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In Business of Additive Manufacturing

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Abstract

The world of manufacturing is rapidly changing. New technologies that become available every day are making a strong impact on the future perception of manufacturing and markets. One of the cutting edge technologies that is bound to influence today's manufacturing paradigms is the additive manufacturing (AM), also known as 3D printing or rapid prototyping. In response to fast advances in practice, attention put to AM is growing in the academic literature. However, a comprehensive overview of the business models for AM is not available in the academic literature. In order to address this issue, the present research reviews the articles that address business models for AM that are published in academic journals. The articles addressing AM business models are found and analyzed providing in this way the state-of the-art in the AM business field. Finally, the directions for the future research are discussed and proposed.

Key words: *additive manufacturing (AM), 3D printing, rapid prototyping, business model, review*

1. INTRODUCTION

The world of manufacturing is rapidly changing. Emerging technologies, like Internet of things, cloud services/computing, virtual reality and so on, are making a strong impact on the manufacturing and market development [1], [2]. Moreover, in recent years, this has led world leading manufacturing countries to think of new directions for their manufacturing development, as for example Germany's Industry 4.0. One of these emerging technologies is the additive manufacturing (AM), with The Economist calling it a third industrial revolution that will change the manufacturing [3], [4].

Defined by a standards organization ASTM International, AM is "a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies" [5]. In recent years additive manufacturing has been treated as a synonym with the 3D printing, although ASTM defines 3D printing as "the fabrication of objects through the deposition of a material using a print head, nozzle, or another printer technology" [5]. Thus, AM is a much broader term that in turn includes 3D printing. But tendency is to use both terms as synonyms probably pushed by practitioners and home users to whom 3D printing comes much easier term to explain and promote than AM.

The AM has been in steady development in the last 30 years. AM development went from rapid prototyping, through rapid tooling, all the way to rapid (direct) manufacturing [6], [7]. Next expected AM development step is printing of finished products and spare parts at home ([7] based on [8]–[10]), named home fabrication [6]. As expected, along with the technology development of AM, various modes for applying AM in business purposes have been introduced during the course of time [11]. "A business model describes the rationale of how an organization creates, delivers, and captures value" [12]. Thus, we define AM business model as:

> *business model that describes the rationale of how an organization using AM technology* creates, delivers, and captures value.*

*AM technology is here treated in a broader sense encompassing not only production of AM products, but also use of other technologies that enable obtainament of the AM product (e.g. the 3D scanning of the objects, 3D model preparation for manufacturing/printing etc.)

However, academic literature does not provide a comprehensive overview of the business models for AM. This is an interesting fact, since a sheer number of academic papers on AM (e.g. 34.272 hits in Scopus database in June 2017) shows that AM is a very popular and vibrant research field. This technological focus of the additive manufacturing literature has been noted also by other authors [7].

In order to fill the gap, a literature review of the available academic literature focused on business models for AM is done. The following sections will present, in the order: Section 2 – The used literature review method; Section 3 – The results of the research; Section 4 –The discussion of results of the research, providing also conclusions and directions for the future research.

2. RESEARCH METHOD

The research has been done using a literature review method ([13], [14] and [15]) in order to record the state-of-the-art of AM business models available in the academic literature. According to the recommendations for literature review method ([13], [14] and [15]), the steps have been recorded in order to assure the repeatability of the research conducted.

2.1 Article search criteria

In order to capture AM literature a number of syntax was chosen, namely: additive manufacturing, 3D printing and rapid prototyping. Using Scopus database and searching in title, abstract and keywords, with "additive manuf*" OR "3d print*" OR "rapid protot*", the search yielded 34.272 hits. This confirms that AM is gaining a tremendous attention in the last couple of years leading to exponential growth of academic publications (Figure 1). Obviously, this is an overwhelming number of hits that are not necessarily directly related to our research topic.

In order to narrow the search and focus to research topic of AM business models, a search term "business model*" was included as a needed term to be mentioned in title, abstract or keywords of the paper. Thus, the search in Scopus was TITLE-ABS-KEY ((("additive manuf*") OR ("3d print*") OR ("rapid protot*")) AND ("business model*")). This search led to 84 hits all together.

In the subsequent step we limited our search to journal articles, to raise the quality level of the reviewed literature. In result 29 articles remained in the search.

In the end, we further limited the search on articles published in the English language which led to 27 hits all together. These 27 articles further underwent selection process in order to finalize the body of articles that would be analyzed.

2.2 Article selection criteria

Further selection of 27 articles was done through abstract reading. The selection criterion used in the abstract reading was:

> *Article is focused on business model(s) for additive manufacturing*

Thus, it is enough that the article provides one way for conducting AM business, not necessarily to provide overview of business models for AM. Also, the article could cover only one aspect of the AM business model to pass the selection criterion.

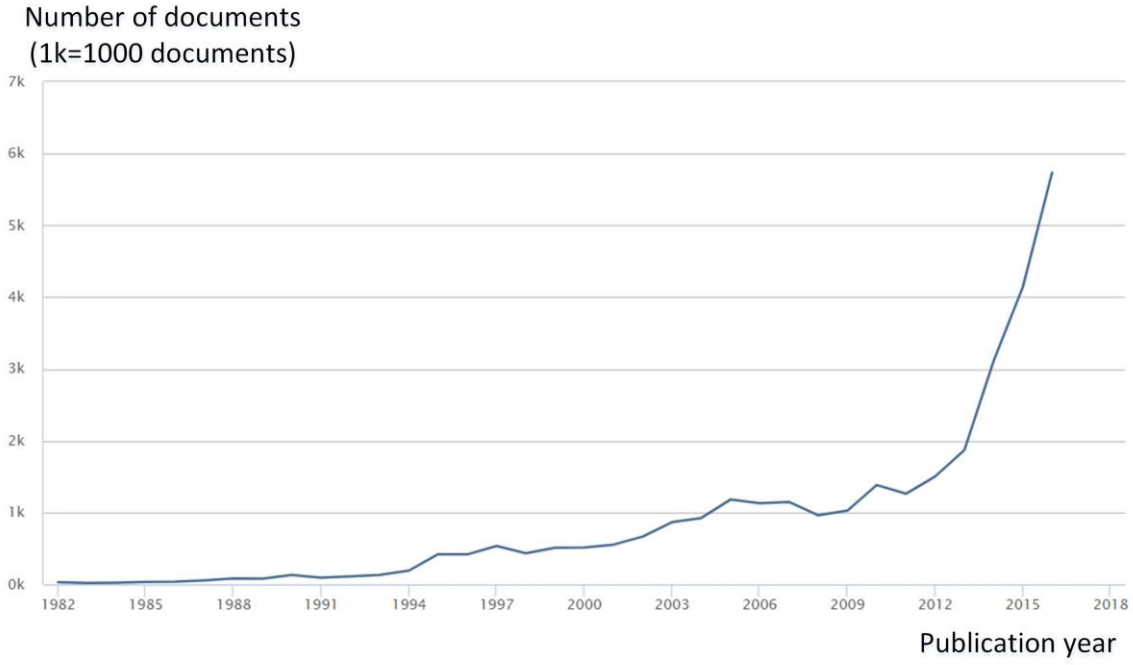

Figure 1. Exponential growth of AM related articles in Scopus database

In the end, 10 articles passed the selection criterion based on abstract reading. Subsequently, one article was removed from selection because it was regarded as outdated for AM field (i.e. published in 2004), and one more article was removed because it was unavailable for download. Finally, the work of Piller et al. [11] was added as a part of a snowball effect. In result, 9 articles were fully read and subjected to content analysis.

2.3 **Content analysis**

The content analysis method [15] was used for the literature review for two reasons. Firstly, a suitable comprehensive framework for AM business models analysis was not found in the available literature. Secondly, authors wanted to keep an opened mind in conducting this literature review which is in line with the use of inductive approach for definition of categories in the content analysis ([15] based on [16] and [17]).

After determining 9 articles for analysis, the content analysis was conducted. Content analysis satisfied the main requirement that two authors had to read every article and agree upon the results of analysis in order to be taken into account. If the agreement was not reached, the third author was called in and his opinion would prevail on the subject of misunderstanding.

3. RESULTS

The full reading of the papers showed that 4 articles do not provide information relevant for systematizing knowledge on AM business models. However, we regard these 4 articles as highly relevant for AM researchers and worth of further reading ([6], [18], [19] and [20]). Rayna and Striukova [6] and Bogers et al. [18] deal with influence of AM on the existing business models. Garrett [19] addresses general trends of AM implementation while Steenhuis and Pretorius [20] explore what underlies the development of the 3D printing and future impact of 3D printing on the manufacturing industry.

Other five articles do address AM business models ([7], [11], [21]–[23]). However, they do this with a very different scope and approach, which ranges from in-depth analysis of one single AM business model all the way to attempt to make comprehensive generalization of the AM business models.

In the rest of the Results section, results gathered from the analysis of 5 papers relevant for the research will be presented ([7], [11], [21], [22] and [23]). In order to facilitate the reader, all articles have been marked by numbers 1 to 5.

Article 1 - Laplume et al. [21] address AM business model of *3D printing shops*. They do so by in-depth analysis of the business model which they define as "localized 3-D print shops capable of printing customized objects on demand".

Article 2 – Jia et al. [22] focus on transformation of supply chain in order to include AM in the existent manufacturing of chocolate products. Thus, they distinguish two types of business models that include AM:

- *Manufacturer-dominant business model for 3D chocolate production* – in which manufacturer adds customized production of the chocolate to already existent make-to-stock production. Thus, "the conventional retailer–manufacturer channel for make-to-stock is complemented by processes pertaining to the production of customized chocolates" [22]. In effect, the chocolate manufacturer is using semi-finished product inventory and 3D chocolate printing machines to obtain the final products.
- *Retailer-dominant business model for 3D chocolate production* – in which the retailer creates customized product using 3D chocolate printer. Product orders are placed online or directly in the store, while semi-finished products are delivered to retailer directly from the manufacturer.

Article 3 – Piller et al. [11] provide an overview of the existing AM business models "that cover different activities in the AM ecosystem". These are namely:

- *3D model marketplace and production service* – the idea of this AM business model "is to connect designers with consumers, thereby collecting certain service and production fee" [11]. Examples of this business model are *Shapeways* and *i.meterialise*.
- *Community-based design sharing platform* – the idea of this business model is "to promote the use of home 3D printers". Example of this business model is *Thingiverse*.
- *FabLabs* – are fabrication labs that provide access to local digital fabrication tools (e.g. 3D printer, laser cutter etc.). Usually they are not profit oriented and work closely with universities and research centers.
- *TechShops* – are similar to FabLabs, but in opposite to them provide the digital fabrication service on pay-by-use basis.
- *3D Hubs* – are platforms that enable users to find nearby 3D printers. The idea of the 3D Hub "is to share the existing capacity of locally available printers. 3D Hub as a match-maker charges a service fee to users".
- *3D scanning and CAD file preparation for printing* – if customer does not start from the existing CAD file, the file must be generated/altered in some way. This can be done by scanning an existing object (e.g.

NextEngine and *Makerbot*) or editing some appropriate CAD file (e.g. *Autodesk*).

Article 4 – Rogers et al. [7] offer two classifications for AM services. Firstly, they classify AM services based on customer the services are aiming at:

- *Consumer 3D printing services* – are 3D printing services targeting private consumers.
- *Enterprise 3D printing services* – are 3D printing services targeting enterprises.

Secondly, based on the varying degrees of interest in and familiarity with AM technology, Rogers et al. [7] divide AM services in:

- *Generative (scanning and construction) services* – which "include all services that aim to generate a 3D model for the customer before subsequently 3D printing it - thus creation of 3D model ready for 3D printing".
- *Facilitative (upload and in-store) services* – which "focus on the printing process itself, tailoring their services to the needs of customers who already possess a 3D model - thus printing of the existing 3D model".
- *Selective services* – which do not "emphasize design or manufacturing, but instead offers customers a database from which they can select a 3D model, decide how it will be printed and in some cases even alter the model itself beforehand".

Article 5 – Mortara et al. [23] classify business models of Fab-spaces. Fab-spaces "encompass organisations which provide a suite of manufacturing tools and technologies openly accessible for use by the public". Mortara et al. [23] classify Fab-spaces into five categories:

- *High-end machines, professionally run virtual Fab-spaces* – that provide high-end printing services, employ skilled design and engineering staff, provide design and consultancy services, and are typically expensive. Other varieties of this category can provide also CNC prototyping machines, low-end software, laser cutting services and so on (for more detailed explanation of sub-categories please refer to [23]).
- *Connected "fabbers"† network: variable quality machines, community run, virtual Fab-spaces* - this category "features web-based networks which connect individual owners of equipment to people who want to use machines. Prices are agreed independently on each job. Collaboration could be in person or online".
- *High-end machines physical Fab-spaces* – this is a physical fab-space that includes workshops with large number of workbenches, high-end CNC and non-CNC machines and high-end software that allow obtainment of high-quality products in plastic, wood and metal. Often provide on-payment advanced classes in design and engineering by professionals. They can also provide consultancy in design and engineering, marketing and legislation services and so on. Usually work on the basis of payed membership.
- *Medium-quality machines physical Fab-spaces* – enable production of high quality plastic and wood product, and middle quality of metal products. Prices vary from one to another fab-space, while access is usually free. Users usually pay the use of machines per hour and/or material used. Can have free use time slots during some of the opening hours and frequently allow service of rental of the complete workshop. Could also provide basic or medium classes in design and engineering by other members, professional staff or external contractors which can vary from free to a medium price. Also membership paying could be applied in this category.
- *Community-run low-end machines physical Fab-spaces* – are community-run physical fabrication spaces with medium-to-low-end CNC and non-CNC machines and low-end software. They allow production of medium-quality plastic and wood product and low to medium quality metal products. Members of the Fab-space provide free or low-cost basic classes in design and engineering. Can have optional membership and open free-time slots during the week. A variation of this category are Fab-spaces that are run by public or university libraries where users pay a low or medium price according to the amount of the material and machines used.

4. DISCUSSION AND CONCLUSIONS

The research presents an overview of the academic literature published on the topic of AM business models. The search and selection procedure in the end led to 5 relevant articles that were reviewed and analyzed in order to obtain the state-of-the-art in the field of AM business models.

The findings confirmed the results of the preliminary review of the literature that the attention given to AM business models is proportionally very small in comparison to the attention that AM receives in the academic literature. Only 5 articles are addressing AM business models in comparison to 34.272 hits related to AM in the Scopus database on June 2017.

These 5 relevant articles differ substantially in their scope and depth of AM business models analysis. While Laplume et al. [21] and Jia et al. [22] have a fairly

† A fabber (short for "digital fabricator") is a "factory in a box" that makes things automatically from digital data (http://www.fabbers.com/What_is_a_Fabber)

narrow focus of the research, Piller et al. [11], Rogers et al. [7] and Mortara et al. [23] provide much broader analysis of the AM business models.

While Piller et al. [11] provide summary and define the existing AM business models, Rogers et al. [7] and Mortara et al. [23] develop frameworks that could be applied for future classification of the AM business models. In this way they set a very good basis for the future research in AM business models.

These three works ([11], [7] and [23]) separately substantially contribute to the AM business models research. However, in conclusion we can say that the best way to use them would be to look at their contributions in a bulk. On the one hand, Rogers et al. [7] provide a high level analysis of the AM business models but without specifying AM business models in details. Piller et al. [11] also cover whole scope of AM business, but without going in deep analysis of the existing AM business models. On the other hand, Mortara et al. [23] focus on very deep analysis of the AM business models that provide production of products, but do not cover AM business models that deal with AM related services only (e.g. 3D object scanning, 3D model preparation for printing etc.). Thus, with previously said, these three papers together provide a complete overview of AM business models available in the academic literature.

The present research has its limitations. The main limitation lies in the question of whether doing the literature review on AM business models is justifiable. It can be argued by some researchers and practitioners that AM field is changing so rapidly that articles reviewed are already outdated when they are published. Even though this might be argued, the authors decided to conduct the literature review in order to understand what does the academic literature offer and to systematize these findings.

The future research will include other methods for determining the scope of business models for AM. This is with having in mind the rapid change in AM, as Rogers et al. [7] pointed out “Due to the somewhat volatile nature of the market, some of the identified companies will likely have either expanded their range of services or gone out of business altogether by the time of publishing [the research]”. For example, the authors could make overview of the online sources on AM (e.g. newsletters, blogs, practitioner publications, web-sites, online databases etc.) or use expert interviews to catch the development of AM business models.

The advantage of the online sources in comparison with academic journals is that they have much higher frequency of publishing and faster response to everyday changes in AM field. For example, the article of Mortara et al. [23] published in 2016 calls upon the list of 73 Fab-spaces collected in the year 2013, which is a lag of 3 years. However, during our research the online database at https://www.fablabs.io/labs showed that there are 1161 FabLabs registered all over the world in June 2017. Thus, it is obvious that online sources are more up-to-date then academic sources that take a lot of time to be published. In comparison to online sources that can react to an AM news in a couple of days, academic journals would in a most optimistic case take at least a couple of months for paper to be published. This difference that is measured from a couple of months up to a couple of years presents a significant lag.

Interviews with AM experts are the second option for the future research that could be followed in order to add to the present research. Present research would gain from expert opinions since experts are capable of “catching” the trends early in their development and providing an overall picture of the AM field as well as some details if necessary. Moreover, analysis of the interviews can lead to some concealed messages that even the interviewed experts were not aware at the moment of the interview.

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