Chapter

From Traditional Manufacturing to Digital Manufacturing: Two Swedish Case Studies

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Abstract

Digital manufacturing can produce new and advanced tools more rapidly and at lower cost than traditional manufacturing. This new technology means manufacturers need to develop innovative business models adapted to this change in the manufacturing landscape. With digital manufacturing, companies have both an opportunity and a challenge. They can enter new markets where large-scale production provides competitive advantage. They can enter niche markets that become more attractive as old boundaries and structures lose relevance. Yet their additive manufactured components must meet the same standards set for conventional manufactured components. However, we know little about how companies manage this change as they make the transition from traditional manufacturing to digital manufacturing. This chapter presents two co-creation digital manufacturing projects between university researchers and Swedish companies. In each project, the goal was to develop sustainable and efficient digital production methods that offer tailor-made product solutions. Various technical methods used in the projects are described as materials, and prototypes are developed, tested, and analyzed.

Keywords: additive manufacturing, business model, digital manufacturing, co-creation, FabLab

1. Introduction

Digital manufacturing, such as additive manufacturing (AM), is presently experiencing enormous growth with no end in sight. We are currently witnessing its powerful effect on a changing manufacturing landscape and on the direct consumer market [1]. These technological developments have attracted the interest of companies in the traditional manufacturing sector.

AM, also known as 3D printing, is the layer-by-layer manufacture of desired components or product geometry from a sliced computer-aided design (CAD) model. With its layer manufacturing technique, AM can produce complex geometries, thus eliminating the multiple process steps in traditional manufacturing and reducing the use and waste of materials. The technique is also faster and requires less energy [2–5].

For these reasons, AM has been described as a sustainable technique [6] and a focus of Industry 4.0 [7].

AM has applications in numerous industries: automotive [8], aerospace [9], medicine [10], energy systems [11], construction [12], food [13], and clothing [14]. Current state-of-the-art AM technologies can be classified into Material Extrusion, Material Jetting, Binder Jetting, Vat photo-polymerization, Sheet Lamination, Powder Bed Fusion, and Directed Energy Deposition [2, 15, 16].

Because of various challenges, however, the full potential of AM is still unexplored. The challenges include insufficient data on large-volume production, too few design principles, inadequate standards for material processing technology, and the lack of quality management routines. In addition, problems exist related to process stability and repeatability [7, 17] and to the difficulty of using polymers and reinforced plastics in the creation of geometries. However, the development of AM technology has made it easier to produce reinforced plastics in complex geometries [18].

Many manufacturers have had to adapt their business models to reflect this redefinition of the product visualization process when prompted by the development of AM technology. Several research articles discuss the importance of such technology-push business model innovation or propose new models with a business and engineering perspective (e.g., see [1, 19]). The literature generally identifies two types of new product process business models [20]: a sequential product development model and an integrated product development model. The sequential model has several stages (from idea to launch with transition gates at each stage. The integrated model (e.g., the sixth-generation innovation model [21]) takes an approach in which activities such as engineering and business are developed in parallel [22].

In the co-creation projects described in this chapter, university researchers collaborated with two Swedish companies in business model innovation that followed the integrated product development model. They integrated the engineering and business perspectives in their projects that aimed at developing sustainable, efficient, and tailor-made products produced with AM.

2. Business model innovation with 3D printing technologies

Originally, only large, industrial companies could afford to use 3D printing technologies. Recent cost reductions in these technologies, however, have made them more affordable for small- and medium-sized enterprises (SMEs) and for individual entrepreneurs [23]. Moreover, 3D printing technologies are increasingly used to develop and produce a wide variety of products for direct consumer markets. The expectation is that the 3D printing technologies will lead to increased competition between the traditional mass production industry and the mass customization industry and among SMEs, individual entrepreneurs, and "prosumers."

The 3D printing technologies, with their new producers, new markets, and new products and applications, present a challenge to current business models. In these business models, competition is the rivalry for markets as viewed from a traditional market economy perspective. In the high-tech economy, business models for users of 3D printing technologies require new perspectives on competition. For example, with the increasing use of AM, a more dynamic market structure may emerge in which former market boundaries and structures are less relevant. As development and production costs decrease, business opportunities may also increase for SMEs as well as for large manufacturers [23, 24].

Companies that engage in AM need to reconsider their value propositions and their operating models. These considerations are fundamental in business model innovation that addresses, at minimum, changes in customer base, in market demand, in competitor rivalry, in product lines, and obviously in the high-tech economy, in technologies.

For example, AM integration into business activities can affect customer involvement and value chains [25], resulting in a shift from a manufacturing-centric business model to a consumer-centric business model that provides value based on customization and co-creation. Furthermore, the shift to consumer-centric business models can lead to more decentralized supply chains. Online platforms can also provide access to digital design files that allow the customer to download, personalize, and manufacture products and their components. While many companies have already identified the business benefits of AM, they may lack the knowledge needed to implement this technology. Knowledge of the entire product development chain is necessary to succeed in integrating AM with other business activities [26].

Companies may be slow or reluctant to recognize their need to shift from one business model to another to meet new market or financial opportunities. Companies must be convinced of the benefits of adapting or even restructuring their business models [19]. For example, companies using 3D printing technologies, such as AM, may manufacture products on demand at minimal cost and may move rapidly upstream or downstream as they focus on design and service. This means companies can more easily adapt the "length" of their business model by increasing/decreasing activity engagement [23].

3. The case studies: the setting

3.1 The FabLab concept

In the case studies presented in this chapter, in which two companies (Alpha and Beta)[1] are featured, researchers from Halmstad University, Sweden, collaborated with two industry partners at FabLab Halmstad in co-creation business model innovation projects. The FabLab concept, which was developed by the Massachusetts Institute of Technology (MIT), is an outreach project initiated by MIT's Center for Bits and Atoms in 2001. The concept has flourished until today there are approximately 1500 FabLabs in 90 countries [27]. At FabLab Halmstad, the focus is on small-scale innovation and experimentation in digital fabrication and production.

3.2 The two companies: Alpha and Beta

Alpha manufactures heaters, saunas, steam generators, and steam baths. Because Alpha currently produces prefabricated products or products with ready-made settings, product customization presents a challenge. The high cost of essential product materials (e.g., aluminum) is another challenge. The purpose of this co-creation project was to explore the use of AM to reduce material costs, production time, and energy usage, to customize some products, and to attract new customers with innovative designs.

[1] Responding to the companies' request for anonymity, we identify the companies by the pseudonyms Alpha and Beta.

Beta supplies rubber products to industrial companies that make their machines and systems safer, quieter, and more energy efficient. Beta has a heterogeneous group of customers in the marine, mining, construction, and sports industries. The purpose of this co-creation project was to explore the use of AM to reduce lead times for customized products, to improve the efficiency of production, and to reduce tooling costs.

In both projects, the polymer-based extrusion process labeled fused deposition modeling (FDM) 3D printing was tested. FDM is one of the most widely accepted extrusion-based processes in the AM technologies owing to its simplified approach to fabricating parts from the CAD model. The approach, which provides customized product development based on users' needs and conditions creates a digital production line by introducing AM, based on the FabLab concept. Typical challenges encountered with the approach include difficulties in the evaluation of new business processes, new distribution channels, and new markets.

4. Research methodology

4.1 The collaborative projects: Co-creation

Co-creation in manufacturing systems is a common theme in manufacturing research [28, 29]. In this chapter, we understand co-creation "as enactment of interactional creation across interactive system-environments (afforded by interactive platforms), entailing agencing engagements and structuring organizations" [30]. The co-creation at FabLab Halmstad, in which university researchers and companies interacted, using digitalized platforms to create value, falls within the framework of this definition.

4.2 The action research approach

We took an action research approach in the two case studies. This approach addresses problems using cross-functional teams in recurring cycles of action and reflection [31]. Investigation and problem-solving are conducted simultaneously in this approach. We collected primary and secondary data from observations, workshops, seminars, meetings, and reports. We collected additional primary data in tests, analyses, and evaluations of solutions proposed. Data were collected from October 2017 to July 2019. **Table 1** presents a tabulation of the hours the co-creation team spent on the Alpha and Beta projects.

Meetings. The scheduled meetings, including workshops, were where goals, plans, deliverables, and results were addressed, and go-no-go decisions were taken.

Research, communications, and observations. Pre-development activities were related to information collection on relevant state-of-the-art techniques, materials, and methods. These activities included investigations of experiments and tests that could meet the projects' requirements. The investigations were documented and submitted in reports. The development activities related to product developing, experimenting, and testing that resulted from feedback from the interviews, meetings, and workshops.

Testing and experimentation. The activities conducted followed the plans formulated in the research, communication, and observation category. Hours engaged in these activities were spent experimenting with new materials, processing and testing the digital methodologies, and producing fully functional prototypes. These mechanical and chemical activities were conducted at FabLab Halmstad.

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Data collection categories	**Company**	**Oct-Nov 2017**	**Dec 17-Jan 2018**	**Feb-March 2018**	**April–May 2018**	**June–July 2018**	**Aug-Sept 2018**	**Oct-Nov 2018**	**Dec 18-Jan 2019**	**Feb-March 2019**	**April–May 2019**	**June–July 2019**	**Total hours**
Meetings	Alpha	2	12	6	2	1	2	2	1	4	2	1	35
	Beta	4	1	21	23	1	2	1	1	20	6	3	83
Research, communications, and observations	Alpha	8	40	16	80	89	5	44	12	48	24	128	494
	Beta	86	32	116	119	4	16	4	2	52	76	2	509
Testing and experimentation	Alpha	0	45	0	141	100	24	112	6	240	160	2	830
	Beta	192	80	256	240	1	16	56	40	156	168	16	1221
Total hours	Alpha	10	97	22	221	189	29	158	21	296	188	128	1359
	Beta	282	113	394	382	5	34	60	43	228	250	19	1809

Table 1.
Data collection in the Alpha and Beta projects (in hours).

5. Results

The co-creation projects aimed to identify which of the companies' various products currently in production were candidates for possible development using AM technologies. This process took place in five stages—from the initial stage of selecting prototype designs to the final stage of prototype testing and evaluation (on prototype testing, see [32]). **Figure 1** presents the timelines of the projects' activities according to these five development stages for Alpha (A1 and A2 prototypes) and for Beta (B1, B2, and B3 prototypes).

5.1 The case study: Alpha

Because Alpha produces products that are prefabricated or with a ready-made settings, it is difficult for the company to adapt their products for customers who have different requirements. Alpha is thus seeking more flexibility in its product development. The high cost of materials is also an issue for Alpha. For these reasons, Alpha is interested in exploring innovative product designs using AM in its supply chain.

For the A1 prototype, the co-creation team studied the possibility of using AM technologies to manufacture Alpha's products. Meetings and workshop were held at FabLab, Halmstad, and at Alpha. Could a 3D printer (FDM) produce a small product component with the required durability and esthetic appeal? The university researchers scanned the market for suitable materials with the product's required mechanical properties and color. They also read published articles on plastics AM. The researchers selected a material in filament form suitable with FDM technology (the Flash Forge Dreamer FDM printer). The component was printed at FabLab Halmstad. After approving the 3D-printed product's strength, durability, and dimensional tolerance, Alpha began producing this small component at their facility. Alpha is still testing the consistency of AM production and studying the frequency and causes of possible failures. Initial results are promising.

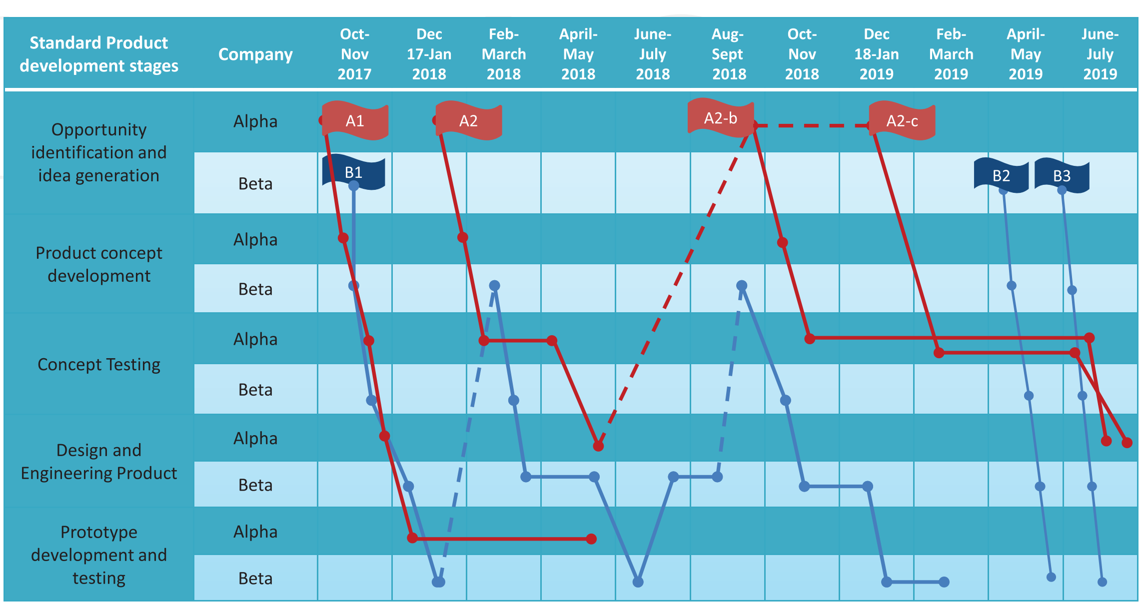

Figure 1.
Timeline of the five stages for the Alpha and Beta prototypes.

For the A2 prototype, the co-creation team investigated the printability of larger and more complex product components. Software was used to simulate the best product design possibility. The chosen design was then printed and tested for durability. To meet industry standards for these components, the co-creation team added another evaluation step to the production process: postprocessing. More test runs were conducted to evaluate the possibilities of printing larger components. A preliminary design of experiments (DoE) was used to understand the influence of the print settings on component quality.

The prototype A2 had mixed results. The required quality was achieved, but manufacturing costs were too high. The printability of larger components was complicated by some major quality issues. Therefore, a design test artifact was introduced to reduce production time and material usage. The surfaces of the test artifacts, which were printed according to the DoE, were measured and analyzed statistically to determine the quality of the print settings. Using the best setting, the components were printed and then postprocessed in a series of chemical treatments, abrasive blasting, and laser finishing to produce the best surface finish.

The modified component design was promising as it revealed a 40% reduction in material use and a nearly 50% reduction in print time. Alpha can use this knowledge in other products that are AM candidates. The university researchers presented the components in their final form to Alpha with the understanding that additional tests would be conducted before the components could be made available for production on demand.

5.2 The case study: Beta

Because Beta aims to reduce the lead time for customized products, to improve the efficiency of production, and to reduce tooling costs, AM is of great interest to the company. The company's interest in AM also relates to its desire for lower production volume and more customized features resulting from its discussions with several important customers. Beta does not currently produce the product prototypes described in this chapter using conventional manufacturing systems.

For the prototype B1, the co-creation team (supported by Beta employees with a background in materials, design, and sales plus various company decision-makers) conceptualized the materials, design, and scale of the prototypes that could be printed using existing 3D printing technology. Meetings were held at Beta and at FabLab Halmstad. The FabLab was an important venue for visualizing the production and test facility.

Prototype materials were selected based on specific requirements and market availability. Beta tested the materials to see if they met dimensional accuracy and surface requirements. The fused deposition modeling (FDM) technique was selected as the 3D printing method. When technical limitations were observed in the tests, it was decided to upgrade the printers. This upgrade significantly improved the 3D printing of the test samples and prototypes. Of the six materials tested, four materials failed, and two materials were approved. In the postprocessing step, the final prototypes were tested against the initial product requirements.

For the prototypes B2 and B3, the co-creation team conceptualized prototypes after examination of the print quality of the B1 prototype. The possibility of printing on the "B-side" was explored for prototype B2; discrete supports were explored for prototype B3. The prototypes B2 and B3 are 3D-printed with the material approved for prototype B1 with the upgraded printing technique. Beta expects to identify alternate solutions to the problems identified with small-scale digital manufacturing production. Beta also plans to continue its investigations into the use of this technology in large-scale manufacturing production.

6. Discussion

In this chapter, we examine how two Swedish companies collaborated with university researchers in the early stages of the companies' experiments with transitioning from traditional manufacturing to digital manufacturing. We described the companies' interest in, and expectations of, the new technologies. We described the various pre-development, development, and post-development activities as the co-creation team produced, tested, and evaluated prototypes for products manufactured using 3D printing technologies. We concluded with the companies' assessments of the future benefits the transition might provide.

Our results provide evidence that the transition to digital manufacturing from traditional manufacturing relates more to iterative stage-based product development models [20] than to integrated product development models [21]. The technological issues such as quality standard for digitally manufactured components and products must be resolved before business issues (e.g., cost and risk) are addressed. The transition should be understood as a trial-and-error process in which knowledge and skills in AM develop from experience and from "out-of-the-box-thinking." For example, when sales and marketing personnel were invited to workshop presentations, creative and unusual ideas emerged.

The case studies teach us that digital manufacturing requires the same strategic planning and committed execution that traditional manufacturing does. However, digital manufacturing benefits more from cross-functional co-creation in business model innovation. Manufacturers (and other companies) that are sufficiently flexible to adapt or restructure their business models in new business environments are well positioned to manage the dramatic, abrupt, and rapid changes inevitable in today's high-tech revolution. Academics can provide the expertise needed for product and process developments. Company leaders can provide revenue, cost, and risk assessments. Together, the two groups can build the co-creation teams capable of managing these changes.

7. Conclusions

7.1 Co-creation in business model innovation

The two case studies exemplify how companies and academia can beneficially collaborate in co-creation teams engaged in business model innovation. Academia can provide volunteer research expertise and experience and even experimental/test facilities, especially for scientific and technical projects. Companies can provide the candidate products that are produced in the traditional manufacturing system. Co-creation activities can lower the knowledge barriers for experimentation and entrepreneurial entry and can shorten development loops, especially for simple constructs. For company leaders who are neophytes in the high-tech world of 3D printing technologies, such assistance can be highly valuable. For academics who often engage with theoretical knowledge, the opportunity to engage with practical knowledge can be equally valuable. From a monetary perspective, company leaders receive free support in co-creation projects; from a knowledge perspective, academics receive real-world experience in co-creation projects.

7.2 From traditional manufacturing to digital manufacturing

The two case studies provide evidence that the transition from traditional manufacturing to digital manufacturing occurs in stages. In the early stages, the AM focus is on existing applications or components combined with cost and efficiency issues. In later stages, the focus shifts from AM potential and knowledge to new products, new markets, and new customers. In all stages, business models require continuous adaptation or even re-structuring. A co-creation team can provide the support needed for such challenging work.

Conflict of interest

The authors declare no conflict of interest.

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