



# Industrial Additive Manufacturing Business Models—What Do We Know from the Literature?

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## 1 INTRODUCTION

Additive Manufacturing (AM or 3D-printing) is commonly understood as the ability to create parts or products directly from digital blueprints by adding material layer-after-layer [1–9]). AM is one of the key-technologies in the Manufacturing 4.0 paradigm that revolves around cyber-physical systems and small-scale data-driven production [10–13]. In this chapter we focus on business models associated with additive manufacturing that we define as *the logic of creating and capturing value through a series of interdependent activities of which one is additive manufacturing*.

The literature on the business models based on additive manufacturing can be divided roughly into four quadrants, based on the speed and strength of the change imposed by additive manufacturing to the world of manufacturing (disruptive or incremental) and, on the other hand, based

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on the openness of the business model adopted by agents (closed or open) [14]. The openness typically is a divisive issue between the open hobbyist additive manufacturing sector and the closed for-profit industrial manufacturing sector. In this chapter we concentrate only on the closed, for-profit industrial sector business models. We omit having a deeper look in the literature that concentrates on small-scale “prosumer” activities, e.g., local print-shops operated by 3D-printing enthusiasts [15], and other user-entrepreneur-based business models, such as AM production design or consulting to other hobbyists [16].

From a production technology point of view the key promise of additive manufacturing lies in the ability of AM to turn physical materials into a desired form without many of the costs one incurs by using conventional manufacturing methods. There is potential for cost savings emanating from AM when machining, molding, casting, and tooling are not required, or there is a remarkable difference to current practice in how much of these costly actions are required [4, 17–22]. One of the drivers of AM is the potential to manufacture certain components or products at a lower cost—this potential has not yet been universally realized, far from it, as AM technology is still in many aspects developmental.

Other technical drivers for the adoption of additive manufacturing may include issues such as the high customization capabilities offered, product quality improvements, e.g., weight reduction and better product geometry, and production flexibility [23]. One obvious, but often unmentioned issue that may drive additive manufacturing technology is its high level of automation. Generally one can observe that the first instances, where additive manufacturing seems to be the most cost efficient way to produce industry-grade components have been found in biomedical, automotive and aerospace industries (see, e.g. [4, 9]).

The diffusion of additive manufacturing technologies is hampered by the limitations to the materials, i.e., filaments that can be used in the process. Generally, AM technology is not far enough to be able to take use of many of the materials available for conventional manufacturing methods, while another material-related issue is the filament unit cost in AM, which is typically higher than the equivalent raw material cost in conventional manufacturing [24]. Also the production speed (rate) of additive manufacturing can be a limiting factor, especially when large components/structures are additively manufactured [25]. It is also noticeable that contrary to conventional manufacturing, the economies of scale in AM are most often limited, as the cost of raw materials typically have a direct

relationship with the production volume [24]. At the time of writing, the majority of additively manufactured products still require surface finishing [2, 4, 22], which makes many of additive manufacturing processes only capable of producing semi-finished products. As a solution for mass production applications several authors, e.g. [3, 24], suggest production layouts combining additive and conventional manufacturing techniques—this means the printing of “near-net-shapes” and machine finishing products with subtractive methods. As with all new manufacturing technologies concerns have been voiced also about the mechanical properties of products manufactured by using AM-technologies [1, 3, 26]. Testing the mechanical properties of 3D-printed structures is one part of the technical research that goes into the development of AM.

One separate and important issue that is connected to additive manufacturing in a “strong” way are the intellectual property rights (IPR) related to both the printed products [2, 18, 19, 27, 28] and materials [23, 28]. As the blueprint, or “recipe”, used in printing is a non-material entity that is owned in closed business models typically by the designer, it is a key component in controlling the overall AM process. Safeguarding the design and the IPR vested in designs are generally issues that may require extensive and even costly actions. In fact, IPR questions must be answered in a general and satisfactory way before additive manufacturing can make a global breakthrough.

Considering the above, one can reasonably state that the AM is not a “one size fits all”-solution, when it comes to deciding the most suitable method of manufacturing on a technical *process level*. This is why it is very interesting and important to understand, where additive manufacturing can make a difference in a business of manufacturing that is, where additive manufacturing technology-based business models make sense and what kinds of applications of additive manufacturing make business sense. Furthermore, it makes sense to understand whether there is, what can be called “transformative power” in additive manufacturing from the business model point of view. In fact, most cases such transformative power exists, because if additive manufacturing technologies make a breakthrough in some areas they will most likely also disrupt the existing *supply chains* (SC) in the related industries. This is due to the fact that the designs used in additive manufacturing are digital and can travel at the speed of light to the location at which the additive manufacturing facility resides, closest to where the product (to-be-printed) is needed. This means, for example, that printing products on location instead of moving them from

one place to another [29] may become one of the ways of doing business in the logistics sector.

Revolutions in how business is done such as the one described above can, if they are widely adopted, lead to large shifts in global value chains (GVC) and may possibly obsolete, first, some of the existing ways of conducting business and, second, the infrastructure connected to it. A key difference between AM-based business models and the conventional business models is that production can be made more on-demand and the necessity to store an inventory is reduced (further). Furthermore, the production of ready-to-use products can be done on-location, or nearer to location [29, 30], which means that in some cases also intermediate products do not have to be dealt with [20, 28]. All in all what one can observe is that the potential for large changes touches the logistics of manufacturing, including what is being shipped, stored, and the origin and destination of the traffic. Importantly, if significant competitive advantage can be obtained by reinventing the way business is conducted, such a change can have global implications in the overall distribution of wealth and may favor the early adopters of AM-technologies. Even though some futuristic scenarios (e.g. [15]) underline the possibility of some underprivileged user-entrepreneurs printing themselves out of poverty, we tend to believe in more realistic visions provided by [31, 32] where the early adopters of AM are typically well-established large, industrial actors located in the (already) wealthy and technologically advanced societies.

Despite the clear weight and importance of looking at the effect AM has on business models and on the global value chains, it has been observed that serious existing academic literature on the topic is lacking and what is available are practitioner and consultancy reports [18, 33]. In the media the disruptive nature and effect of AM tend to be hyped, while academic literature is typically more conservative [34].

A review article can also be used in the development of fresh ideas, rather than merely concentrate on synthesizing the existing body of research [35]. In this vein, the objective here is to shed light on what has been already written on industrial additive manufacturing based business models and to identify and to shortly discuss the most promising business models and their implications on the short- and on the long-term future, where on the short-term the changes may be *incremental*, while *disruptive* changes can take place on the long-term.

This chapter goes forward by first having a look at the short-term implications of additive manufacturing and incremental business model

development and then turns to discuss the long-term development and the disruptive additive manufacturing based business models. The chapter is closed with a summary and some conclusions are drawn.

## 2 SHORT-TERM IMPLICATIONS OF ADDITIVE MANUFACTURING AND INCREMENTAL BUSINESS MODEL DEVELOPMENT

A case study of hearing aid industry [36] shows, how the adaptation of AM-technologies can happen fast, when proper (profit) incentives are in place. The same study however also concludes that already having dominance over important and complementary assets such as distribution channels, customer registers, and patents, can limit the extent at which AM technologies enable new competitors to enter in the market. In other words, it is clear that in situations where additive manufacturing would cannibalize existing “good business” there is a tendency to slow down adoption, especially in firms that already enjoy a competitively advantageous position over their rivals (for extensive discussion, see, [22]). On the short-term additive manufacturing seems to serve as complimentary to the conventional manufacturing methods and replace conventional production only where it is clearly more overall cost effective technology. It can be posited that the short-term effects of additive manufacturing are case-specific and driven by company-level business drivers [37, 38].

### *Generally on Current Applications*

The use of AM-technologies can be divided into (1) rapid prototyping; (2) rapid tooling; and (3) rapid manufacturing [23, 26, 38, 39]. Of these, the first one is routinely used in various industrial settings, as it clearly reduces both the costs and the time to market for new products [40]. In rapid tooling applications, AM-technology is used to support conventional manufacturing processes, e.g., by producing molds. Due mostly to unresolved IPR-issues, additive manufacturing activities is typically kept in-house [29, 34] and contracted AM-suppliers typically operate from centralized locations [41] instead of providing capacity on-site.

Polymer-based AM-technologies are used to produce medical or prosthetic devices [9, 36] in the industrial setting, but also to create home-made toys or household commodities by the hobbyists. The common

factors for these sectors are the high customization requirements, unitary demand, and also low standardization and the relative indifference to IPR. Metal printing technologies enable a cost effective way to produce parts that are typically either expensive to produce by using conventional manufacturing methods and/or difficult to machine [17, 42]). The current defining key-feature of AM is to produce customized parts with small lot sizes. This means that AM is not likely to replace the existing, highly automated and capital-intensive, investments in mass manufacturing machinery. The future role of AM, according to [34], may be to support these mass-production investments by replacing mass-production in the production of less frequently demanded products. This line of thought can be regarded as contradictory to the ideas presented by, e.g., [20, 28] who see AM as a primus motor in the reduction of the minimum efficient scale of manufacturing.

### *Additive Manufacturing in Spare Parts Service*

An emerging application of additive manufacturing is the production of spare parts for technically high-end industries such as the automotive and the aerospace industries [43–46]. The aerospace industry may be the single most prolific user of additive manufacturing for components at this time.

Spare parts supply in industrial applications has some distinct characteristics, which make it an especially good match with additive manufacturing technologies that offer reduced lead times to minimize supplier inventories [47], and, at the same time, extend the time OEM (Original Equipment Manufacturer) support products [24, 48]. Typically the demand for spare parts is not uniform through time and manufacturers try to minimize the spare parts inventory, while they need to be able to deliver the demanded parts quickly. Keeping either expensive equipment ready to produce more spare parts or holding large inventories for products near their time of discontinuation is very expensive and additive manufacturing offers a way out from this dilemma. The critical question to answer when making decisions about going to spare parts manufacturing with AM is whether, when, and under which conditions it is more feasible to take into use additive manufacturing over conventional manufacturing methods for spare parts. It may make sense to migrate to AM from originally conventionally manufacturing spare parts at some point, where the demand no longer supports mass-production. The AM adoption

becomes an optimization problem, where profit is the target of optimization.

Today, aggregating enough demand for the relatively high-cost AM-equipment to be profitable in distributed locations remains a pivotal issue together with existing the problems that face product quality and the speed of delivery [44, 49, 50]. This observation points to the (obvious) fact that, similar to mass-production, being able to run production close to capacity is important from the point of view of profitability also for AM, and the inability to do so is an issue [49]. In a review of [51] regarding the supply chain scenarios of AM, the least considered option for additive manufacturing was the “old-school factory”-type manufacturing of products under stable demand. However, as AM equipment can produce a quite unlimited selection of different geometries there is considerably more flexibility in what can be produced and the problem of filling equipment capacity may be a smaller hurdle in the quest for profitably running the shop. Due to the need to service spare parts is often imminent, Holmström and others [44] conclude that, as a relatively slow process, additive manufacturing are never going to fully replace the policy of storing some of the most critical spare parts in the service location.

### *Product Service Systems (PSS)*

One driving force of AM-adoption may be the emergence of service-based business models also around additive manufacturing or supported by additive manufacturing. If the user of a “machine” pays for the usable hours rather than for the machine itself, then the onus of keeping the machine in operable condition falls on the lessor. It may be beneficial to be able to tie predictive maintenance capabilities with additive manufacturing to make the machine downtime, for which no revenue can be reaped, as low as possible. This kind of thinking is very similar to the thinking behind business models that can be found, e.g., in power generation and that are tapped into by, for example, Rolls-Royce’s Power selling “power by the hour” [47] and where instead of a one-off lump sum investment payment a client pays a stable stream of revenues for the power received during the years as a service purchase.

Business models that combine products and services (that can be the manufacturing as a service) are commonly referred to as Product Service Systems (PSS), we refer the interested reader to see [17, 52]. One can

anticipate the rise of PSS-based business models in high-technology industries, where the complexity of equipment is constantly increasing and thus ever more secured with IPR. Matsumoto and others [17] discuss the use of additive manufacturing specifically in parts-remanufacturing and discussion about other AM-based maintenance applications can be found, e.g., in [47, 53]. One central problem that surrounds universal application of additive manufacturing to, among others, “spare parts as a service”- businesses is the fact that so far no universal standards for industrial AM platforms exist [49]. This means that, today the seemingly similar additive manufacturing set-ups are not necessarily able to produce required spare-parts and hints that agents that are able to jointly commit to a standard, or otherwise able to create an official or a de-facto standard, may be able to reap benefits over non-standardized AM manufacturers in the PSS-business over the long haul.

### 3 LONG-TERM IMPLICATIONS AND DISRUPTIVE BUSINESS MODEL DEVELOPMENT

The applications of additive manufacturing with the highest business value potential are most likely in the printing of complete parts of assembled products, or in the printing of whole products. This business falls under the rapid manufacturing genre of applications. If AM-technologies were to develop from their current niches of manufacturing into a universally accepted and applied method of manufacturing there is a chance that also a large portion of the future capacity of manufacturing has to be built based on additive manufacturing technology. Rayna and Striukova [21] envision that (B2B) customer-owned 3D-printers might become one key complementary asset for some manufacturing companies, when uncertainties around the technology are resolved. This would mean that the manufacturing for clients could happen by clients with IPR provided by the original manufacturer. This kind of thinking highlights the existing and future capabilities of market incumbents to access customer networks, see discussion in [19]. Again the issue of standardization is important, if a customer has a non-standard set of equipment then such B2B “network use” is not possible, which makes standardization as a key enabler of the disruptiveness of additive manufacturing technologies.



### *Rapid Manufacturing*

It is proposed in the existing literature that additive manufacturing could be used in the launch phase of a product [27], something that can be dubbed “Bridge Manufacturing” referring to the phase of bridging the understanding about whether it makes sense to invest in mass-manufacturing or not. Bridge manufacturing can also be used in situations, where a new product is launched, but the production lines commissioned for mass-manufacturing are still under construction. In essence, bridge manufacturing with AM may give an edge for the existing market incumbents to quickly update their product range and supply and to speed-up the delivery process for early (often high-price paying) customers. Bridge manufacturing with AM can also serve as a valuable option to test out new designs, before making sunk and fixed investments in mass-manufacturing equipment.

There is also literature that suggests that AM is a good choice for the manufacturing of products with a stable demand [54], and literature that names AM to be suitable for conditions of declining demand [48], which is referred here as “End-of-Life Manufacturing”. These, as well as bridge manufacturing, are based on the existence of a digital model for the product. For selected end-of-life components, AM-based “digitalization” of existing production may actually be relevant. In the case of new products with uncertain demand patterns it may be a good idea to design products AM-compatible directly, even though they were to be produced initially using the methods of manufacturing. This creates an option of commencing production by using additive manufacturing methods at any time. So far, AM has not been used in bridge-manufacturing, or in end-of-life manufacturing in a notable scale.

In industrial AM-systems, it is essential to ensure the purity of the used raw materials [20] due to the risk of contamination that correlates with product quality. This makes it generally infeasible to change the printed material in machines between print-jobs (even if the machines are able to print by using multiple raw materials) and suggests that the minimum size of an “all purpose” industrial grade printing facility must include a number of material-dedicated AM-machines [26]. A Delphi-study conducted among industry experts and presented in Jiang and others [19] suggests that critical parts manufactured with AM will be produced in specialized hubs to ensure quality, whereas non-critical parts can be printed also locally. It seems that print-quality is an issue that is taken rather seriously in the literature and that may affect also additive manufacturing business-models, at least initially.

### *Closed-Loop Manufacturing*

Creating a product in one place directly from its raw materials enables a better tracking of its individual components [20]. As enticing this might be from the environmental perspective, data-sharing on material specifications is still mostly inhibited by the existing material patents [55] add that also some of the large 3DP-equipment manufacturers cherish the cartridge-sales -based business models with close filament specifications. Even though, AM reduces the direct energy and material consumption the production of filaments (e.g. metal powders) can be a major resource consumer. The overall environmental effect is therefore a huge issue that would require further, system-level, studies [18, 20, 47, 53, 56–59].

## 4 CONCLUSIONS AND FUTURE DIRECTIONS DEVELOPMENT

As the AM-technology is able to overcome the evident technical issues one-by-one, the focus of research interest is likely to shift towards its industrial applications. We predict that the economies of scale will take a central role in and the scenarios of small-scale, locally operating manufacturers become marginalized. The focus in business model applications will be increasingly on developing cost-effective, centralized manufacturing capabilities able to manufacture an ever widening range of high quality products on-demand (see also [34]). This development would realize some of the key benefits of AM-technology while ensuring the economies at the same time.

We anticipate that these “factory-scale” AM-facilities locate themselves near the end-customers for fast delivery and, more importantly, within fast access to global supply chains of raw materials (relatively near harbors, airports, and railway-hubs), as the manufacturing technology moving towards additive manufacturing does not make these factories of the future independent of raw materials logistics. In fact, the selection of raw materials stored on-site would likely increase rather than decrease, assuming that one would be able (and willing) to also manufacture “intermediate components” from the scratch.

Generally speaking the importance of customization, an issue highlighted in the “AM positive literature” versus the true nature of customer-needs remains an open question. Even if many products can be custom made or tailored with low extra production costs in theory, we

suggest that the vast majority of customers, whether B2B or B2C, would still prefer standardized OEM-approved make-to-stock (MTS) items for increased (and promised/assured) security and warranty. Another point that supports additive manufacturing based production of MTS-items is the fact that making to stock is a way to guarantee high-enough equipment utilization rates, which are typically important for being able to insure investment payback and in large-scale operations for creating economies of scale in terms of raw material purchases.

An important and quite intuitive point to make is that in manufacturing, as elsewhere, the bottom line of financial analysis drives the actions of agents—there will not be a drive towards additive manufacturing if there is no business case. This is as true for mass production of items with AM-technologies as it is for customized small-scale production. There must be some additional featured benefit from adopting additive manufacturing that enables reaping extraordinary profits through the adoption, such as the benefits that can be derived from puncture-free long-life car tires produced with additive manufacturing en masse and that can guarantee profits on the long run. In light of the existing literature, additive manufacturing does provide a solid, new method of production that is already applied in special applications, but the high costs of production, technical constraints, and some unresolved issues with regards to IPR make additive manufacturing today (2020) unable to make a “holistic” breakthrough. However, as technical issues and intellectual property issues are resolved and as cost of production with additive manufacturing technologies are pushed down, we feel it is inevitable that additive manufacturing will have a growing place in the manufacturing systems of tomorrow by partially replacing, but more often complementing, traditional methods of manufacturing.

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