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DIGITAL KNOWLEDGE TRANSFER FOR ADDITIVE MANUFACTURING USING BLENDED LEARNING

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ABSTRACT
Additive manufacturing (AM) processes provide new levels of design freedom during product development as a result of the layer-by-layer build-up process, so that graded lattice structures, internal cooling channels, or other geometrically distinctive design features are taken into account at an early stage of product development. In addition, these complex geometric features can be realized without significant additional effort during the additive manufacturing process while complying with the restrictions of AM. The "Design for additive manufacturing" research field is trying to offer methods and tools to support the product developer in exploiting the AM potentials and to maintain compliance with the restrictions of the manufacturing process to be able to apply these design freedoms in a targeted and benefit-oriented manner during product development. However, due to a lack of AM knowledge and limited software solutions, the application of these methods and tools is not always possible, because necessary AM knowledge is partial or even completely missing. For this reason, teaching and learning offers are needed that systematically impart specific AM knowledge so that these barriers in product development can be overcome. In this paper, the systematic knowledge acquisition for specific AM knowledge is presented using the example of interactive teaching and learning offers. For this purpose, the basics of systematic knowledge transfer for AM will be discussed first to show the state of research. This is followed by the presentation of the interactive learning environment, which makes AM-relevant topics experienceable utilizing interactive 3D models. Finally, a validation of the presented learning environment for the transfer of specific AM knowledge is presented.

Keywords: Additive manufacturing, blended learning, design for additive manufacturing, AM-knowledge, interactive learning environment

1 INTRODUCTION

Additive manufacturing processes provide the users with new levels of design freedom during part design and product development in general. The reason for this is the layer by layer build principle which is applied during additive manufacturing and thus provides users with unique design potentials which, in addition to the realization of undercuts, the manufacturing of distinctive bionic structures, also enable the manufacturing of lattice structures without significant additional effort during the manufacturing process. [1–4] In research, some potentials of additive manufacturing processes have already been identified, so the possibilities of this manufacturing process are also increasingly known in companies. [1,2] However, the exploitation of the potentials is a major challenge for designers and product developers, because necessary knowledge is not sufficiently available, or prior knowledge is required for interpretation. As a result, to exploit and consider AM potentials during part design, users need basic experience in additive manufacturing processes to apply a variety of available methods and tools. [5,6]. In addition to the potentials, the restrictions of the process must also be taken into account for robust and reproducible manufacturing, otherwise, the correct and error-free manufacturing of the parts cannot be guaranteed. [1,2] Due to this, the research field Design for additive Manufacturing tries to develop and prepare methods and tools to support product developers to ensure a systematic knowledge transfer for additive manufacturing [7–14]. Additionally, the methods and tools should also be used in the context of academic education to impart AM knowledge and competencies to engineering students during their education.

This paper presents the knowledge acquisition for specific AM knowledge using the example of interactive teaching and learning offers for the application of infill structures and the implementation of different lattice structures. For this purpose, first, the basics of design for additive manufacturing concerning systematic knowledge transfer are presented, and in the following the acquisition and preparation of specific AM knowledge is explained. This is followed by the presentation of the interactive learning environment for blended learning methods, which makes digital content tangible with the aid of 3D models, and a brief validation of the presented learning environment for the transfer of specific AM knowledge. Finally, a summary and a conclusion are given.

2 DESIGNS FOR ADDITIVE MANUFACTURING

The Design for Additive Manufacturing research field develops methods and tools that support the methodical design process on an ongoing and phase-by-phase basis and provides tools for the identification, application, and implementation of AM potentials while taking process-specific restrictions into account. [2,4,7]

In the DfAM context, one focus is currently on how AM design potentials and process-specific restrictions can be taken into account in the idea and conception phase of the general product development process [2,3]. For this purpose, different solution proposals were developed within the research field, which supports during product development and consist of design rules, checklists with indications of AM potentials, AM-specific knowledge bases [8,15,16] or additional tools like the systematic network of AM design potentials [3] or the matrix of conflicting AM potentials [17] exist. In addition, the empowerment of users is also increasingly in focus, because the possibilities of additive manufacturing as well as the benefit-oriented application of the design potentials can only be realized with the help of benefit- and goal-oriented procedures or instructions. Consequently, the preparation of specific AM knowledge and the development of training and teaching concepts are the focus of current research. [4,5]

In summary, it can be stated that in the research field of design for additive manufacturing, various tools and methods have been developed to support product developers for the benefit-oriented application of AM potentials, so that assistance is available for users with varying application possibilities. Some of these tools have even been implemented digitally, such as the interactive Semantic network of AM design potentials according to Kumke [2], but the majority of the available tools have not been implemented digitally and are available as principle cards, design rules, and process models in analog form. For the systematic knowledge transfer of the benefit-oriented application of AM potentials, significantly more interactive and digital teaching and learning tools should be available, since these, especially in times of corona pandemic and home office, convey the content in a guided manner and thus have significantly less potential for the incorrect application.

In the following, the elaborated tools are explained concerning infill structures as well as the implementation and realization of different lattice structures utilizing additive manufacturing processes.

3 INTERACTIVE TOOLS FOR THE TRANSFER OF AM KNOWLEDGE

Digital and interactive learning tools offer both students and professionals non-linear access to information and are also accessible regardless of time and location. In addition to flexibility, interactive learning environments allow users to learn a topic area at their own pace, adapted to their prior knowledge and subjective level of expertise. Furthermore, alternative learning strategies such as collaborative learning or blended learning methods can be applied, and areas such as lifelong learning and further acquisition of learning material are greatly facilitated. Especially in the context of blended learning, hybrid models are occasionally used in universities, where lectures and interactive tools are used cooperatively in teaching. In order for the interactive tools to be used in a benefit-oriented and targeted manner in teaching, certain prerequisites must be met. [2,15,18]

Besides the methodological aspects, which also have to be chosen sensibly in the context of interactive teaching, there are special requirements for the user interface, the provided preceding and subsequent knowledge as well as for the implementation possibilities of the tools. The preceding and subsequent knowledge must be explicitly adapted to the contents of the lecture and must be designed to be complementary. In this way, animated and interactive 3D models can be visualized and digitally experienced in the area of design theory. The user interface must be designed to be self-explanatory and intuitive so that all functionalities are apparent and easy to understand.

As a result, a homepage was designed within the scope of the studies that provides various interactive courses and tools as well as specific knowledge by means of a learning management system (LMS). Fig. 1 shows the schematic structure of the knowledge system and visualizes exemplarily the access to the contents. Accordingly, the knowledge system has a navigation and access bar to access specific topics. It also identifies the representation area that provides opportunistic and restrictive AM knowledge. In addition, the knowledge system includes lessons on different additive manufacturing topics to learn specific topics through self-study. Users are guided by the LMS and use interactive visualization tools on additive manufacturing processes as well as short videos, texts, or self-tests to consolidate what they have learned and to receive feedback. The focus of the knowledge preparation was on a comprehensible communication of the potentials and limitations of additive manufacturing processes, especially for lattice and infill structures.

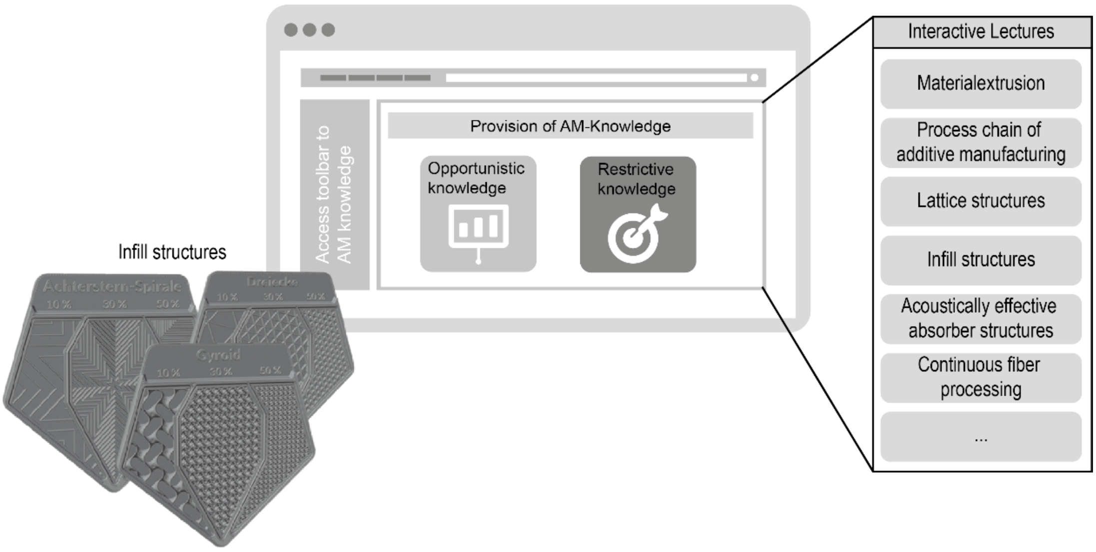

Figure 1. Schematic representation of the Interactive Knowledge System for imparting AM knowledge

The core element of the interactive tools of the knowledge system are varying 3D visualizations of specific AM potentials. In the context of this work, these are different lattice and infill structures that function as visual objects and are intended to convey necessary AM knowledge with the help of additional information. The structure of the interactive digital tools is designed in such a way that, on the one hand, the 3D geometry can be virtually experienced and examined. On the other hand, helpful information and further references are made available directly in the digital tool. Specifically, 3D models are prepared with the help of Web-GL plug-ins and thus made virtually usable. For this reason, the user interface allows users to rotate and resize the geometry data and to obtain further information using descriptions, highlights, or selectable buttons. Taking the infill structures as an example, users can switch between the different infill tiles and thus directly see the geometric shape in terms of form and infill density. In addition, geometry parameters are available that represent the 3D printed part with the selected infill type.

Figure 2 shows different infill structures that can be experienced as part of interactive models in the knowledge system. These infill plates show the name of the infill structure at the top and represent the geometric shape with varying infill densities in the panels below. It can be seen that increasing the infill density leads to smaller geometric features of the structures and thus the infill structure as such becomes more compact.

In the context of the virtual lessons, users have access to various topics which, in addition to basic knowledge of additive manufacturing processes, also include more specific topics such as the benefit-oriented application of AM potentials. In this way, for example, the application and implementation of differently shaped lattice structures can be learned and applied. The structure of the lessons is based on best practices, starting with a short introduction to the subject area, increasing the specificity of the topic and making the content more complex. For this purpose, explanatory videos and descriptive texts are provided to convey the topic as simply and effectively as possible. For better understanding, the topics are also included in the interactive knowledge elements, so that this knowledge should also be conveyed

interactively. Self-tests are available to check the level of knowledge or to monitor the success of the learning objectives, giving users an overview of what they have learned.
By using digital tools, digital data can be prepared interactively and enhanced with the help of additional information that can be retrieved. This possibility offers great potential for independent continuing education, as the methods and workshops can be designed with the help of digital tools in such a way that knowledge carriers do not necessarily have to be present so that the transfer of knowledge can also be sensibly carried out through self-study. The digital tools support this approach immensely and thus also help to improve and promote lifelong learning sustainably.

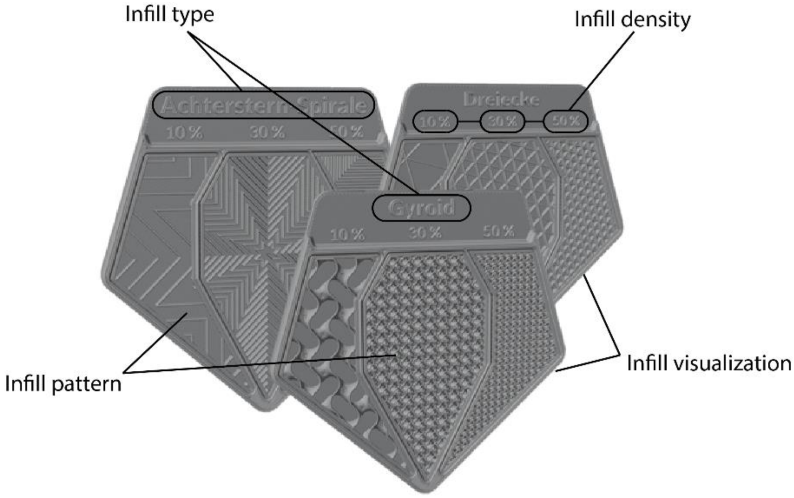

Figure 2. Selected infill tiles for visualization of infill structures and infill densities

4 APPLICATION AND VALIDATION OF DIGITAL LEARNING TOOLS

Systematic knowledge transfer for additive manufacturing is currently often realized with the help of workshops or by providing analog tools and methods. This type of knowledge transfer is possible, but the unguided provision of the tools and methods does not give product developers any guidance on how to use the tools during product development, which also prevents corrective measures. As a result, Digital Tools for Knowledge Transfer offer good opportunities to enable a structured transfer of the acquired knowledge. Blended learning methods are particularly interesting in this context, i.e., approaches to link virtual, digital learning tools with classic learning offerings. In addition, the virtual learning environments, at least in the example presented here, can also be produced as physical objects, making hybrid learning possible.
To evaluate the developed knowledge system, the interactive lessons on infill and lattice structures were made available to students in a workshop format as part of the course "Computer Aided Design". In this way, the useful application, functionalities and usability are to be reviewed and a comparison between digital and analog teaching is to be made possible. The structure of the workshop is divided into a basic introduction to the topic of additive manufacturing processes, so that rudimentary knowledge is available. However, this introduction could also be realized with the help of digital tools. This was followed by a brief presentation of the knowledge system and an introduction to the design task. The students had the task to ensure a benefit-oriented application of the AM potentials and to select suitable grid structures in the context of the topology optimization. For this purpose, a large number of potential lattice structures were available for selection with the tools provided, whose advantages and disadvantages as well as mechanical properties can be displayed with the help of the interactive environments via the geometry and other information. Thus, in this case, the knowledge system served to impart knowledge about specific characteristic values and application scenarios for the corresponding lattice structures. In addition, the students also had the task of preparing additive manufacturing for a given geometry whose application purpose was described. In order to ensure successful manufacturing as well as reasonable usability of the component, a suitable infill structure should be identified that allows material savings while still meeting the mechanical requirements of the component. Fig. 3. shows a selection of illustrative objects that represent different lattice structures and are examined in more detail within the interactive lessons.

Figure 3. Selected lattice structure cubes for visualization of different lattice structures

The workshop was conducted with 14 participants who first completed the interactive lessons on infill and lattice structures to build up necessary knowledge. Subsequently, the students worked on the design task without further instructions. It was found that necessary information was available and thus initial results could be generated quickly. The selection of suitable lattice structures was well done by the participants and almost all subjects were able to identify useful structures. Also, the selection of suitable infill structures could be done without problems by the workshop participants. The use and application of the knowledge system succeeded intuitively for the workshop participants and did not pose any challenge. As a result, the interactive lessons provided a good opportunity for students to acquire specific knowledge using virtual learning methods. The workshop and the application of the knowledge system fulfilled the expectations and could show that with the help of interactive tools a time and location independent teaching by means of BL methods is possible. Especially the self-tests are in this context a good learning target control for the students to get individual feedback, which normally rarely happens at universities.

5 CONCLUSIONS

Within the scope of this work, an interactive knowledge system for teaching AM potentials using the example of infill and lattice structures was developed. The core element of this knowledge system is formed by virtual and interactive lessons, which are supposed to convey specific AM knowledge. For this purpose, explanatory videos, descriptive texts and interactive geometric data visualizations are used to provide further information on the respective topics interactively. In addition, self-tests are used to provide the users with a learning success control.

Through the use it could be determined that the use of digital learning offers a significantly higher flexibility for the users and still offers specific advantages in terms of guiding the users through the content as well as a profitable interaction with the knowledge to be imparted. In the context of additive manufacturing processes, interactive tools can be used to make visual objects available via the Internet in a cost-effective and straightforward manner, so that 3D printing results can be made available even without a manufacturing facility. The sensible and user-oriented integration of digital and interactive learning offers in workshop concepts and other classic offline learning offers represents a key factor for the targeted and efficient application of these learning offers and was applied in rudimentary form in the context of this contribution. It could be determined that the different offer formats require explicit coordination with each other to achieve the highest possible compatibility as well as a coherent concept. The use of digital learning offers based on Web-GL plug-ins provides the user with a good and uncomplicated possibility to experience the 3D models and to obtain further information.

As a result, the created learning environments offer a good added value to the user when it comes to obtaining information on specific AM knowledge. However, for the systematic transfer of knowledge for AM, these digital learning offers must be implemented in fully comprehensive workshop concepts or use cases, so that a specific development problem is present along the product development process and thus parallels specific development problems in the own company become apparent. In this way, the specific knowledge transfer methods for specific AM knowledge can be combined with real process knowledge for additive manufacturing, and the added value is significantly increased. However, the usability of the interactive tool should still function as a stand-alone tool and thus only address a specific problem or potential during the use of AM. In addition, a combination of digital tools is possible without further. Furthermore, a significantly larger group of test persons should be used for the evaluation of the tools and the entire concept, so that the opinions are more expressive and meaningful extensions and optimizations can be incorporated into this project based on the feedback.

REFERENCES

[1] Gebhardt A. Additive Fertigungsverfahren: Additive Manufacturing und 3D-Drucken für Prototyping - Tooling - Produktion. 5th ed. München: Hanser; Ciando; 2016.

[2] Kumke M. Methodisches Konstruieren von additiv gefertigten Bauteilen. Wiesbaden: Springer Fachmedien Wiesbaden; 2018.

[3] Kumke M, Watschke H, Vietor T. A new methodological framework for design for additive manufacturing. *Virtual and Physical Prototyping* 2016;11(1):3–19. https://doi.org/10.1080/17452759.2016.1139377.

[4] Watschke H. Methodisches Konstruieren für Multi-Material-Bauweisen hergestellt mittels Materialextrusion: Universitätsbibliothek Braunschweig; 2019.

[5] Schumacher F., Watschke H., Kuschmitz S. and Vietor T. Goal Oriented Provision of Design Principles for Additive Manufacturing to Support Conceptual Design. *Proc. Int. Conf. Eng. Des.* 2019;1(1):749–58. https://doi.org/10.1017/dsi.2019.79.

[6] Wegner A. and Witt G. Konstruktionsregeln für das Laser-Sintern. Zeitschrift Kunststofftechnik (WAK) 2012;2012(3):252–77.

[7] Adam G. A. O. and Zimmer D. On design for additive manufacturing: evaluating geometrical limitations. *Rapid Prototyping Journal* 2015;21(6):662–70. https://doi.org/10.1108/RPJ-06-2013-0060.

[8] Bin Maidin S., Campbell I. and Pei E. Development of a design feature database to support design for additive manufacturing. *Assembly Automation* 2012;32(3):235–44. https://doi.org/10.1108/01445151211244375.

[9] Ehlers T., Tatzko S., Wallaschek J. and Lachmayer R. Design of particle dampers for additive manufacturing. *Additive Manufacturing* 2021; 38:101752. https://doi.org/10.1016/j.addma.2020.101752.

[10] Gibson I., Rosen D. and Stucker B. *Additive Manufacturing Technologies*. New York, NY: Springer New York; 2015.

[11] Glasschroeder J., Prager E. and Zaeh M. F. Powder-bed-based 3D-printing of function integrated parts. *Rapid Prototyping Journal* 2015;21(2):207–15. https://doi.org/10.1108/RPJ-12-2014-0172.

[12] Lachmayer R., Gembarski P. C., Gottwald P. and Lippert R. B. The Potential of Product Customization Using Technologies of Additive Manufacturing. In: Bellemare J, Carrier S, Nielsen K, Piller FT, editors. *Managing Complexity*. Cham: Springer International Publishing; 2017, p. 71–81.

[13] Marjanović D., Štorga M., Pavković N., Bojčetić N. and Škec S. (eds.). *DESIGN 2016: Proceedings of the DESIGN 2016 14th International Design Conference*. Zagreb: Fac. of Mechanical Engineering and Naval Architecture Univ; 2016.

[14] Rosen D. W. Computer-Aided Design for Additive Manufacturing of Cellular Structures. *Computer-Aided Design and Applications* 2007;4(5):585–94. https://doi.org/10.1080/16864360.2007.10738493.

[15] Kuschmitz S., Watschke H., Schumacher F. and Vietor T. Bereitstellung von Lösungsprinzipien für die additive Fertigung zur Unterstützung der Bauteilkonzeption in der industriellen Praxis. In: Kynast M, Eichmann M, Witt G, editors. *Rapid.Tech + FabCon 3.D International Hub for Additive Manufacturing: Exhibition + Conference + Networking*. München: Carl Hanser Verlag GmbH & Co. KG; 2019, p. 75–88.

[16] Weiss F., Binz H. and Roth D. Approach to consider Rapid Manufacturing in the early phases of product development. In: Weber C, editor. *Design for life.* Glasgow: Design Society; 2015, p. 1–10.

[17] Fuchs D., Kuschmitz S., Kühlke K. and Vietor T. Identifikation von Zielkonflikten bei der Anwendung von Potenzialen additiver Fertigungsverfahren. In: Lachmayer R, Rettschlag K, Kaierle S, editors. *Konstruktion für die Additive Fertigung* 2019. Berlin, Heidelberg: Springer Berlin Heidelberg; 2020, p. 223–244.

[18] Plappert S., Hoppe L., Gembarski P. C. and Lachmayer R. Application of Knowledge-Based Engineering for Teaching Design Knowledge to Design Students. *Proc. Des. Soc.: Des. Conf.* 2020; 1:1795–804. https://doi.org/10.1017/dsd.2020.300.