



HAL
open science

Investigating the Use of Immersive Technologies for Additive Manufacturing

Gustavo Melo, Ahmed Ercan, Moritz Kolter, Johannes Henrich Schleifenbaum

► **To cite this version:**

Gustavo Melo, Ahmed Ercan, Moritz Kolter, Johannes Henrich Schleifenbaum. Investigating the Use of Immersive Technologies for Additive Manufacturing. IFIP International Conference on Advances in Production Management Systems (APMS), Sep 2022, Gyeongju, South Korea. pp.469-476, 10.1007/978-3-031-16411-8_54 . hal-04768969

HAL Id: hal-04768969

<https://inria.hal.science/hal-04768969v1>

Submitted on 6 Nov 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution 4.0 International License



This document is the original author manuscript of a paper submitted to an IFIP conference proceedings or other IFIP publication by Springer Nature. As such, there may be some differences in the official published version of the paper. Such differences, if any, are usually due to reformatting during preparation for publication or minor corrections made by the author(s) during final proofreading of the publication manuscript.

Investigating the use of immersive technologies for Additive Manufacturing

Gustavo Melo¹[0000-0001-5872-8158] Ahmed Ercan¹, Moritz Kolter¹[0000-0002-8908-3564] and Johannes Henrich Schleifenbaum¹[0000-0002-7675-6547]

¹ Chair for Digital Additive Production, RWTH Aachen University, 52074 Aachen
gustavo.melo@dap.rwth-aachen.de

Abstract. The demand for Additive Manufacturing (AM) is continuously increasing, so new challenges must be overcome. For instance, in the event of a pandemic, location-independent communication must be ensured so that the production and the training of workers can continue. As a result, digital learning and teaching techniques have gained traction, especially in location-independent interventions. Those techniques enable synchronous and asynchronous, location-independent transmission of information and data, however, they are mostly designed for theoretical contents. In order to ensure physical learning as well, more immersive technologies must be resorted to. Thus, this study investigates the extent to which Extended Reality (XR) technologies can be used in AM. Two workshops were held to gather expert opinions on how Virtual Reality (VR) and Augmented Reality (AR) can be utilized in AM. It turns out that the technologies can be used in a variety of ways, especially in areas such as training, visualization, information, simulation, checking, and communication. The greatest added value with minimal effort could be achieved in the location-independent training and assistance of employees.

Keywords: Additive Manufacturing, Augmented Reality, Virtual Reality

1 Introduction

1.1 Initial Situation

The development of laser technologies has significantly increased the application potential of Additive Manufacturing (AM), especially in industry. The diverse and promising technologies that enable direct and rapid manufacturing of parts thus offer a wider range of applications for efficient production. However, production does have vulnerabilities, especially in times of a global pandemic [1]. In order to implement AM in traditional production, AM users need to be on-site. Unforeseen obstacles can cause problems, especially for training topics where participants rely on on-site instructors. To circumvent these issues, alternative methods are now being researched. Digital learning and teaching options are being taken up as a basic solution.

1.2 Objective

The hypothesis to be investigated is potential for use of digital learning and teaching techniques exists in the context of training opportunities. To this end, building on the current state of AM and digital learning and teaching methods, which are currently of particular relevance, the future potential uses of immersive learning technologies will be analyzed. The work is intended to make a general contribution to the development of these technologies in order to highlight their future prospects in AM.

1.3 Research approach

In view of the objectives, a qualitative research approach will be used in this study. To this end, a literature review of the current state of AM and digital training options, in special the immersive ones, will first be conducted. Subsequently, group discussions in the form of two workshops will be conducted in order to answer the research hypothesis. The participants of the two workshops are respectively AM researchers from academia and AM users from industry. Finally, the results will be discussed and summarized.

2 State of the Art

2.1 Additive Manufacturing

The demand for additively manufactured products has steadily increased over the years. The global 3D printing market size reached \$12.6 billion in 2020 [2]. While it is predicted to increase to US\$37.2 billion by 2026 [2]. Additive manufacturing, also known as 3D Printing, is a layer-wise manufacturing process in which components are manufactured by applying material layer-by-layer without the need for tools. A typical workflow consists of Design, Pre-Process, AM-Process, Post-Process and Quality Assurance. In general lines, Design step covers the construction of the part/product, Pre-Process deals with the data preparation of the file to be additively manufactured in the subsequent step. Typical Post-Processes are the removal of the part from building platform as well as surface finishing, being finalized by Quality Assurance steps covering destructive and nondestructive testing. Digital and three-dimensional models form the basis for this process. The term AM comprises several process categories. For this study, the most widespread technology for metallic materials was taken as the focus of our investigation: Laser Powder Bed Fusion. This process consists of applying layers of metallic powder which are selectively melted by a laser beam in a protected atmosphere [3].

2.2 Extended Reality

Advancing digitalization is responsible for creating new opportunities and challenges for industry. Especially in the working world of Industry 4.0, in which the interaction between human and machine plays a significant role, hence digital competencies are gaining a continuously growing importance. Thus, the interest in exploring and

implementing training opportunities using Extended Reality (XR) technologies is increasing. The term XR implies immersive technologies such as Mixed Reality, Virtual Reality and Augmented Reality.[4]

Augmented reality (AR) technology is based on the fundamental principle that users move around their real environment with full awareness while interacting with virtual information and objects [5]. In order to apply AR technology, the real environment must first be captured. This is usually done using a camera. The captured data is visualized on a projector. The visualization can take the form of a screen display, for example. In this case, a fixed camera is used to capture predefined markers. Depending on the position of these markers, a positional representation can be made. One option for the application of AR is the use of head-mounted displays. Here, the camera is located on the head and captures the environment from the user's viewing perspective. The device is usually worn on the head in the form of goggles, allowing flexibility of movement and position [6].

Virtual reality (VR) is based on the basic idea of presenting a computer-generated simulation of a realistic experience. The technology is used to completely block out the real world and replace it with a virtual environment [7]. Thus, the user has the sensation of being involved in the synthetically generated environment. This sensation is also called immersion. In industry, this technology is mostly used to gain a stereoscopic view of computer-generated objects. Interaction is made possible through the use of hand-held input devices. This technology creates a great advantage in that three-dimensional models and products can be spatially displayed, analyzed, and interactively handled [8].

3 Method

The present research is based on a qualitative methodology, which is particularly appropriate, compared to quantitative methods, when little information is available on a topic. The qualitative research approach is based on generating theory statements that are captured through empirical data. In qualitative research, participants report on their experiences rather than taking positions on predetermined topics. The generation of qualitative data is possible via interviews, focus groups, observations, or documents. The qualitative approach, in special the focus group discussion, is therefore the more suitable variant in the present work since the statements of the participants have a corresponding analytical reference point [9]. The participants are thus AM experts and the data collection takes place in the form of focus group discussion held in a hybrid format assisted by digital canvas and teleconference tools. The essential difference between the latter and an interview is that in a group discussion several interviewees refer to one topic of investigation at the same time [10]. In order to facilitate such a group discussion, two workshops of 2 hours long each are conducted in this paper. This approach is often used for qualitative research to gather responses from a group of people on a particular topic. In this case, in order to integrate different opinions into the discussion, participants who work in different fields are specifically included. During the workshops, the participants, in total 18 individuals with 2 to 10 years of experience, were

divided into six groups accordingly to their expertise to maintain clarity and cover the whole AM process chain: Design, Pre-Process, In-Process, Post-Process, Quality Assurance, and Other. For a successful focus group discussion, the Miro platform is used. This offers participants the opportunity to work simultaneously on the same interface. This way, they can communicate their ideas and assign them to the areas through integrated functions such as creating notes, labeling or drawing. The workshops were carried out in September and November 2021 and aimed to present the XR technologies under investigation to the participants and to gather expert opinions on the extent to which these technologies can be integrated into the manufacturing steps along the AM process chain. The evaluation of the data took place via Mayring's process model, which is used for qualitative content analysis and covers the following steps: determine material, determine direction of content analysis, select form of content analysis, interpret results, define quality criteria [11]. The analysis took place in the course of this work using the analysis software MAXQDA.

4 Results

Fig. 1 shows the result of the industrial workshop displaced on the Miro board covering the whole AM process chain. On the left, XR use cases in manufacturing were elucidated and on the right ideas from the AM experts were gathered and discussed. The discussion of the focus groups has been recorded, transcribed and coded using the grounded theory described by Mayring [11]. After first-order and second-order coding, six fields of usage of XR in AM have been identified namely: Information, Checking, Communication, Visualization, Simulation, Training. Each of these groups can be split up into subgroups as given in Table 1. Furthermore, the industrial workshop has been used to identify low-hanging fruits described in more detail in the next section.

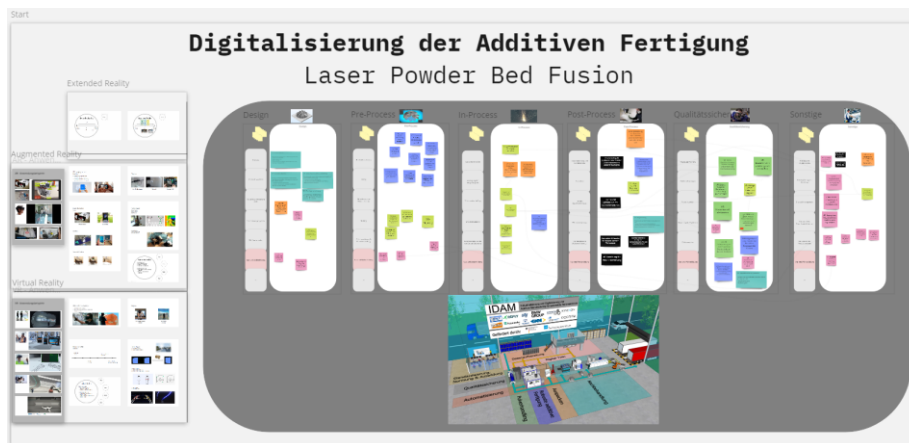


Fig. 1. Visual results from industrial workshop displaced on the digital canvas in Miro.

5 Discussion

In the industrial workshop, recommendations were voiced to filter and implement so-called low-hanging Fruits, according to Varela and Ramquist [12] and shown in Fig. 2. The term low-hanging fruit refers to items that could have a high impact with little effort. The two axes in Fig 2. define effort and impact. Items with low effort and a low impact are classified as 'harmless weeds'. Items with high effort and high impact are classified as 'the best of the best'. Factors that have high effort and low impact should be avoided and are classified as rotten tomatoes. Items that have a strong impact and require low effort should be prioritized.

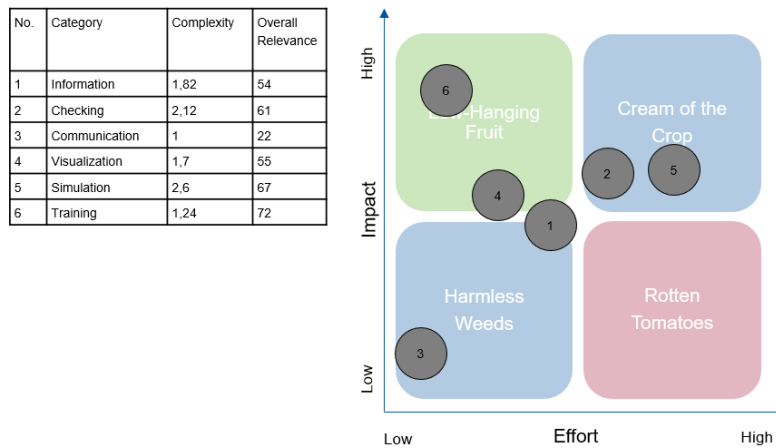


Fig. 2. Classification of the categories in the low-hanging fruit matrix (own representation after Varela and Ramquist [12]).

The strength of impact can be related to the relevance of the technologies considered, which can be scaled depending on the frequency of mention in the workshops.

The relevance is evaluated considering the following aspects:

- Number of different areas in which the points were taken up,
- Number of workshops in which the points were addressed,
- Mention of the points in the discussion,
- Picking up the points in brainstorming.

The effort, on the other hand, is reflected in the complexity and feasibility of implementation. This evaluation is performed based on the state of the art of research and the results described in the previous chapters. Complexity is ranked building on feasibility with values between 1 and 3. **Table 1** shows an overview of the categories after the compilation and analysis of the data material with respective points. **Fig. 2** shows the classification of the categories in the low-hanging fruit matrix according to Varela and Ramquist [12]. The criteria for relevance are summed up and the criteria for complexity are averaged for each of the six key categories. It can be seen that the points of

communication are classified in the 'harmless weeds' area. The reason for this could be that advanced technology is not needed for secure and stable communication.

Table 1. Categorization

Activity	Complexity	Relevance
Information		
Display powder status	2,33	9
Visualization of production status and parameters	1,75	15
Display component information	1,50	15
Display status about next steps	1,5	11
Display warnings	2	4
Checking		
Comparison of TARGET and ACTUAL geometry	2,8	14
Recognition of hotspots, complexities and internal structures	1,375	20
Verification of certain aspects of a component	1,8	15
Direct process monitoring	2,5	12
Communication		
Virtual exchange with customer	1	12
Virtual presentation and discussion	1	10
Visualization		
Virtual representation of the production process	1	11
Visualization of the component in different environments	1,6	13
Visualization of components printed in the past	2	8
Visualization and evaluation of data	2,14	15
Visualization of the component	1,75	9
Simulation		
Visualization of the component condition and the tools	2,6	14
Execution and display of simulations	2,67	14
Virtual designing	2,67	7
Dimensional accuracy check	2,875	19
Direct operation	1,75	13
Training		
Training without teacher	1,5	19
Training with instructor	1,13	22
Remote assistance, support, and maintenance	1,08	31

In addition, this category could be seen as self-evident, since communication must always be guaranteed. For the 'simulation' and 'checking' categories, the evaluation diagnosed high effort overall, but also strong impact. This suggests that participants would like to see advanced features that could add a lot of value. However, the state of the art is not advanced enough to implement them without further difficulty. If the goal is to achieve high impact with a low effort, the application areas 'visualization' and 'information' could be an efficient choice. This result is especially conditioned by the

motivation to visualize information that currently can only be obtained on-site. This work hypothesized that the considered technologies can be particularly efficient in the area of training. Based on the matrix, it can be seen that the highest impact can indeed be achieved here with minimal effort. This is due, among other things, to the fact that the technology offers a new training dimension that enables the transmission of not only theory and language but also facial expressions, gestures, and physics, regardless of location and time. Thus, the hypothesis was confirmed and the subcategories of training - instructor-led, instructor-less, and remote assistance - are classified in the low-hanging fruit domain.

6 Summary and Outlook

With the present scientific work and the associated empirical investigation, a contribution regarding the use of immersive technologies along the AM process chain was made. Thus, based on the state of the art of research, it was recorded that the technologies of XR can form a basis for a practical, time-independent, and location-independent delivery of training, but it can potentially create benefits in several other areas.

For this reason, two focus group discussions were conducted in form of a hybrid workshop. The participants were experts in the field of AM. The workshop aimed to present the technologies under investigation to the participants and to gather expert opinions on the extent to which these technologies can be integrated into the manufacturing process. It was hypothesized that the technologies could achieve the greatest added value in the area of training opportunities. As a result, it was determined that the established hypothesis was confirmed. In addition to training opportunities, there is also potential in other areas such as information, visualization, checking, communication, and simulation. Using a low-hanging fruit matrix, it was shown that the implementation of technologies in the area of 'training' can achieve the greatest added value with the lowest effort. Furthermore, it was stated that in the areas of 'displaying information' and 'visualization of data' a high added value can also be achieved with little effort. The implementation of technologies in the areas of 'checking' and 'simulation' is more complex, although there is also a high relevance and demand here.

The workshop methodology in a hybrid format has shown to be a good approach since it was appreciated by the participants and direct follow-up projects within an XR development roadmap were initiated, especially for training. As limitation, it became apparent that the participants in the workshops were rather less engaged with the XR technologies. This was partly due to the fact that experts from the field of AM were selected for the research study. Thus, ideas were collected about the XR technologies that could potentially be implemented in the field of AM. The criteria to what extent this is feasible, to what extent the implementation is worthwhile or what challenges might arise for the development were not considered. Thus, in the next step, it must be taken into account that opinions must potentially be collected from experts who are primarily concerned with XR.

Acknowledgments

The authors would like to thank the Federal Ministry of Education and Research of Germany (BMBF) for funding the research in the project Industrialization and Digitalization of Additive Manufacturing for automobile series production (IDAM, grant number 13N15084) and the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) for funding under Germany's Excellence Strategy – EXC-2023 Internet of Production – 390621612.

References

- [1] Naghshineh, B., Carvahlo, H., The implications of additive manufacturing technology adoption for supply chain resilience: A systematic search and review, *International Journal of Production Economics* (2022) doi: <https://doi.org/10.1016/j.ijpe.2021.108387>
- [2] M. Placek, *Share of sales revenue of additive manufacturing by industry* / *Statista*. [Online]. Available: <https://www.statista.com/statistics/1268618/share-sales-revenue-of-additive-manufacturing-by-industry/> (accessed: Nov. 20 2021).
- [3] U. Berger, A. Hartmann, and D. Schmid, *3D-Druck - Additive Fertigungsverfahren: Rapid Prototyping, Rapid Tooling, Rapid Manufacturing*, 2nd ed. Haan-Gruiten: Verlag Europa-Lehrmittel - Nourney Vollmer GmbH & Co. KG, 2017. Accessed: Oct. 10 2021. [Online]. Available: <https://www.europa-lehrmittel.de/downloads-leseproben/50335-2/3194.pdf>
- [4] F. Palmas and P. F.-J. Niermann, Eds., *Extended Reality Training: Ein Framework für die virtuelle Lernkultur in Organisationen*. Wiesbaden, Germany: Springer Gabler, 2021.
- [5] R. Azuma, Y. Baillet, R. Behringer, S. Feiner, S. Julier, and B. MacIntyre, "Recent advances in augmented reality," *IEEE Comput. Grap. Appl.*, vol. 21, no. 6, pp. 34–47, 2001, doi: 10.1109/38.963459.
- [6] A. Mehler-Bicher, *Augmented Reality: Theorie und Praxis*, 2nd ed. Berlin/München/Boston: Walter de Gruyter GmbH, 2014. [Online]. Available: <https://ebookcentral.proquest.com/lib/kxp/detail.action?docID=1634280>
- [7] S. Mann, T. Furness, Y. Yuan, J. Iorio, and Z. Wang, "All Reality: Virtual, Augmented, Mixed (X), Mediated (X,Y), and Multimeditated Reality," Apr. 2018. [Online]. Available: <https://arxiv.org/pdf/1804.08386>
- [8] B. Bertsche and H.-J. Bullinger, Eds., *Entwicklung und Erprobung innovativer Produkte - Rapid Prototyping: Grundlagen, Rahmenbedingungen und Realisierung*. Berlin, Heidelberg: Springer Berlin Heidelberg, 2007. [Online]. Available: <http://nbn-resolving.org/urn:nbn:de:bsz:31-epflicht-1586761>
- [9] T. Brüsemeister, Ed., *Qualitative Forschung: Ein Überblick*, 2nd ed. Wiesbaden: VS Verlag für Sozialwissenschaften, 2008.
- [10] W. Hussy, M. Schreier, and G. Echterhoff, *Forschungsmethoden in Psychologie und Sozialwissenschaften für Bachelor: Mit 54 Abbildungen und 23 Tabellen*, 2nd ed. Berlin, Heidelberg: Springer, 2013.
- [11] Mayring, Philipp. *Qualitative Inhaltsanalyse: Grundlagen und Techniken*. Weinheim: Beltz, 2015. Print - ISBN: 9783407293930.
- [12] G. Varela and K. Ramquist, *Low-Hanging Fruit Matrix*. [Online]. Available: <https://theleansixsigmaoffice.com/2017/03/18/low-hanging-fruit-matrix/> (accessed: Dec. 15 2021).