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A Benchmark of Service Providers in Additive Manufacturing

Stefan Junk
Professor
University of Applied Sciences Offenburg
Germany

Steffen Schrock
Scientific Assistant
University of Applied Sciences Offenburg
Germany

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Athens Institute for Education and Research
8 Valaoritou Street, Kolonaki, 10671 Athens, Greece
Tel: + 30 210 3634210 Fax: + 30 210 3634209 Email: info@atiner.gr URL: www.atiner.gr
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A Benchmark of Service Providers in Additive Manufacturing

Stefan Junk

Steffen Schrock

Abstract

The number of users of Additive Manufacturing has increased significantly over the past years. Generally, for the production of 3D-models, a user can choose between two options: On the one hand they can master the procedure 'in house', with their own equipment, or, on the other hand, they can commission it from a service provider. Since very little is known about the service industry in this field, this publication aims at providing a detailed overview of this market. In doing so, the focus of this contribution lays on the market for Fused Deposition Modelling FDM and also 3D-Printing 3D, because these two additive manufacturing technologies offer a large scope of applications from product development to the creative industries. As a first step, an extensive market analysis among the service providers active in the markets in Europe, as well as globally is conducted. This provides an overview of the available manufacturing capacities and a range of feasible product sizes for 3D-models. Next, several sample components, representative of the various areas of application, were developed or selected. The analysis of the product range of a large variety of service providers yielded a comprehensive overview of cost and lead time available in the market. In addition, extensive technical testing was conducted to determine and compare the quality (e.g. surface roughness, dimensional accuracy and visual inspection) and the strength (materials hardness) of the requested components. The results of this survey, which are presented in an anonymous form, support the user in the selection and appraisal of service providers according to technical and economic criteria. Furthermore the results generated from this investigation are part of a current research project with the objective to significantly simplify the selection of processes for the industrial user.

Keywords: Additive manufacturing, Benchmark, Fused Deposition Modelling, Service provider, 3D-Printing

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Introduction

The Research project Digital Manufacturing for Creative Industries (DiMa) has set for itself the goal of dismantling the barriers that currently exist in order to help small and medium-sized companies in creative industries use digital manufacturing technologies. With this in mind, suitable processes for creative industries are first selected here, with the assessment of the technical and economic criteria. Companies can use these criteria to check both the technical feasibility of their projects and the economic efficiency of the models to be produced.

There are currently numerous processes available on the market capable of generating models for many different areas of application with the aid of additive manufacturing technology. The 3D printers used for this range from build-it-yourself kits for DIYers and hobbyists through to large-scale equipment used in industry (Wohlers, 2014).

3D printing (3DP), also named Binder jetting BJ, has established itself as an important technology. It can be used to produce full-color models. For this procedure, a composite material made of gypsum and plastic is sprayed with a binder material and additionally with color. A supporting structure is not required due to the powder bed. Post-processing includes de-powdering, as well as the infiltration of the model to increase its stability. Fused deposition modeling (FDM) has proven to be a second important procedure. In this process, wire-shaped filament is extruded at about 280°C and constructed layer by layer. The materials used are in general plastics, like e.g. ABS or PLA. Furthermore, a supporting structure can be constructed, if necessary, which can then be removed again either mechanically or chemically.

There are now some service providers who offer to perform 3D printing but also FDM on the behalf of customers as well. However, there has been little reliable analysis of the cost and performance structures of these providers to date. Price differentials were determined through benchmarking based on requests submitted to these service providers and the models supplied were evaluated and compared using qualitative and quantitative criteria. The findings help support the selection of suitable processes in creative industries as part of the DiMa project.

Literature Review

A variety of different additive manufacturing processes have been available for the last three decades. (see Gibson et al., 2014; Gebhardt, 2013; de Beer, 2012). There are a certain number of publications within the literature which compare different providers of individual additive manufacturing processes or a broad range of processes and providers against one another. These comparisons look at both the technical and economic criteria of the individual processes.

For example, Kim and Oh (2008) compared a range of AM processes using various quality criteria (such as precision and surface quality) and the achievable strengths in a very comprehensive study. A number of sample components were also developed and produced. In addition to this, the various systems on the market were compared with respect to their installation requirements and the possible sizes of 3D models. The costs of the individual processes were only presented in general. Very big differences with respect to the quality and strength achievable through the processes were found in this mainly technical comparison. This comes as no surprise, as a wide variation in results is to be expected just given the large number of materials and processes used. Additionally, only the kinds of machines found in conventional laboratories were compared, so there was no consideration of service providers at all.

A benchmark for laser sintering was presented in a recent study by Baldinger and Duchi (2013). A series of five sample components were also designed in this. Subsequently, various service providers on the global market were approached and the results were economically evaluated. By focusing on one process, the results of the study relating to economic efficiency are very meaningful. However, as the quotations were simply assessed but the sample components were never produced, it is only possible to make indirect statements about the quality of the sample components, e.g. using the layer thickness information provided by the various providers. To this day, these and other results from different contributions have been incorporated into an extensive meta-study by Yoon et al. (2014).

Besides these scientific process comparisons, benchmarks can also be found in trade journals with ambitious end consumers as the target group. For example, König and Barzock (2011) compared different service providers in a German trade journal (Magazin für Computertechnik). This publication focuses on providing concrete, practical advice to end users. The homepages and offerings of different service providers were presented in detail, for example. Sample components from various providers and processes were also compared with one another. Unlike the scientific studies, the service providers here were actually named. The number of service providers looked at was also somewhat low.

Approach

Using market research, a number of service providers offering model manufacturing using the 3DP or FDM process were identified. Besides the location of national and international providers, the printer type used by the service providers and thus the maximum model size that could be manufactured were also documented. The number of providers contacted, as well as the different modes of communication are listed in Table 1. In addition, the various offers received and the numbers of components actually ordered for the analysis have also been given.

The service providers were asked for a quotation for five models in order to obtain meaningful price ranges. The models were specifically selected with the subsequent test methods in mind. The first fundamental difference noticed between the service providers involved the ways in which they handled the quoting process. All service providers were asked in various ways to provide a quotation. Once there were sufficient quotations, it was possible to make statements about the length of time it took to quote, the price and the stated lead time.

To allow for an examination of the quotations received in terms of performance, up to ten providers were commissioned to each produce the same model. Measured values resulted from the analysis, providing information on the quality of the service providers. These values were used as the standard by which the competitors examined were compared. These criteria were divided into a customer-specific and product-specific approach.

Table 1. *Comparison of Service Providers*

Process	**Number of detected providers**	**Request via [%]**			**Number of received offers**	**Number of placed orders**
		e-mail	**online**	**upload**		
Binder jetting BJ	29	31	45	24	14	10
Fused deposition modelling FDM	25	56	32	12	12	7

The customer-specific approach covered all the factors which might arise in the course of the ordering process. Starting with the final price requested, including all additional costs (such as any packaging costs), the payment options offered were then evaluated. It was also possible to analyze deviations between the stated and actually required lead times.

The model received was the focus of the product-specific approach. The technical properties of the supplied product were especially examined in this. Various tests were performed in the laboratory at Offenburg University of Applied Sciences to test the models according to the defined test standards. Measurements to analyze surface quality were also performed by an external company.

Requested Parts

The aim of the request was to gather enough quotations so that the subsequent test results could be generated with a sufficiently large volume of data. Care was taken to select the most meaningful models possible which would most clearly demonstrate the differences between the service providers. The same models were requested in all cases to facilitate a direct price comparison of all service providers. These were five models with different properties (see also Table 2).

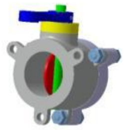
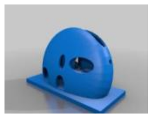
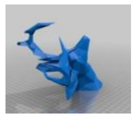
Model 1

This specimen is a cuboid frame with different edge lengths. The idea behind the model is to have a relatively large object so that a considerable amount of space (bounding volume) would be needed in the construction chamber while the material volume would be low. Material consumption and the processing time represented a basic cost factor of the actual model. The material costs were reflected in the volume of the object, i.e. the actual solidified material. The object size has the biggest effect on the processing time for a print job. The model height (z-axis) is especially crucial to this.

Model 2

With edge lengths of 80 mm x 50 mm x 50 mm (W x H x D), this model has a considerably smaller bounding volume than model 1. The object also has sections facilitating meaningful laboratory testing. Measuring points created through divergent pockets and holes allowed the dimensional accuracy to be referenced. One pocket has five arched lamellae for determining the level of detail. These are each 1.5 mm thick and positioned 1.5 mm away from each other. The model also has several large, unbroken surfaces for surface measurements. Beside the pocket with the lamellae is a cut hemisphere. This represents a complex geometry which is difficult to achieve using conventional manufacturing processes.

Table 2. *Geometrical Properties of Specimens*

Specimen					
Number	1	2	3	4	5
Volume [cm^3]	110.9	96.1	125.8	44.7	208.8
Ratio volume: enveloped volume	1:19	1:2	1:5	1:6	1:16

Model 3

A throttle valve is selected as an example of a request in the area of rapid prototyping. This model has high requirements with respect to dimensional accuracy and attention to detail. If Binder jetting is applied, this specimen is to be printed in a variety of colors.

Model 4

Models 4 and 5 have been selected with particular consideration for the requirements from the creative industries. These are not technical models, which frequently are based on a variation of simple forms (e.g. cylinder, cuboids). Rather, these two models are characterized by a large number of free form surfaces that have an irregular run. This model represents a building object in the form of a shell, e.g. like an architect might commission.

Model 5

This is a design object with a conspicuously coarse structured structure (low poly). “Low poly” means few polygons and therefore larger triangular surfaces. The 3D data for models 4 and 5 comes from the Thingiverse.com online database and is used unchanged.

Analysis of the Service Offerings

Firstly, possible service providers were selected. Providers offering the required 3DP process had to be found. There were no geographical limits. The national and international providers who generate models using 3D powder printing found for this work were asked to provide a quotation. The requested service involved the manufacture of the individual models with different geometries. The models were used to ask for a quotation from the providers. This allowed us to determine the prices of the individual service providers. Information on e.g. the volume of the construction chamber was derived from the type designation. This volume is crucial to the maximum model size that can be manufactured.

Selecting the Service Providers

The market for service providers in the area of rapid prototyping is growing and new providers are constantly coming on board (Wohlers, 2014). A lot of providers who listed BJ or FDM amongst their services were included. Some providers were found directly using popular search engines. Furthermore, lists with potential suppliers were employed that had been posted on various internet platforms on the topic of “additive manufacturing”. This search results give a general overview of the retailers without going into the processes they offer. The respective websites of the retailers were then analyzed to see what processes they offered. All of this research resulted in a list of potential providers located all over the world.

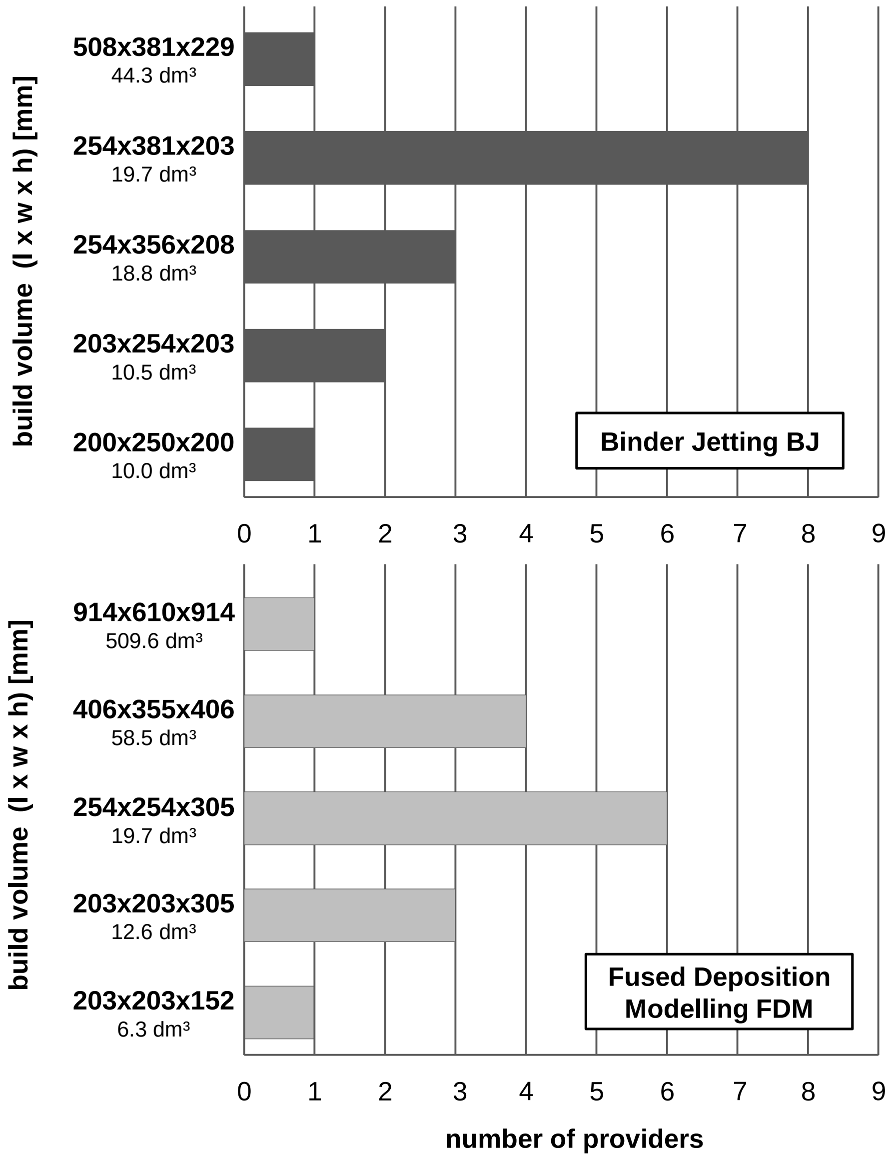
There were no geographical limits when selecting the service providers. However, only mostly large service providers offer to ship goods to Germany. This is one reason why the majority of the providers included in the study are based in Germany. In addition to this, search engines are programmed in such a way that the results of German origin have greater relevance on a German search platform and therefore appear higher up in the ranking. For example in BJ this resulted in 24 providers from Germany, two each from Belgium and France and one from the U.S. There was no discernible trend towards any particular location in Germany, with providers being located all over the country.

Printers Used and Construction Chamber Size

The printers used by the service providers became known during the analysis phase. As there is only one manufacturer of devices for Binder jetting, all came from the same range of models. The first three generations were developed by “ZCorporation” (today merged with “3D Systems”) and were “Zprinter” models. There was a groundbreaking advancement right in the first generation. It was possible for the first time to print colored models with the Z406. The speed of the 3D printing process increased in the second generation. The machines also became cheaper. The product range was extended in the third generation and the machines now came in different sizes as well. The printers also consisted of two sections for the first time – one for the printing process and a post-processing area for removing unused material.

We were able to find out the device type used by 15 of the service providers. These were devices across the first three printer generations. The most popular printer was identified as the ZPrinter 650, with a construction space measuring 254x381x203 mm. This was used by more than half of the service providers. The entire distribution is shown in the diagram below, using the size of the construction chamber as the criterion (Figure 1).

Figure 1. *Construction Space Measuring*



Besides marginal differences such as printing speed and detail reproduction, the construction chamber is the most elementary difference between the devices. A printer's construction chamber determines the volume of the maximum permissible model size. Therefore, it is a significant economic efficiency factor for the service providers. If there are sufficient orders, then a larger construction chamber means that more projects can be manufactured per print process.

While looking for providers in the area of "fused deposition modeling", the search also specifically focused on the printing systems that were used. Frequently, the suppliers would not disclose the printing system used, as they were not ready to participate in a benchmark study. However, a sufficient number of other suppliers was found that were willing to disclose this information. All of the printers used were manufactured by "Stratasys", which is one of the largest producers of 3D printing systems worldwide. The portfolio in the area FDM-printer ranges across nine different models from three series. Each series has specifically been developed for a certain production standard and scope, and covers all target groups of FDM printers, from personal use to large-scale manufacturing companies. Several models have the same build area - they have been combined accordingly in Figure 1.

The comparison of the build area sizes available in the market in BJ and FDM shows that the smallest machines offer a build area of approximately 6 dm^3. However, many suppliers use machines with build areas between 19 and 58 dm^3, either to be able and provide larger components or larger quantities of small components. However, really large machines with a build area of more than 500 dm^3 are only used by a small number of suppliers.

Model Request

The aim of the request was to gather enough quotations so that the subsequent test results could be generated with a sufficiently large volume of data. Five models were selected as references for this.

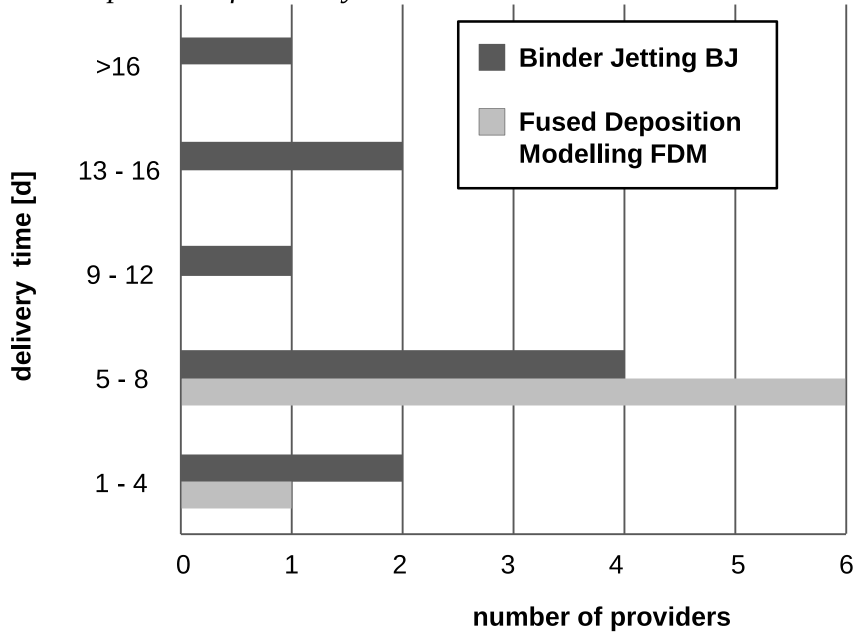
Three different ways in which service providers receive requests were identified while requesting the models. This was the direct upload of the STL file, a request using an online form and a request via email (Table 1). In BJ, the lead times of three to fifteen working days were recorded between the conclusion of the order process and the delivery of the ordered models (Figure 2). Only one provider still hadn't delivered after 22 working days. In contrast, the delivery times were significantly shorter with FDM. All of the components ordered were delivered within 8 days.

Technical Evaluation of the Test Specimen

Technical properties can best be determined using standardized test methods. To achieve neutral results, all reference models (model type nr. 2, see section "Model 2") were removed from the packaging in which they were sent, numbered and stored together in a separate box. The models then underwent the following testing:

- Visual inspection
- Test for dimensional accuracy
- Hardness testing
- Test of the surface quality

Figure 2. *Comparison of Delivery Times*



Results

The examinations showed that it is possible to have a model manufactured using the BJ or FDM process even without CAD knowledge. If the customer has a credit card or PayPal account, international service providers can also be included. These are often larger service providers that are able to offer attractive prices and a wide variety of material. They are mainly aimed at private users who are less bothered about fast delivery.

The prices requested by the vendors can be simply expressed using the cost per model volume (see Table 3). This resulted in BJ in clear price ranges from €0.56 to €4.21 per cubic meter. With regard to the FDM process, the analysis showed an even wider range of prices for individual components from € 0.46 to € 4.52. The average price in the case of BJ, at € 1.49, was significantly lower than the average price with FDM at € 2.03. The client should be aware in advance how big the printed model should be and how soon the model is needed.

The service providers have different types of printers for manufacturing models. Different sized construction chambers are available depending on the printer used. The selection of potential service providers was further limited through this in the case of the larger models. The lead time criterion in particular might be crucial for many users. For development-related orders, a service provider quotation with a short lead time is a “better value” than a cheaper quotation which will only be delivered 14 days later.

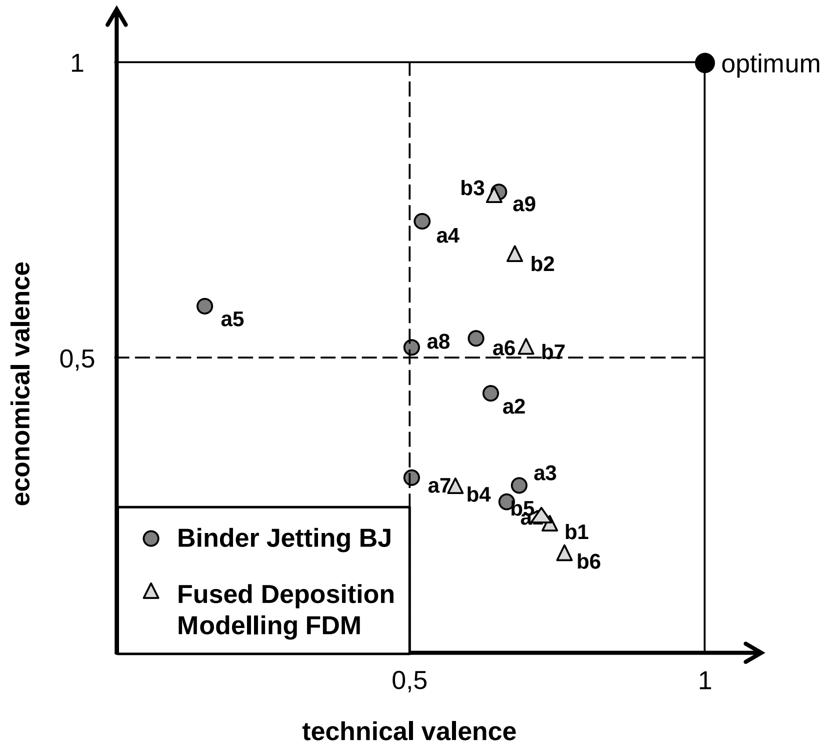
Another important criterion is the number of units required. If a client wants greater units of a model to be produced, the price structures change significantly. From consultations with providers, it was found that they add on a surcharge for setting up the machine in the case of a single order. However, not all providers have tiered pricing. Therefore, tiring should be looked out for when ordering larger quantities. The percentile saving can be about 26 % in BJ or 27 % in FDM towards an individual order.

Table 3. *Comparison of Prices in Binder Jetting BJ and Fused Deposition Modelling FDM*

Specimen Number	1	2	3	4	5	All Specimen
BJ: Average Price 1 pc. [€/cm^3]	1.47	1.34	1.35	2.16	1.16	**1.49**
FDM: Average Price 1 pc. [€/cm^3]	2.45	1.34	1.58	3.84	1.23	**2.03**
BJ: Average Price 20 pc. [€/cm^3]	1.14	0.92	0.96	1.60	0.88	**1.10**
FDM: Average Price 20 pc. [€/cm^3]	1.96	0.95	1.11	2.47	1.01	**1.50**

Qualitative differences could not be derived from the price structures. However, a technical/economic evaluation showed that in BJ four of the nine providers tested performed strongly in both economic and technical terms (see Figure 3). In contrast, the same evaluation done for FDM processes shows that, 3 out of 7 suppliers are able to position themselves in the quadrant close to the optimum. When determining the optimum cost target, reference values for each process derived from the literature (Whitepaper, 2009) and information from system manufacturers (Projet homepage, 2014; rapidobjet, 2015) were used.

Figure 3. *Technical and Economic Evaluation*



Summary

Various providers of 3D printing services were examined and compared with one another within this benchmark. Besides determining the price ranges when ordering different unit numbers, tests were also performed in the technical area, such as testing the surface quality and dimensional accuracy. This study has shown that there is a wide range on the price and the model quality. Likewise, there is also a wide range of suppliers for the FDM procedure, with varying prices. In both cases, larger lot sizes can result in a price reduction of about 27 percent. All in all, the cost for models manufactured with the FDM process is approximately 25 percent higher than with the BJ process. Furthermore was detected that four out of nine service providers offer a good price/performance ratio.

It can be expected that the 3DP process to become more established, which means the situation in the service market will change again. Besides technical and economic changes in the area of 3DP, the market for other additive manufacturing processes will also develop further. A benchmark like the current one performed here can be carried over to other printing processes and offers a good way of showing change over time if conducted a number of times. On the one hand, the FDM sector shows that a large number of suppliers of “home printers” will be entering the market. On the other hand, a wide variety of different materials, like e.g. PLA and others are available in this sector.

Further processes, such Multijet-Modelling MJM, are to be examined in the future as part of the DiMa research project. These production processes are also of interest to creative industries.

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