AM experts and experts for production systems and their planning.

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PERSPECTIVELE EXPERȚILOR ASUPRA ADOPTĂRII FABRICAȚIEI ADITIVE ÎN INDUSTRIE ȘI IMPLICAȚIILE INTERCONEXATE ÎN STRUCTURILE DE PRODUCȚIE

Rezumat: Fabricația aditivă (Additive Manufacturing - AM) este un subiect tot mai important pentru multe companii la nivel global. Cu dezvoltarea progresivă a AM și utilizarea sa în producția în serie, integrarea tehnologiei în structurile de producție existente devine un criteriu important pentru eficiența producției. Această lucrare examinează calitativ starea actuală și perspectivele diferite privind integrarea AM în structurile de producție. Au fost identificate patru teme principale. Concluziile cheie se referă la interdependențele și implicatiile semnificative ale AM în cadrul structurilor de producție. Au fost identificate aspecte specifice legate de AM. Acestea pot fi folosite pentru a crește eficiența și aplicarea practică a tehnologiei în industrie și ca bază pentru analize economice.

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