Enabling Co-creation in Product Design Processes Using 3D-Printing Processes

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Abstract. For a long time, geographical distances restricted competition, nowadays competition is global. Thus, companies must build up strategies to cope with this situation. Individualized products could help enterprises to retain customers and their market position due to a differentiated supply. In this research paper we discuss 3D-printing processes as enabler for Co-Creation in product design processes. It enables enterprises to react quickly to customer preferences and changing trends e.g., in design. Furthermore, 3D-Printing enables the integration of customers into product innovation processes. This ends up in Co-Creation and the emergence of related advantages (e.g., customer-centric products or production processes). However, operational processes when using 3D-printing processes for co-creation were not investigated in depth so far. But nevertheless, the improvement of manufacturing processes is important in BPM practice and research as well. Therefore, we address this gap in our paper.

Keywords: BPM · Production processes · 3D printing · Co-creation · Customer integration

1 Introduction

For a long time, geographical distances restricted competition, nowadays competition is global [1]. Thus many enterprises face increasing challenges to compete with competitors having substantial cost advantages e.g. by producing in Asia [1]. For many products nearly equivalent alternatives from different suppliers around the globe are available [2]. A possibility to face cope with these challenges is the upcoming trend of individual and customized products [3]. Customer requirements are becoming more specialized especially in terms of individualized products [4]. Companies react to these changes by individualizing products and related business processes according to individual preferences and thus improving their own supply and retaining a competitive position [4]. A second strategy to cope with competitors from low-wage companies is quick response to the customer [5]. Companies such as Trigema [6] show that being able to quickly produce parts and adjust related processes according to customer specifications near to the target market is a viable strategy.

F. Daniel et al. (Eds.): BPM 2018 Workshops, LNBIP 342, pp. 96–106, 2019.
https://doi.org/10.1007/978-3-030-11641-5_8

In manufacturing, 3D-printing [7] is a key technology for implementing strategies aiming at responsiveness and individualization. They enable manufacturers producing economically even small quantities down to lot-size 1 [8]. Therefore, it does not surprise that according to Gartner Research 3D-printing [9] will change many production business models and related business processes [10].

One of the main advantages of the 3D-printing is, that a multitude of parts can be produced from the same base material, thus warehousing and logistics are simplified [11]. This is a huge difference to traditional manufacturing techniques like milling or carving, where a supply of different raw material must be maintained in order to react quickly to customer requirements [11]. Another advantage of additive manufacturing processes is for instance, that 3D-printing have the possibility to quickly produce parts according to customer specifications and to adapt changes in the design quickly.

The combination of quick response and individualization is the key to Co-Creation, the integration of the customer into product innovation processes [12], especially open innovation [13]. By quickly providing prototypes to the customers, collecting feedback and using it for redesign an improvement cycle can be initiated that is not possible with traditional manufacturing technologies due to their high latency [12].

Existing research on the 3D-printing focused either on technical aspects of development or high-level. strategic (management) questions (e.g., [14, 15]). However, there is a gap between these two research areas. The operational processes when using 3D-printing processes for co-creation were not investigated in depth so far. But nevertheless, the improvement of manufacturing processes are important in BPM practice and research as well [16–18]. We address this gap in our paper investigating *"The benefits and influencing factors gained by enabling customer integration into product design by using 3D-printing processes."* as part of an ongoing research project.

Our paper is structured as follows: Sect. 2 after introducing the subject a background of 3D-printing processes and co-creation aspects is given, Sect. 3 the research model as well as the pre-study design is defined, Sect. 4 Research methods and data collection are described, followed by Sect. 5 were results are shown and Sect. 6 a conclusion is given.

2 Background

Product design processes and product lifecycle management are an important area of research on business process management [16–19]. Now, changes of the consumer's role in product design and design relevant technologies such as 3D-printing increasingly impact the product design processes. To demonstrate these impacts 3D-printing will be investigated. Afterwards the influence of co-creation on product design process will be analyzed.

2.1 3D-Printing

3D-printing is an additive manufacturing approach [7]. Contrary to subtractive processes such as milling or drilling 3D-printing is depositing material to create parts. Its potential to revolutionize processes and manufacturing even has been referenced in the State of the

Union address [20]. In 2018 the spending on 3D-printing is estimated at 12 Billion $ [20]. By 2022 the market will increase to 20 Billion $ [20]. 3D-printing is primarily applied to manufacturing tasks that have a high degree of complexity and/or customization [7]. Due to its additive approach, 3D-printing is able to produce complex parts at the same price than complex parts. It is even possible to easily cope with complexities making conventional manufacturing difficult or impossible. In [21] typical complexities are identified: features, geometries, parts consolidation and fabric step consolidation.

2.2 Co-creation with 3D-Printing

For a long time, product design and development were driven by a serial approach [22], e.g. waterfall like model. Starting from a collection of requirements, more and more concrete specifications are developed [22]. They are basis for the design of the product. Finally, production starts and is transported to the customer.

This classical design approach [22] is expert-driven, top-down-oriented and uses a strict separation between the role of the product designer and the product user. In this approach, the core-competency for product design is assumed nearly completely at certain experts, that build up their knowledge through own studies and experience. They create a plan how to match the assumed or collected user requirements by a certain design and implementation of the product. Typical for this approach is the strict separation of designer and consumer roles. The consumer is involved only at clearly defined points of developments e.g. he was interviewed or asked to fill out questionnaires.

Nowadays, however, the advantages to integrate the customer more intensively are broadly accepted [23]. First concepts such as open innovation [13] recognized the value provided by inputs of external stakeholders such as the consumer. Co-creation is the active involvement of the consumer into the design, creation and distribution of products [14, 24]. Both terms overlap partially. However there is co-creation outside open innovation if the input of the consumer does not end in a commercialized product [14]. At the same time open innovation may happen with other stakeholders than the consumer, thus not being considered a co-creation [14].

3D-printing is an enabler for co-creation by facilitating to capture ideas, suggestions and feedback of the consumer. Through 3D-printing the customer can be better integrated into the production process. The spectrum ranges from influencing the design of mass products to the individual design of products [14]. By using a co-creation approach design processes can be improved in terms of quality, time and costs [25]. Also the relationship and related business processes with customer can be strengthened [26].

The integrating of customers into business processes is always a challenge in research and practice [27–30] for various different reasons. In example, mostly it is quite difficult for customers to participate in the processes. Besides complicated user interfaces, there is also a lack of knowledge due to the actual structuration of the process and the possible opportunities to improve it. Furthermore, finding a place where customers are able to contribute to a certain process is still quite hard. Customers normally want a comfortable solution. That means in fact, that they want to contribute at a time, place and way determined by themselves and not the supplier. Any restriction like an enhanced booting time of the computer could have a negative impact.

3 Pre-study Design: Benefits from Using 3D-Printing

Unfortunately, there is a lack of research about the benefits from 3D-printing processes based on a structured literature review in leading databases like SpringerLink, AISeL, IEEEXplore recommend by the literature [31]. Nevertheless, production processes are an important area for BPM projects [16–18]. The integration of 3D-printing can improve related business processes and integrate the customer into the production process. Therefore, we designed and implemented an empirical pre-study to discover the benefits from 3D-printing processes. This step is important to prepare future studies as well as ensure that it gain relevant and significant results. The study design, implementation and results are described in the following and is summarized in the following Fig. 1.

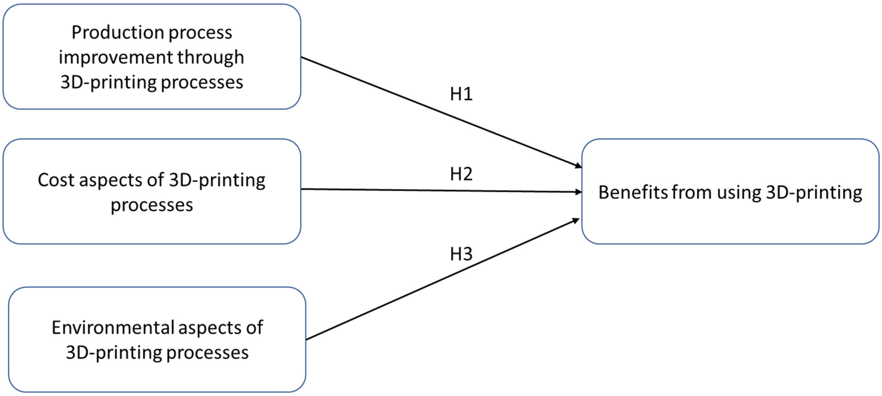

Fig. 1. Research model

The improvement of processes is a very important factor in BPM research and practice (e.g., [25, 32, 33]). The improvement of processes is related with a huge effort and integrates concepts of co-creation as well as is knowledge intensive [32]. To improve co-creation and integrate the individual preferences of a customer, the use of 3D-printing can be useful [12]. Therefore, we suppose that the improvement of production processes via 3D Printing creates benefits by more co-created products and a more flexible production:

H1: A production process improvement through the use of 3D-printing influences positively the benefits from using 3D-printing

Cost aspect of process and related information systems as well as production systems should be not neglected (e.g., [34–36]). For instance, 3D-printing processes could reduce the costs of the design and production of a product by increasing co-creation with the customer and to be more flexible in the e.g. selection of the production place and related shipping costs. Furthermore, the customer's preferences can be captured more easily and correctly by using a co-creation approach. the necessity of additional queries and adaptions due to wrong interpretations or analysis is reduced. This leads us to:

H2: Cost aspects of 3D-printing processes are influencing benefits from using 3D-printing

Environmental aspects are getting more and more important in BPM research and practice as well [36]. Customers, (governmental) institutions, the organization itself and many more stakeholders want to optimize their environmental impact and related business processes [36, 37]. Production processes using 3D-printing and capturing the customer needs more exactly by co-creation can be more environmental-friendly. In natural resources can be saved in the production process as well as the waste of e.g. unused products can be avoided. Therefore, we assume a positive influence of the environmental aspects of 3D-printing processes to the benefits from using 3D-printing:

H3: Environmental aspects of 3D-printing processes influence positively the benefits from using 3D-printing

In the following, we describe our research methods and the data collection to discover our research model.

4 Research Methods and Data Collection

For the investigation of our research model, we used a quantitative research method conducted via an online-based survey like recommended in the literature [38, 39].

Our study was implemented through the open source survey tool Limesurvey [40] and pre-tested in the fourth quarter of the year 2017. After improving the questionnaire based on the pre-test results, we implemented our survey also in the fourth quarter of the year 2017. At the beginning of our questionnaire, we implemented check questions to ensure that we only get answers of 3D-printing experts with related process knowledge. We contacted the experts formally and informally via email, professional social networks (like XING, LinkedIn), Blogs, telephone etc. According to the research model, the main questions of the survey were ranked on a five-point Likert scale [41]. The relevant questions can be found in the appendix section of the paper. Other questions like the years of working experience were collected using an open question format. After cleaning our data because of e.g. missing values or expert level/correct check questions, we got a final sample of n = 111 experts. On average, the participants had 13.3 years of working experience in the relevant field. Most of our experts in the sample currently using 3D-printing (77.27%). The other experts are planning to use, consult or have worked with 3D-printing as well as have the related knowledge. The experts worked for leading enterprises in Germany, Austria and Switzerland. In general, our experts assign high benefits to using 3D-printing processes according to our study.

For analysing our research model with our collected empirical data, we used a structural equation modelling approach (SEM) [42, 43]. The approach connects our causal model (research model) to the empirical data via the use of partial least square regression [42, 43]. Significances were analysed via the recommended bootstrapping algorithms [42, 43]. We used Smart PLS version 3.2 [44] to develop the SEM. This research approach is often used in research (e.g., [44–47]).

The quality metrics of our data are satisfying, therefore we assume that our results are valid and reliable. According to Chin [48] the coefficient of the determination (R^2) is in a good range (0.475 > 0.19). Furthermore, Cronbach's Alpha (>0.70), and the composite reliability (>0.70) are satisfied. All quality metrics of our model are listed in Table 1.

The results are more precisely described in the next section.

5 Results

Regarding the research model and our collected data, we got the following results of our SEM analysis (Fig. 2 as well as Table 1):

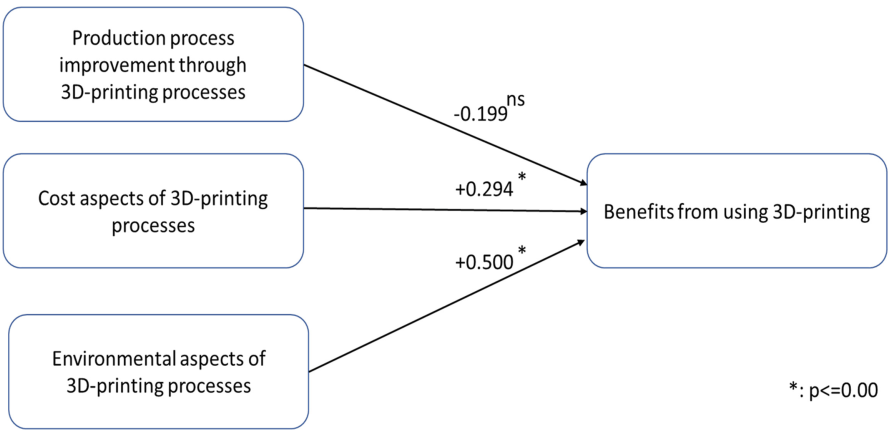

Fig. 2. Results of the SEM

Hypothesis 1 (*A production process improvement through the use of 3D-printing influences positively the benefits from using 3D-printing.*) must be rejected, because of a missing significance (p = 0.113 > 0.05). This might be explained by deeply divided opinions of our experts in this issue. Maybe there are some business case specifics (e.g., current level of production process automation), we have not covered in our survey. Future research should there investigate this aspect more detailed.

Regarding our analysis, we can confirm hypothesis 2 (*Cost aspects of 3D-printing processes are influencing benefits from using 3D-printing*). We discovered a significant positive influence (+0.294) cost aspects have on the perceived benefits of using

3D-printing. Our experts see great potentials in reducing the cost of a business process with related 3D-printing technology in the production environment. For instance, as explained before the cost for stocking raw materials sink strongly, because now the customer himself has to take care for supplying necessary materials. Furthermore, cost related to the execution of the process (e.g., energy, manpower) were transferred to the customer as well.

Finally, our data support the supposition given in hypothesis 3 (*Environmental aspects of 3D-printing processes influence positively the benefits from using 3D-printing*). A significant, positive path coefficient (+0.500) indicates, that the improved environmental aspects of the business process lead to a higher benefit. Our experts see high potential of 3D-printing processes by improving environmental aspects. Integrating 3D-printing in related business processes can improve environmental aspects and also the benefits of using 3D-printing. This is in line with current general research about environmental aspects of BPM (e.g., [37]).

In summary, the important details of the SEM are described below:

Table 1. Quality metrics of the SEM

	Path coefficient	Significance (p-values)	Cronbach's Alpha	Composite reliability
Production process improvement	–0.199	0.113	1 (*1 item*)	1 (*1 item*)
Cost aspects	+0.294	0.00	0.709	0.811
Environmental aspects	+0.500	0.00	0.766	0.894
Benefits from using 3D printing	–	–	0.798	0.845

In the following section we want to conclude based on our results.

6 Conclusion

The use of 3D-printing generates promising potential both for research and practice. We addressed some gaps in the existing research about the benefits of 3D-printing processes. We developed and implemented a first pre-study to get empirical insights. We found that cost as well as environmental aspects of 3D-printing processes are positively influencing the perceived benefits from using 3D-printing.

We contribute to the current literature in different ways. We extend previous work on the use of co-creation in business processes and show the relation to 3D-printing. Furthermore, we add knowledge on the environmental aspects of manufacturing related business processes based on 3D-printing processes. Managers can use our knowledge e.g. for decision support and evaluation of 3D-printing business cases. Regarding their business model, they can reduce costs and can implement more environmental processes.

Limitations can be found in the research method and asked experts. It was not possible to address all possible experts. However, regarding the current literature (e.g., [34, 50]) we collected a satisfying sample. Capturing the arguments given while discussion hypothesis's 1 result, also the composition of the questionnaire might be able to improve in terms of different business case specifics.

Future research projects should start at this point and extend the sample e.g. to other countries like US, Australia, BRIC states and compare as well as extend our results. The use of research methods like Case study research for the evaluation of 3D-printing processes could be a good starting point for future research. Furthermore, a deeper look into the factors influencing 3D-printing benefits, new ways of designing the collaboration network of 3D-printing process partners (e.g., through smart contracts [52]) and a broader case-individual discussion of e.g. environmental aspects should be done. Also implications on information system design [51], enterprise architecture [49] are important to discover.

Appendix

The excerpt of the main pre-study items (Table 2):

Table 2. The excerpt of the main pre-study items

	Items*
Production process improvement	• Improvement of production
Cost aspects	Cost reduction of: • piece production costs • material expenses • storage costs • changeover costs • labor costs
Environmental aspects	• Waste avoidance • Use of recyclable and renewable resources
Benefits from using 3D-printing	• Benefits of 3D-printing in general and resulting from digitization, customer-integration, place, production output & time, etc.
Working experience	• Years of working experience

*: *translated from the German language*

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