Work-Process Orientated and Competence Based Professional Training for Skilled Workers in Laser Additive Manufacturing

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Abstract. In production technology innovative machining methods such as additive manufacturing are changing the work-fields and work-processes of skilled workers and thus their professional training needs to be altered. Laser additive manufacturing currently experiences introduction in serial applications in aircraft or medical industry. In this context parts of very high quality are mandatory and to achieve this it is necessary to set up processing strategies and parameters. Nevertheless a high complexity in the relationship between parameter setting and process outcome is characteristic for additive technology. Due to this fact comprehensive experience and know-how, which is yet few to be found, is demanded from machine operators. Surveys conducted in the industry show that consequently changed qualification requirements upon skilled workers can already be defined in detail for additive manufacturing. Therefore a corresponding professional training was developed which is work-process orientated and focuses on the specialized competencies for professional decision-making and responsibilities. In this context the training approach explicitly does not concentrate only on simple machine or process instruction for additive manufacturing. Rather the methodical didactic concept bases on a blended learning approach which includes the combination of multiple learning locations as well as project based learning in a professional context. Here technical contents are connected to a sequence of tasks in form of modules each with a reference to the professional practice. In this way also the shift towards close to engineering tasks and methods for continuous self-learning are addressed. Finally learning systems regarding the infrastructure and capacities that are required for a learning environment are assessed. In conclusion additive manufacturing and its digital process chain represents a typical example for changing work settings for trained professionals in the context of increasingly interconnected industrial processes. Therefore the developed professional training can perspectively also be transferred to further processes in Industry 4.0.

1 Introduction

Additive manufacturing (AM) currently experiences introduction in serial applications for example in aircraft or medical industry. Especially the aircraft and aerospace industry represents important fields of application for AM as a high degree of

M. Meboldt and C. Klahn (eds.), *Industrializing Additive Manufacturing - Proceedings of Additive Manufacturing in Products and Applications - AMPA2017*,
DOI 10.1007/978-3-319-66866-6_30

geometrical freedom for lightweight design and series with a small lot size can be achieved [1, 2]. In this context direct manufacturing of final products by selective laser melting (SLM) represents the field of application with the biggest developing potential which is expected to significantly expand further throughout the following years [1]. Already within a timespan of about 10 years a growth from 3.9% in the year 2003 to 19.2% in the year 2012 in directly manufactured final products based on the overall manufactured parts, prototypes and models by additive manufacturing shows this increase which is expected to continue further [3]. Nevertheless the enormous potential provided by AM can only be exploited when there are appropriately skilled workers available in the industry throughout all steps of the process chain [4]. Consequently, based on the continuous development and the increasing wide spread use of AM technology, a built-up of well-trained skilled workers should be aspired. Therefore the present paper makes an approach for an innovative training method contributing to the situation of training and education in the field of AM.

2 State of the Art in Professional Training for Additive Manufacturing

As Germany represents a significant corporative actor in AM technology its situation of education and vocational training is exemplarily analyzed. In the German vocational training and education system the introduction of AM methods has already taken place for six professions such as production technologists (Produktionstechnologe/-in), technical product designers (Techn. Produktdesigner/-in), technical model makers (Techn. Modellbauer/-in), engravers (Graveur/-in) and casting mechanics (Gießereimechaniker/-in) [5].

A performed analysis of curricula for these professions in the metal industrial sector shows that training contents of AM are already placed within the standard formal guidelines between the 2nd and 4th year of vocational training [5]. For these professions the following exemplary competencies regarding AM methods are to be studied [5]:

- Preparation of AM production processes
- Planning and manufacturing of prototypes and samples
- Choosing suitable methods for transferring data in exchange formats like STL etc.
- Computer assisted manufacturing of models, forms and samples
- Developing parts from plastic regarding methods from forming and primary shaping in the context of assemblies

Nevertheless, regarding that there is a total number of more than 30 professions in which a professional career can be aspired in the metal processing industry, this situation shows that AM it still few to be found in professional curricula when compared to conventional manufacturing methods such as milling or turning and if it is found the detailed AM technologies are not explicitly named [6]. In contrast to this the introduction of more contents regarding AM would be desirable especially for substantial professions like aircraft device mechanics (Fluggeräte-mechaniker/-in), precision mechanics (Feinwerkmechaniker/-in), industrial mechanics (Industriemechaniker/-in), mold makers (Werkzeugmechaniker/-in) or product developers [7].

Furthermore, besides the initial vocational training, trainings for skilled workers with advanced professional experience are already provided e.g. by research institutes, universities, companies or professional associations such as ‘Hochschule Schmalkalden’, ‘Fraunhofer IFAM’, ‘LZH Laser Akademie GmbH’ or ‘LZN Laser Zentrum Nord GmbH’ in terms of workshops or longterm courses of studies [8–11]. LZH offers a training for “Specialists for additive manufacturing methods/rapid technologies” in accordance to guideline DVS®3602-1 which represents a certified professional training [10].

The amount of training possibilities underlines that there is a significant offer and demand of professional AM training present in the market. From the perspective of the AM users this provides the opportunity to choose between different forms of training and to decide the best suitable training method for each specific need. The work-process in AM represents the focus for learning in the present paper and learning methods in terms of an educational scientific point of view are subordinated given that approved methods are combined in an innovative setting focusing on a vocational scientific point of view [12–15].

3 Identification of Competencies for Additive Manufacturing

In AM professional reality it is necessary to be able to apply knowledge in consistently new and challenging situations and potentially also to be able to transfer knowledge to variable AM technologies. Therefore the acquirement of competencies is necessary. In this context the term of competencies includes the subjective perspective of employees and is therefore more comprehensive than a qualification [12, 13]. For the purpose of the identification of required competencies for AM in a first step a sector analysis was performed followed by a questionnaire based survey regarding topics such as utilized laser based manufacturing methods, field of activities, state of knowledge and type of experienced training. The questionnaire provided access to a feedback of 40 professional respondents from companies in the laser based manufacturing branch. Though the sample of the survey does not allow a statistical analysis or verification yet results were consistent so that it was possible in this manner to specifically design the framework for the following interviews [16]. The interviews were conducted with selected experts from the industry. They were executed with regards to a determination of up-to date qualitative data directly from the industrial application of AM. To be able to compare the results from the surveys these were structured using an interview guideline organized by the topics ‘future development of AM methods’, ‘skilled labor in this context’ and ‘demands for qualification’. The structured but open interviews were executed with 5 stakeholders from different branches of the metal processing industry such as dental technology, suppliers for aerospace industry, small and medium-sized businesses from mold making, research centers and service suppliers. The interviewees were holding functions in divisions of technical management, development, design and manufacturing and represented both personnel in leading positions as well as employees in technical executing positions.

To be able to acquire target-oriented information from the interviews specific AM methods need to be chosen. This is also necessary for the development of an exemplary learning situation thus the training needs to address specific AM methods. Based on the analysis in Sect. 2, the initial inquiry towards interview partners and the following interview preparation on the one hand powder-bed based SLM was selected due to a high significance for industrial applications in metal and plastic. On the other hand fused deposition modeling (FDM) based on extrusion of filament was selected. This considers the suitability of FDM for training regarding costs for machines and raw plastic material. Furthermore also end products and functional prototypes are usually manufactured in an industrial context by FDM [17].

For the evaluation of the interviews audial recordings were transcribed and analyzed based on determined categories in accordance to the steps of the process chain in AM. This approach was chosen due to the fact that the competencies for skilled workers in AM were expected to be well correlated to the steps of the process chain in AM. The process chain is complex due to its manifold steps and thus demands an expertise in different disciplines from skilled workers. The process chain contains steps in Pre-, In- as well as Post-processing such as a discussion with a customer, 3D-CAD design, revision of digital data, slicing, manufacturing, finishing and collaborative discussion [18, 19] (Fig. 1). In this context the didactical concept of learn and work assignments (LWA) is introduced which consist of 'Assignment of order', 'Planning', 'Execution' and 'Closure' [14]. In conjunction to the steps of the AM process chain analogies to the phases of learn and work assignments can be seen (Fig. 1). Therefore this connection is exploited in the development of a didactic concept in the following section.

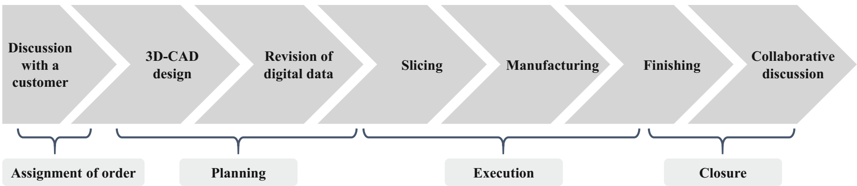

Fig. 1. Process chain in additive manufacturing regarding the work-processes

The results of the interviews emphasize demands of competencies within the fields shown in Fig. 2. Furthermore the aggregation of identified competencies from the interviews is shown (Fig. 2). For the development of creative solutions in a discussion with a customer, competencies such as problem solving, planning as well as social and technological competencies are required. Throughout the following steps of the process chain competencies are demanded that comprise the adept handling of computers and software. Competencies in information technology (IT) have to be applied to knowledge in design for AM as well as to technological competencies covering e.g. AM specific process knowledge. Therefore interdisciplinary thinking and acting is necessary.

In the context of the design and data preparation process it depends on the size, the organizational structures and thus the degree of division of labor within each business unit how intensively the skilled worker is involved in this step. Nevertheless within

Competencies for additive manufacturing	Planning / Method	IT	Technological	Social
PRE - process	• Overview of various AM manufacturing methods • Identification of geometrical freedom for design • Optimization of transmission of force • Assessment of part behavior to avoid residual stress • Consideration of part properties influenced by build-direction and part orientation	• Handling of various software for design • Creation of 3D data (possibly from 3D scanning) • Correction of errors in 3D volume models • Handling of various software for positioning and part orientation • Configuration of data formats	• Overview of available materials • Transferring of data • Definition of support material	• Development of creative solutions in a discussion with a customer • Usage of professional vocabulary in native and English language
IN- process	• Monitoring of the initial phase of the AM process • Decision-making to continue or abort the process	• Possible redefinition of support material	• Handling of various machine types • Choice of process parameters for manufacturing • Calibration of nozels at FDM • Handling of metal powder regarding the safety instructions	
POST - process	• Overview of methods for post processing (e.g. shot peening, milling etc.) • Planning of steps for post processing and sequencing them • Choice of tools for post processing (e.g. chipping tools) • Choice of clamping for post processing • Review of the process results • Development of proposals for improvement		• Background in material science • Background of heat treatment and metallography • Removing of support material • Understanding of technical drawings and quality assurance documents • Choice and application of measuring equipment • Modification of surfaces in texture and color • Assembly of multiple components and norm parts • Overview of specialties of cleaning for various machine types • Changing of filter units with regards to applying safety and disposal instructions	• Discussion of creative approaches resulting from process review

Fig. 2. Competencies for additive manufacturing structured in matrix form

training for AM all steps of the process chain should at least be addressed in a basic manner to enable e.g. problem solving competencies when manufacturing problems arise from other parts of the process chain than the ones in which certain trained staff is specialized in.

In summary the surveys conducted in the industry show that competency requirements upon skilled workers can already be defined in detail for additive manufacturing and that a high demand throughout all levels of degrees including also technicians, master craftsmen and engineers is persistent. Therefore in the next step a corresponding professional training is developed which explicitly does not concentrate only on simple machine or process instruction for additive manufacturing but is work-process orientated and focuses on the specialized competencies for professional decision-making and responsibilities.

4 Development of Work Process Orientated Professional Training

Since the qualification and competency requirements upon skilled workers are identified a corresponding professional training is developed in the following section. It is work process orientated and focuses on the specialized competencies for professional decision-making and responsibilities. Furthermore it addresses homogenous as well as heterogeneous target groups from various professions and experience levels. Therefore the derived exemplary learning situation for AM can be integrated in initial basic vocational training as well as in the advanced training of skilled workers.

As described in the prior section the acquirement of competencies for skilled workers in AM is necessary. Nevertheless competencies are greatly difficult to be taught in ex-cathedra teaching situation in which solely theoretical knowledge is transferred. The ability to self-organized and creative acting under the uncertainty of open system environments is rather imparted in process orientated learning with self-reflection of technical content. This can be achieved by applying the approved didactic concept of learn and work assignments (LWA) [14]. These represent situations in project form which are process- and task-orientated, containing problem situations with regards to real vocational context [14]. The configuration of the learning situation should be orientated towards the principle of wholly acting and should address the steps ‘Informing’, ‘Planning’, ‘Executing’ and ‘Checking’ to achieve the superordinate aim of acting orientation [15]. Therefore a LWA consists of the four phases ‘Assignment of order’, ‘Planning’, ‘Execution’ and ‘Closure’ in which a product or a service is realized in context to a reality based customer and manufacturing order. Based on specific operational challenges trainees realize and deliberate practical solutions within a team while the implementation of the above named competencies is achieved by embedding them into the each LWA’s project step (Fig. 3).

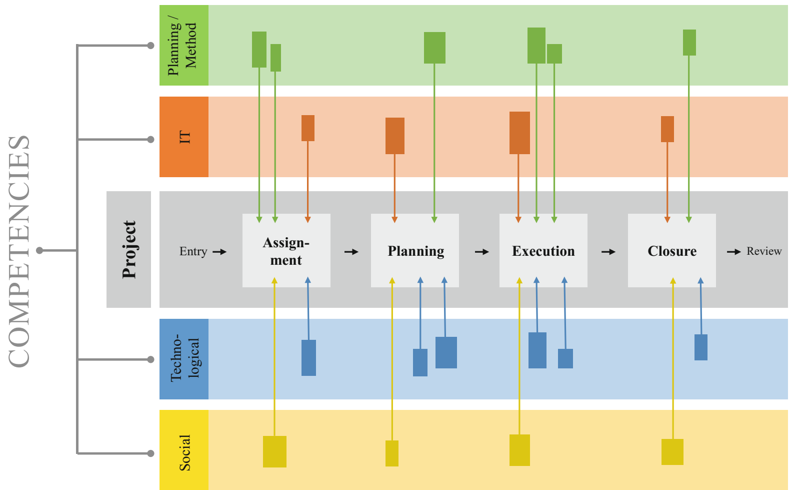

Fig. 3. Structure of learn and work assignments (LWA)

Furthermore as an innovative approach in this contribution the conception of a LWA for AM training is simultaneously merged with the methodical didactic concept of a blended learning approach which includes the combination of multiple learning locations (Fig. 4). These are specifically used to address each particular content in an each suitable learning environment and thus enhance the learning process overall. By this combination of two didactic methods conventional teaching structures can be overcome and a project based learning approach is realized which imparts the necessary professional competencies for AM.

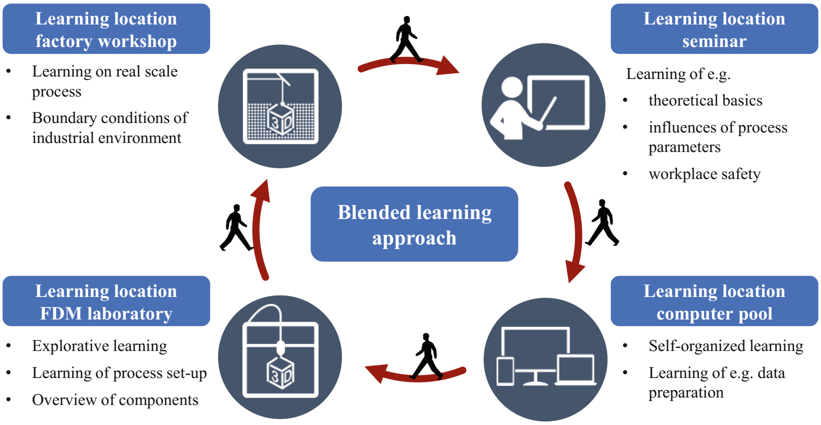

Fig. 4. Blended learning approach with different learning locations

For the developed training four learning locations can be identified. These consist of a seminar room, a PC-pool, an AM laboratory e.g. equipped with a FDM machine and an industrial sized workshop with access to SLM machines.

The learning location of a seminar room as well as a PC-pool is suitable for the first phase of the LWA. A customer order is introduced by the trainer where the manufacturing of a prototype part is queried first from plastic material and in a later serial production from metal material. The queried part contains AM relevant elements that demand an AM specific design. Aspects such as lightweight potential, integrated functions, individualized components or a minor lot size can be addressed. Also necessary theoretical basics about AM are introduced. The trainees form project groups and process assigned tasks within the prepared project framework under supervision of the trainer. The first application of the developed LWA showed that groups of up to 5 people are feasible. Depending on the training situation also the introduction of a group design challenge with the aim to achieve the best technical solution for the projected part can be taken into consideration. The teams gather information about relevant AM methods autonomously and after inquiry the stakeholders exchange their achieved results. In this way besides the technical competencies also methodical and social competencies are trained simultaneously. The trainer chairs the learning process, complements neglected content, corrects in case of mistakes and directs towards the next phase of the LWA. Also the learning location of an AM laboratory can be used to provide the trainees first hand insight of the components of AM machines.

In the planning phase of the LWA the trainer introduces the steps of the AM process chain and demonstrates the handling and possibilities of data preparation software such as the placement of support structures and part orientation in the building chamber. Therefore a learning location equipped with digital media is necessary. Further the trainees themselves apply the creation and configuration of CAD-data as well as the correction of digital models and final data preparation for the AM process with corresponding software on computer workplaces under the guidance of the trainer.

In the execution phase of the LWA the trainees transfer the prepared production data of their group to the FDM machine followed by the definition of process parameters and set-up of the process. In this context learning locations such as an AM laboratory and also a seminar room or PC-pool can be used e.g. to learn about influences of process parameters in the AM process. Finally the trainees observe the start-up phase of the building process and after finishing of the building process the groups execute the prior planned steps of post-processing.

In the closure phase of the LWA the reflection of achieved results is carried out. After finishing of the manufacturing process the quality of the manufactured part of each group is assured. The trainees therefore are coached in handling of corresponding measurement equipment and they document the results in quality protocols. This proceeding aims towards a self-responsible reflection of the process results by the trainees. Successfully passed process steps as well as occurred problems are documented and propositions for improvement are made. These are subsequently discussed with the trainer and modifications are defined for the derivation of a manufacturing procedure for the metallic serial part.

Since the application of FDM cannot reproduce the whole complexity in each step of the process chain for industrially relevant, metal processing SLM the trainees commence a second manufacturing cycle. Else e.g. the handling of metal powder and filter components would be neglected and also the post-processing for both manufacturing method differs. The project groups are therefore passing through the steps of the process chain for the metallic part where the trainer focusses on imparting SLM specific differing competencies while the group works more self-reliant on the process steps analogous to FDM.

Nevertheless also limitations of the LWA can be observed from an initial application of the training. In this way the evenly integration of all group members turned out to be challenging. Also setting up of small groups means a splitting of the learning group and thus demands a high commitment of the trainer. In term of the project timeline the LWA needs to be divided in multiple sessions due to the time consuming manufacturing process which could mean a limitation e.g. in a scholar context. Finally also limited view and space in front of AM machines may conflict with the fact that manufacturing may be started at once from multiple groups which therefore are all meant to observe the proper start-up of the process at the same time.

5 Summary and Outlook

In the presented contribution a professional training was developed combining two didactic concepts. In this way the training provides future perspectives for employees in initial basic vocational training as well as in the advanced training of skilled workers. The learning situation enhances a straight forward access to innovative technologies of

AM and prospectively important competencies can be acquired by a variety of target groups. The AM training furthermore reacts to a typical example for changing work settings for trained professionals in the context of increasingly interconnected industrial processes. Therefore the developed training can perspectively also be transferred to further processes in the context of Industry 4.0. Following steps can be seen in the detailed evaluation during an implementation of the developed professional training. With future development also approaches of learning in a virtual additive manufacturing environment is thinkable and learning content can be provided by this media.

Acknowledgments. The authors would like to thank Mr. Springer, P. whose graduation thesis resulted from the course of this work.

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