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NEW DEVELOPMENTS IN DESIGN EDUCATION FOR ADDITIVE MANUFACTURING

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ABSTRACT
Additive manufacturing (AM), or 3D printing (3DP), has increasingly become more wide-spread and applied to a great degree over the past years. Along with that, the necessity for training courses which impart the required knowledge for product development with 3D printing rises. This article will introduce a "Rapid Prototyping" workshop which should convey to students the technical and creative knowledge for product development in using additive manufacturing.
In this workshop, various 3D printers are initially installed and put into operation for the construction of self-assembly kits during the introduced training course. Afterwards, the students use databanks to select and download suitable components for the 3D print on the basis of criteria. Lastly, the students develop several assembly kits independently and establish design guidelines based on their experience. The students likewise learn to estimate and evaluate economic boundaries such as, e.g. costs and delivery times.
For a start, it is a new approach to be using various assembly kits. These are up to date with current technology and dispose of features such as, e.g., additional nozzles for support material and heated building platforms. Moreover, a comprehensive evaluation of the training success will be conducted. The students' level of knowledge in various areas will also be determined and compared with surveys taken before and after the conducting of the workshops. Additionally, cost and delivery time estimates and knowledge of databanks will be determined through concrete questioning.

Keywords: Design Education, Additive Manufacturing, workshop, evaluation, 3D-Printer.

1 INTRODUCTION

Over the past few years, both the diversity of methods for Rapid Prototyping (RP) or Additive Manufacturing (AM) and their areas of application have grown tremendously [1]. A reason for this are among other things the new possibilities additive manufacturing offers with regard to the free design of components. To maximize the possible potential of this new, generative manufacturing process, the particularities of the layered structure must already be taken into consideration in the development and construction of components and products [2]. However, education and training often continue to focus on conventional, i.e. transformative and chipping manufacturing approaches, and as a result, many engineers today have only very limited skills and knowledge with regard to AM [3].
To remedy this deficiency, a number of textbooks and construction guidelines have been created. Moreover, several universities have established lectures and seminars that take design for AM into account [4, 5]. However, these classes, in general, use laboratories that provide access to a large number of 3D printers. As a result, students are able to use the laboratories, but unfortunately, they often lack a deeper understanding with regard to the production technology and its possibilities and limitations in practical application.
This paper, therefore, presents a new course in which industrial engineering master's students learn to comprehend the manufacturing technology of AM, and to independently develop a construction aligned with it. A close and practical collaboration of manufacturing technology and construction is established in this manner. In the new course "Workshop Rapid Prototyping", the students first assemble a variety of 3D printers by themselves. In this process, new equipment is used that can utilize both construction and support material. Then the students have to commission the 3D printers and install and operate the driver software for the 3D printers and the software for creating the layers. In a next step, the construction of the components for the additive manufacturing is carried out. In this

process the students can profit from the knowledge they gained from the assembly of the 3D printers and their first experiences from the 3D printing of components, which had been downloaded from an internet database. They also can use their skills from the lectures “Computer Aided Engineering 1” (Bachelor level, 90 h workload) and “Computer Aided Engineering 2” (Master level, 120 h workload). Furthermore, the students determine the cost and manufacturing time of the components, to be able and perform an economic assessment.

2 LITERATURE REVIEW

Implementing the application of AM technologies in educational settings has already been successfully occurring for several years [6, 7]. Today there is great diversity regarding theoretical education in product development which offers a detailed description of procedure and processes ranging from introductory books to extensive facilities. In practical training, various studies exhibit that rapid accessibility of prototypes is guaranteed by the application of AM which ensures the students direct feedback with respect to the viability of their designs [8 -10].

Until recently, the application of AM technology in education was limited as a result in that, as a rule, only a few devices were available at university laboratories. Moreover, specially trained operating personnel were often required for these devices. In order to circumvent this hindrance, laboratories with a greater number of smaller 3D printers were increasingly built at universities [11]. This way, larger groups of students could also be guaranteed access to the devices after a shorter time. Nevertheless, the students are simply users of the technology in these laboratories and do not receive a deeper look into the manufacturing process and the exact operating process of the 3D printer.

The application of self-assembly kits presents an additional approach to communicating the specific requirements for generating components and products using AM. In this, the students first install a 3D printer as an assembly kit and put it into operation. In doing this, they gain a good understanding of the function of the 3D printer. This understanding can later be used in the generation of components, e.g. in the form of construction guidelines [12].

Several 3D printers, identical in construction, were used in previous studies; these printers could only use building material rather than support material. Design freedom was thereby very limited. Additionally, a software package was applied which could only influence the data preparation to a lesser extent. Thus, only limited latitude was available for the variation of the setting parameters [13].

This article will examine a further development of this approach. Thanks to these new developments, students now can get a deep insight into the manufacturing technology of AM. Furthermore, new technological developments, like for example an additional extrusion nozzle for the support material or a heated building platform are integrated into the workshop. As different brands of 3D printers are used, the students can also get to know and compare different designs of the machines. Furthermore, the students independently develop components, and in doing so they also develop design guidelines for AM. Moreover, a variety of software tools for data preparation will be implemented. To facilitate the evaluation of the students’ progress, assessments were carried out both before and after the course. In this way it can be determined, what knowledge students acquired in the course of the class, for example with regard to the technology, the construction and the economic framework.

3 3D PRINTERS USED AND PROCESS CHAIN

First, the function of the 3D printers used in this study will be explained and compared. This approach offers the opportunity to evaluate different hard- and software and should enable the students to learn from different types of 3D printers. Then the process of additive manufacturing will be illustrated in combination with the application of 3D printers as a self-assembly kit.

3.1 Selected 3D Printers

All the 3D printers used in this study operate with the Fused Deposition Modelling (FDM) process (see Tab. 1). In this, a plastic filament is heated in a nozzle and extruded. The extruded material is placed on a construction platform. When the application of a layer has been completed, this construction platform and the next layer can be applied. Three different 3D printers were used in this study; all were made available as assembly kits to the students. The printers, more than anything, differ in design, the size of the installation space and the printable layer thickness. As a rule, in changing the nozzle diameter, an adjustment to the filament diameter is also possible.

Table 1. Specific parameters of the 3D printers used

Name of device	Felix 3.0	RepRap Protos V2	Ultimaker 1
Design/machine frame	Aluminium frame	Steel frame	Wooden frame
Installation space [mm]	255 x 205 x 225	230 x 230 x 125	210 x 210 x 205
Layer thickness [mm]	0,05 – 0,25	> 0,1	> 0,02
Filament diameter [mm]	1,75	3	3
Heated platform	yes	yes	yes
2nd Extruder (Support)	yes	yes	yes
Construction materials	PLA, PET, ABS, PVA, Nylon, HIPS etc.	PLA, PP ,PS, ABS, PVA etc.	PLA, ABS etc.

It was demonstrated here that all 3D printers are originally equipped with an extrusion nozzle for construction material. In addition, an extension kit to mount a second nozzle for the application of support material can be acquired. Likewise, a heated construction platform can be installed optionally; the heated platform is supposed to contribute to reducing the warping of the components due to thermal stress. These hardware extensions also make adapting the software necessary.

3.2 Process chain from virtual 3D model to physical model

First, the process of additive manufacturing will be explained in combination with the application of 3D printers as self-assembly kits (see Fig. 1). The basis for additive manufacturing is always a 3D model for a component or for a product. Ordinarily, this is modelled within the framework of product development with the aid of a CAD system. As an alternative to this, data of an existing component can also be gathered by means of a 3D scanner. In this case a Reverse Engineering is necessary to convert the point cloud from the 3D scan to a volume model. Today a huge variety of 3D models are also available to download on Internet databases.

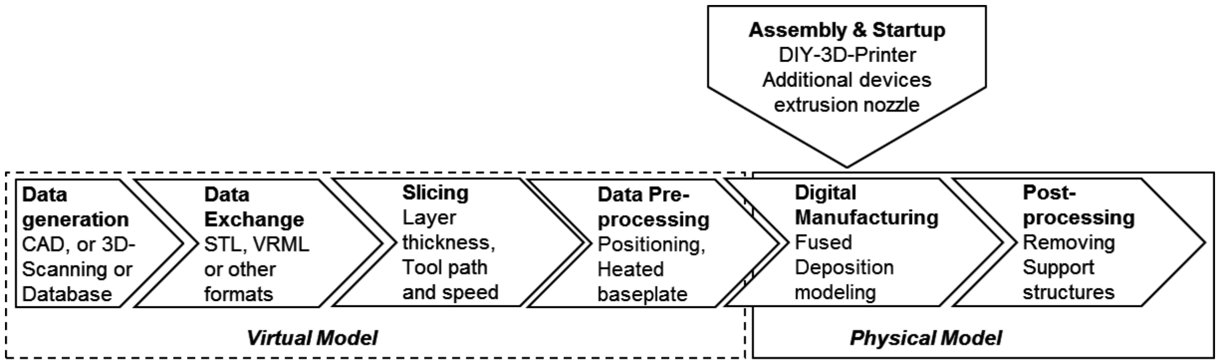

Figure 1. Process chain in Additive Manufacturing in combination with the assembly and startup of a DIY 3D-Printer

The 3D data is then transferred to the data preparation with the aid of an interface. Generally, the STL format is used for this; this format presents a very simple and freely available data format which is used by many CAD software packages. The data preparation splits itself into two steps which is also conducted by varied software tools for different 3D printers. For one, the component is segmented into individual layers, and the toolpath of the 3D printer must be created. In this study, software tools such as, e.g., CURAEngine, SFact or Sliz3r, which are available as freeware or open-source software, were used for this "slicing." In this step, parameters, such as layer thickness and speed, are set. In the second step of data preparation, the machine parameters still need to be set which include positioning in installation space, temperature of the building platform or also the temperature of the extrusion nozzles. The previously mounted assembly sets are employed in the realisation of the physical model. At the conclusion of the manufacturing process, the components still need to be detached from the building platform. Should additional support material be used, this must be removed and disposed of either, e.g., mechanically or by washing out.

4 RESULTS FROM THE RAPID PROTOTYPING WORKSHOP

4.1 Implementation of the Rapid Prototyping workshop

Industrial engineering master's students have first assembled a 3D printer in several groups of two persons each in the context of the Rapid Prototyping workshop and then put it into operation (see Fig. 2). A laptop PC along with the assembly kit was at the disposal of each group in order to install the necessary software. Parallel to this, the groups were tasked to create components for the 3D print. This task was divided into two parts. First, the students were to search various databases offering downloadable components for 3D printing. Then components suitable for the 3D printers were to be downloaded. There were certain restrictions to be considered in this such as, e.g., dimensions of the installation space, presentability of details taking the layer thickness into account. Lastly, the downloaded component should be 3D-printed and analyzed.

Figure 2. Students assembling a 3D printer (left), examples of downloaded component (middle) and component developed by the students (right)

The students were to develop and build an additional component on their own in the second subtask. In this, they should use the experience from the assembly and the 3D printing of the downloaded components in order to establish construction guidelines for suitable construction of a 3D print. In conclusion, the students were to represent the results of their work in a presentation. The students should outline both the technical aspects, such as boundary conditions and obstacles in the assembly, and economical aspects, such as a cost estimate for the manufactured components, in their presentations.

4.2 Evaluation of the results from the RP workshop

In the evaluation, the time required by the students for the construction and operation of the 3D printer was calculated first. A total workload of 60 hours is available for the course. Instructions from the Internet for the construction were at the disposal of the students. This exhibited that the construction is often difficult due to imprecise information. In particular, mounting the additional nozzle for the support material proved to be complicated as this was, as a rule, not explained in the standard instructions.

The operation of the hard- and software was also very time-consuming because the different software packages had to be installed first. Furthermore, the students still had to become familiar with operating the individual software packages and tools. In part, the assembly and operation of the 3D-printers was also made difficult by missing or defective components and the time-consuming search for software updates. On average, the three groups required approximately 28.8 hours for the construction and 24.9 hours for the operation.

In order to test the success of the training, the students were questioned about various aspects before beginning and after concluding the course. In this way the students should assess their level of knowledge in the areas of practical and theoretical knowledge, cost and delivery time as well as data transfer and design rules with regard to 3D printing (see Fig. 3). A scale of one (little knowledge) to six (very good knowledge) was used for this. It shows that the students assessed their knowledge in all areas after the workshop as better than prior to it. A particularly high knowledge achievement was recognizable in the areas of practical knowledge and data transfer.

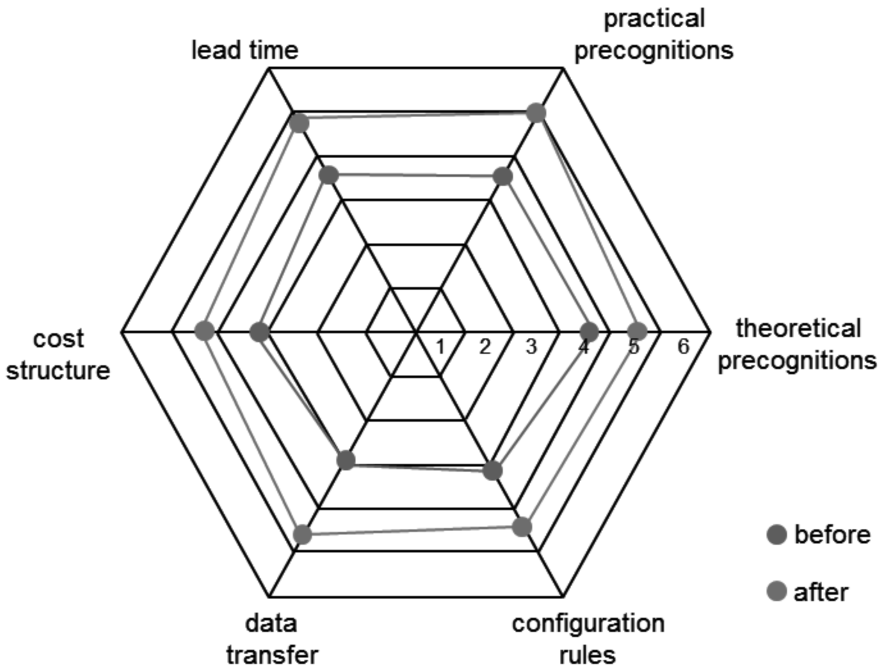

Figure 3. Evaluation of the students' level of knowledge before and after the workshop

How the students can estimate the cost and delivery time of a specific component was also examined. A bracelet with dimensions using additive manufacturing was presented as a sample geometry. It came out that the students estimated the manufacturing costs considerably too high and the delivery time too long prior to the beginning of the workshops. Moreover, there was great uncertainty in that, for example, the range of the estimated price stretched from half to 2.5 times the actual price. After the workshop, the median of the students' estimates for the cost and delivery time lay clearly closer to the actual value than previously.

Lastly, it was also studied how many or which databases the students knew or used for the search of existing and, ordinarily, free 3D models. It became apparent that most of the students were familiar with none or only one database prior to the workshop (average 0.33 per student). At the conclusion of the workshop, all of the students were familiar with a number of databases (average 3 per student) and also used these for their work (see Fig. 4).

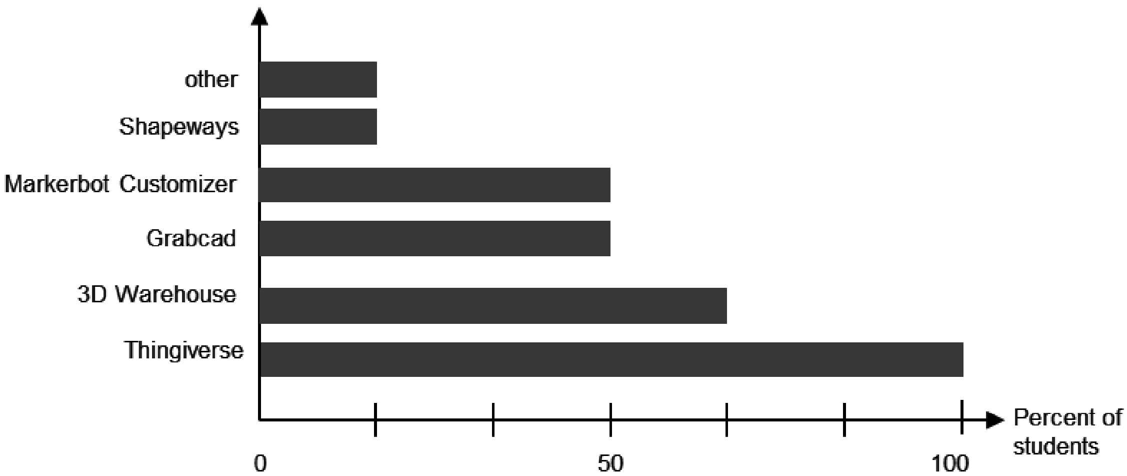

Figure 4. Degree of familiarity of different databases to download 3D models for 3D printing after the workshop

5 CONCLUSION

The assessments of the evaluation results demonstrate that the students could significantly expand both their theoretical and practical knowledge of 3D printing in many areas through participation in the workshop. Estimating the aspects of cost and delivery time was also considerably better with the experiences from the course. In the end, the students had a better perception of which models are best suited for 3D printing through the targeted search for 3D models in databases specified for this. Based on this, the students could develop and use their own design guidelines as well as test the effectiveness.

Nevertheless, it appeared that the assembly and operation of the assembly kits are very time-consuming. A majority of the scheduled working time was used for these two steps. The reason for this was the, in part, insufficient instructions, missing components and defects which can also, in part, be traced back to the faulty operation of the still inexperienced students. In similar courses in which 3D printers, identical in construction, are used, it was apparent that the student teams could easily and gladly support each other in solving problems. Yet because different assembly kits were applied in this course, this effect could hardly be used. Thus, for the students and instructors, the frustration of the time-consuming assembly and the tedious operation are, unfortunately, an obstacle to the positive experiences in the design of components suitable for 3D printing and the joy of creating 3D models. On the other hand, the use of different 3D printers gave the chance to evaluate different hard- and software. In order to focus on design and construction for AM, it is advisable to use already assembled 3D printers.

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