

Business Model Innovation in the Additive Manufacturing Equipment Sector

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Abstract

Additive manufacturing has grown from an initial prototyping application into a core production technology. The increasing applicability of additive manufacturing in sectors such as aviation and health care has created an attractive market for emergent and established firms alike. One can also identify a plurality of business models among these equipment suppliers. A business model articulates the customer *value proposition*, how *value is created*, the means of *value capture* and the partners in the *value network* – the four Vs. The business models of these equipment supplier firms include equipment sales, equipment as a service, the sale of supplies and platform-based integrated solutions, among others. The emergent firms presented here are Stratasys and 3D Systems; similarly, the established firms considered here are Hewlett-Packard and General Electric. The chapter employs the four Vs framework to analyse how their business models have evolved. It provides an overview of additive manufacturing businesses, compares the business models in the four firms, discusses the different business models in four other nascent firms, and discusses implications for managers.

1. Introduction

Additive manufacturing (AM) is the construction of a three-dimensional object through materials being added together, typically layer by layer, and it is positioned to provide a disruptive transformation in industrial production technology [1]. Since the emergence of AM technologies in the 1980s, AM has developed rapidly and evolved into a viable industrial manufacturing solution to drive digital manufacturing [2]. As of 2019, the global market of the additive manufacturing industry, including hardware, software, materials and services, is estimated to be worth over 9 billion dollars [3].

Understanding the additive manufacturing industry requires an appreciation of the business models of the firms involved [4]. While additive manufacturing makes technological advances for production, it still requires firms to operate profitable business models that deliver the technology to industrial and hobby customers alike. While some firms in additive manufacturing have emerged exclusively to operate in this industry, other firms are established players in other sectors but drawn to the potential of AM. We term these “emergent firms” and “established firms”, respectively. Together, they create a vibrant AM industry characterised by a plurality of business models among competing firms.

The literature discusses the impact of additive manufacturing on the production and process innovation and its influence on business models and business model innovation [5-7]. Klöckner et al. [4] discussed the various business models that could emerge from the combined use of blockchains and additive manufacturing technology, such as distributed manufacturing. Since designing a suitable business model is critical for the development of an emerging industry, there is growing consensus that more studies on the business models of additive manufacturing should be conducted. For instance, Bogers et al. [8] argued that additive manufacturing would alter business models in the consumer goods industry. They also demonstrated that additive manufacturing makes the business model more consumer-centric by shifting value-adding activities from the manufacturer to the consumer, and compared to the conventional manufacturing sectors, the supply chains for additive manufacturing were more decentralised. Rayna and Striukova [2] identified that rapid prototyping and tooling was not disruptive for business models but raised competition. However, they indicated that additive manufacturing and home fabrication could significantly disrupt business models. Holzmann et al. [9] conducted an empirical study on the business models of the additive manufacturing industry and concluded two distinct business model patterns, the “low-cost

online business model” and the “technology expert business model”. Studies have argued that business models have agency to shape actions and influence the actions of constituent stakeholders, both with and across the networks of firms, which in turn shapes the business model [10]. Studies have emphasised the market-creation aspect of additive manufacturing. For instance, Hartl and Kort [11] showed different possible market structure outcomes for the possible market entry of a firm with additive manufacturing technology. Building on two game theoretical models, Kleer and Piller [12] investigated the market dynamics of additive manufacturing and derived propositions in terms of how user adoption of additive manufacturing influenced the structure of the market.

A business model is a representation of a firm’s activity system, seeking to connect the internal perspective pertaining to resources and routines with the external perspective relating to partners, markets and customers [13-15]. Hence, the business model articulates how the firm implements its strategy and operates in the market.

To achieve this, a business model needs to clarify the firm’s value proposition to the customer. The business model usually consists of four components, including value proposition, value creation, value capture and value network [16]. The four Vs are part of the complex system of business models, as shown in Figure 1, which demonstrates what value is proposed to connect its customers, how value is created, how value is captured and also what network is interrelated in linking its partners [16]. These can be summarised as the four key components of a firm’s business model. Business models help us to understand how value is created by the firms, the capture of value in terms of revenue streams, the value proposition of firms, and the partners in the value network, in order to achieve their business strategies in the additive manufacturing industry.

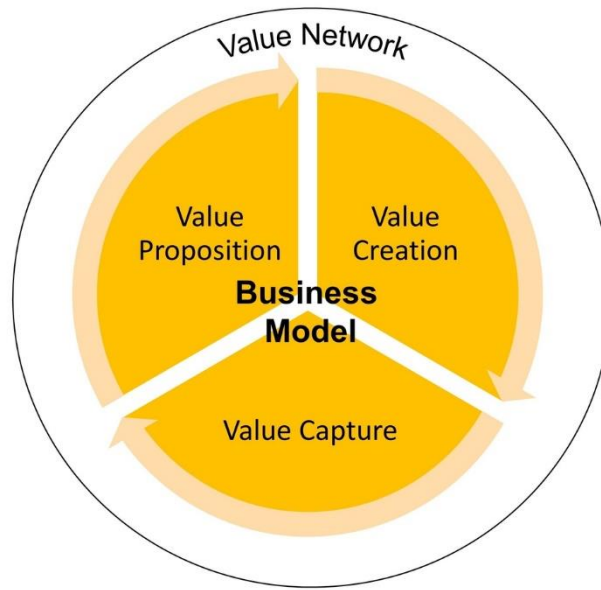


Figure 1: The four Vs business model

Source: Adapted from [16]

This chapter showcases the importance of business models for understanding the additive manufacturing industry. Business models not only explain the revenue streams of additive manufacturing but also offer insights into the structure of the industry itself. This chapter delineates the business models of emergent and established firms in the AM industry in terms of the four Vs outlined above. Four case vignettes are presented: two each for emergent firms and established firms. The emergent firms presented are Stratasys and 3D Systems – their business models illustrate how they first sought to develop the market for additive manufacturing before pivoting their business models for economic viability. The established firms presented are Hewlett-Packard (HP) and General Electric (GE) – their business models instead illustrate that these firms adopted additive manufacturing to advance their broader corporate strategy. Taken together, the actions of such emergent firms and established firms explain the business rationale for the structure and relationships in the additive manufacturing industry. The remainder of this chapter is as follows. Section 2 offers four case vignettes. Section 3 discusses the business model design in these four firms and four other nascent firms and the managerial implications. Section 4 presents the conclusion.

2. Case vignettes

Additive manufacturing went through a phase of market awareness and exuberance, which saw increasing stock prices for manufacturers, attracted substantial funds for acquisitions and

mergers and triggered intensive competition in the industries among different types of business [17]. To compare the difference in their business models, we selected firms that could provide the contrast between emergent and established firms, reflecting the various iterations of the business activities. In this section, we examine four firms, including two emergent firms and two established firms, to provide the case vignettes of business model innovation in the additive manufacturing sector. In the first case we examine one of the emergent firms, Stratasys, a global leader in 3D printing and additive solutions, materials and services. In the second case we examine the other emergent firm, 3D Systems, the inventors of 3D printing and a worldwide provider of 3D printers, materials, CAD software and a parts-printing service. In the third case we examine the business model innovation in an established firm, HP, a mature information technology company that developed and provided a wide variety of hardware components, software and services. In the last case we examine the other established firm, GE, a multinational conglomerate that operates through multiple segments: aviation, health care, power and energy, digital industry, venture capital and finance.

2.1 Emergent firm: Stratasys

Founded in 1989, Stratasys is an American–Israeli manufacturer of 3D printers and 3D production systems for in-office prototyping and direct digital manufacturing. The early core technology provided by Stratasys is the fused deposition modelling (FDM) technique, which is now prevalent across the three-dimensional printing sector. Following the successful invention of this technology, Stratasys has developed ways in which shapes could be created accurately, layer by layer, ultimately aiming to automate the manufacturing process.

Since selling its first product, the 3D Modeler, in 1992, Stratasys has gone on to create the first thermoplastic for three-dimensional printing, and got listed on the NASDAQ in 1994. To obtain and establish competitive advantage in rapid prototyping, Stratasys acquired the rapid prototyping intellectual property of IBM and employed 16 former IBM engineers who had been developing a small 3D printer based on an extrusion system. FDM by Stratasys became the best-selling rapid prototyping technology in 2003. Stratasys has since become one of the most innovative companies in additive manufacturing, introducing the first three-dimensional printer for production in 2008. By merging with Objet, a privately held additive manufacturing company, which distributed 3D printers worldwide, Stratasys consolidated its position as a market leader in 2012. Apart from technology, their combined marketing and sales capabilities extended the geographic reach of the company. Their industry customers were

different too – Stratasys catered to Caterpillar, Xerox and Honeywell, while Objet served Adidas, Intel and Mercedes; their combined entity thus had an improved market share.

Stratasys operates in the automotive, aerospace, medical and industrial sectors. It has also explored applications in entertainment and consumer goods. As an early company in additive manufacturing, it had the added burden of educating the market and raising awareness among design and student communities. While the company's initial business model was based on the sale of printers, it has increasingly servitised its value proposition to its customers. Servitisation is the process of shifting a company's offerings from the traditional sale of goods to a bundle of products, services and ongoing support [18,19].

The company has developed its broad expertise in additive manufacturing technologies through large-scale acquisitions. These acquired companies have added significantly to the patent portfolio held by the company. Stratasys has spent over \$2.2 billion on acquisitions, working out at an average of approximately \$200 million per acquisition. Some of the major acquisitions by Stratasys were Makerbot, Solid Concepts and Harvest Technologies.

The company has explored business-to-consumer and business-to-business segments differently. It offered desktop printers to hobbyists and manufacturers for the purpose of making plastic models and prototypes – its acquisition of Makerbot in 2013 at \$403 million was carried out to improve this business. Stratasys launched Makerbot retail stores in several major US cities to target the relevant consumer segment. Another attempt to reach the consumer segment was through a retail printing partnership with UPS and FedEx, whereby Stratasys sold printed parts to consumers through UPS and FedEx locations. By 2017, Stratasys had curtailed its ambitions for these desktop printers, focusing on professional printers instead. Its experiments with professional printers for the business-to-business segment have been more successful.

Stratasys started developing its direct service bureau, RedEye, in 2005, through which it offered the sale of printed products to industry clients. Its later acquisitions of Solid Concepts and Harvest Technologies have expanded this direct service bureau. Industry clients can order a small number of prototypes, or large-volume production runs through this direct manufacturing. In 2011 the company explored the monthly leasing of printers with supplies, and built a digital platform through acquisitions. Since 2015, Stratasys has also offered consulting services to help manufacturers via its acquisition of a consulting firm, Econolyst [20].

Stratasys has been building its expertise in various additive manufacturing technologies, while experimenting with diverse sectors, market segments and business models. Some of these experiments have been more successful than others. Today, Stratasys manufactures in-office prototyping and direct digital manufacturing systems, and it prioritises the professional market segment. Its collaborations are primarily for design software.

2.2 Emergent firm: 3D Systems

Another pioneering firm in additive manufacturing is 3D Systems, an American technology company founded in 1986. 3D Systems became one of the first 3D printing companies, after its co-founder Chuck Hull filed the patent for stereolithography apparatus (SLA) in 1984. Prior to the introduction of SLA rapid prototyping, it was complex, time-consuming and also costly to produce concept models. The innovation of SLA reduced the amount of resources needed and increased the quality and accuracy of producing the concept models; it also made it feasible for commercial applications. 3D Systems mainly offered rapid prototyping through its SLA technology. It is a design-to-manufacturing solutions provider that sells additive manufacturing printers, scanners and feedstock materials; it also offers a printing service.

The early offering of the company was in rapid prototyping through its stereolithography technology, where 3D Systems helped companies to rapidly design and develop prototypes before committing to costly production. The initial years of additive manufacturing coincided with the early years of the company itself. 3D Systems, therefore, had to educate manufacturers, engineers and designers through technology demonstrations and educational events. Over the decades, 3D Systems adopted an aggressive acquisition strategy. It acquired more than fifty companies when the additive manufacturing sector was exuberant, but most of these were small-scale acquisitions, averaging less than \$5 million per acquisition. These acquisitions helped 3D Systems to build its digital platform, through which the firm has interacted with its clients and more broadly shaped its business model.

3D Systems has long explored revenue streams from services to complement its sale of hardware. This can be seen in two facets of the company's strategy: the digital platform and material sales. The digital platform has enabled a direct manufacturing service for 3D Systems and driven design productivity for clients. Taken together, this has helped in educating designers and enhancing the market. As early as 2008, 3D Systems enabled designers and engineers to experience additive manufacturing through Pro-Parts, its online rapid prototyping and manufacturing parts service with online pricing guidance, for non-commercial parts [21].

Acquisitions such as Geomagic (in 2013) and Cimatron (in 2015) helped 3D Systems to improve its CAD/CAM expertise to span design, scanning and manufacturing across industry sectors, including die and mould, tooling and functional end-use applications. Software has also helped with productivity enhancement for clients. In 2018 it partnered with Dassault Systèmes, the publisher of Solidworks CAD software, offering 3DXpert as complementary software to help designers optimise designs for additive manufacturing. It has helped its clients to streamline 3D scanning and printing for plastic and metal additive manufacturing. Such a digital platform also helped it to offer a manufacturing service bureau. For example, its 2014 acquisition of Robtec, a Brazilian additive manufacturing service bureau, expanded its Quickparts service offerings to Latin America. 3D Systems has since launched e-commerce sites for its industry printers.

The other non-hardware revenue stream is from the materials business. This is similar to the traditional 2D desktop printer model, where the bulk of the revenue is derived from feedstock sales. Printers planted at client sites can later be harvested through materials sales [22]. This approach has been developed further over the years. In 2020 the company completed material testing to ASTM and ISO standards and made the data available to manufacturers [23].

3D Systems has also built collaborations beyond software. It has had a long-standing collaboration with BMW, including on-demand manufacturing services for 3D Systems to print design and functional prototype parts, tools and fixtures for BMW [24]. In the defence sector, 3D Systems has collaborated with aviation firms and even US Navy shipbuilding. The 3D metal printer at the shipbuilding site produces marine-based alloy replacement parts for castings, as well as valves, housings and brackets [25]. Its emphasis in recent years has been its Figure 4 Production platform for industry customers, who can use its 3D systems software and its broad range of materials.

2.3 Established firm: Hewlett-Packard

Hewlett-Packard's ambition is to disrupt the industrial and manufacturing sector and to become a key player in the Fourth Industrial Revolution through additive manufacturing [26]. Hewlett-Packard (HP) is a Silicon Valley technology pioneer, founded in 1939. The Hewlett-Packard Company (1939–2015) offered hardware, software and services to a wide range of customers. In 2015 the Hewlett-Packard Company bifurcated into HP Inc. and Hewlett Packard Enterprise. HP Inc. focuses on personal computers, printers, scanners and other hardware devices,

including additive manufacturing printers. Hewlett Packard Enterprise focuses on servers, data storage and cloud computing.

For HP Inc., the traditional rivals in printer-making have been companies such as Canon and Xerox. The traditional 2D printer business model has relied on providing the initial hardware at a low price, with the bulk of the revenue accruing from the necessary complementary products and services, in this case, the ink cartridges as consumable supplies. However, emerging technology such as additive manufacturing required a different business model design from HP. For instance, firms with emerging technology in additive manufacturing needed to invest more not only in technology research and development but also in educating the market, while established firms usually need to maintain the advantages in their business models and may extend their services to enrich their value networks. The company's broad vision is to usher in the Fourth Industrial Revolution through technology disruption driven by additive manufacturing.

HP has been scoping out the additive manufacturing industry for many years. As far back as 2010, HP entered an agreement with Stratasys, a pioneer in fused deposition modelling technology, for the latter to manufacture HP-branded 3D printers. They used FDM technology patented by Stratasys, and the devices were desktop printers for the prototyping of small build sizes. HP marketed and distributed these products globally through its vast sales channels. It hoped to reach 3D designers who were using HP's 2D printers. This agreement with Stratasys was discontinued in 2012, and in 2013 HP announced its plans to develop its own technology and manufacture its own device for additive manufacturing. With the benefit of hindsight, we can identify two limitations in the collaboration between HP and Stratasys. First, they were using FDM, a type of legacy technology with a print quality not well suited to production applications. Second, the market for desktop printers, which could be catered to by this collaboration, was not becoming mainstream, as initially predicted. We can now see that industrial-grade applications in the business-to-business market were a better target for companies to pursue.

In 2014 the parent company split into two, with additive manufacturing falling under HP Inc. HP initially planned to build on its printer heritage and to make up for revenue shortfall in its core computing business [27].

The company today offers additive manufacturing capability through its Multi Jet Fusion (MJF) technology, which offers engineering-grade materials with great overall

properties at the site of the client, thereby bringing the client into the Fourth Industrial Revolution. These products offer two uses for the customer: in-house rapid prototyping and final part production. The company offers a 3D-as-a-service subscription business model. This facilitates automatic replenishment of 3D supplies, tracking of billing and usage, and support services, including a pay-per-build service. This relies on the use of hardware, data, software and services.

HP is developing two key collaborations: materials and software. The company has been developing an open materials platform engaging with over fifty materials manufacturers, including BASF, Arkema, Evonik and Lehmann & Voss. This offers a wider portfolio of materials to HP's customers through its printers. Innovative speciality chemicals companies can generate revenue for themselves through this open materials platform [28].

Similarly, HP has also collaborated on software. Siemens is a seller of product lifecycle management software. HP and Siemens collaborate on additive manufacturing factory optimisation, performance analytics and data intelligence. HP has also collaborated with Dassault Systemes, the publisher of the Solidworks 3D modelling programme, which is popular among designers and engineers, to help them reimagine products for additive manufacturing production.

It is also important to understand the choices that were available to HP and the strategic rationale behind choosing how to participate in additive manufacturing. HP chose to focus on developing the technology and offering the hardware, while letting other companies capture revenue in materials and software. The core competency of HP guided the company to offer a hardware platform upon which other companies could offer material choices.

2.4 Established firm: General Electric

General Electric (GE) is arguably one of the longest-established technology companies in the world, founded in 1892 [29]. Its key segments in the twenty-first century are aviation, health care and power. GE has been exploring additive manufacturing applications in aviation and health care. Because of its long history in these sectors, it has a deep understanding of customer needs, quality requirements and part certification. GE's approach is characterised by a reduction in engineering costs for high-value complex metal parts [30]. Its foray into additive manufacturing can be illustrated through its applications in aviation.

General Electric is using additive manufacturing to produce complex fuel nozzles for its next-generation commercial jet engine in partnership with French firm Snecma. Each of

these engines has up to twenty such fuel nozzles. By employing additive manufacturing in its design of jet engines, GE could reduce the number of components from 900 to just 16, making the LEAP engine 40% lighter and 60% cheaper; the reduction in components also reduced the number of suppliers GE depended on [31]. This LEAP engine is used in the Airbus A320neo. Similarly, GE went from having approximately 800 parts to fewer than a dozen parts in its turboprop engine [32]. As a designer of aircraft engines, GE benefited from a one-third reduction in development time for the engine [31]. By using additive manufacturing for castings, rather than a ceramic mould, GE's production process became more efficient. More broadly, since GE's set-up expenses have been reduced, additive manufacturing is well suited to short production runs. This efficiency improvement results in cost savings for GE when producing aviation parts.

The additive manufacturing business model is also applied in General Electric's health-care business. GE is applying additive manufacturing to the manufacture of ultrasound probes, which are used to produce ultrasound imagery of patients [33]. GE employs additive manufacturing to reduce the time it takes to cut and refine patterns on the probe face. The cost reduction is a benefit for GE when delivering these products to its regular health-care clients.

While HP chose to partner with materials developers and software companies, GE chose to acquire instead. In 2016 GE acquired Arcam and SLM for around \$1.4 billion. Arcam had invented the electron beam melting machine for printing metals and also produced advanced metal powders. SLM produced laser machines for metal-based additive manufacturing. Both firms were also serving the aviation and health-care sectors, where GE has interests. The Arcam investment was intended to grow the company's additive manufacturing base outside GE and across multiple industries. Arcam continues to be based in Sweden, specialising in orthopaedic implants and aviation. Its business model is based on the sale of its additive manufacturing machines at client sites [34], unlike the GE aviation example. These acquisitions also boosted GE's in-house research expertise on materials and digital productivity. GE was a supplier of additive manufacturing parts to its clients but a customer of additive manufacturing technology itself. Bringing Arcam and SLM in-house therefore reduced the design and material costs for GE [35]. Further insights into this are available. In 2013 GE acquired the Italian company Avio Aero, which had been a supplier of mechanical transmission systems to GE for around three decades [36]. Avio Aero was itself a client of Arcam for additive manufacturing machines. In 2016 GE's acquisition of Arcam expanded its business boundary to include its earlier tier-one supplier, Avio Aero, and in turn its tier-two

supplier, Arcam. A timeline highlighting the key events for Stratasys, 3D Systems, HP and GE are shown in Figure 2.

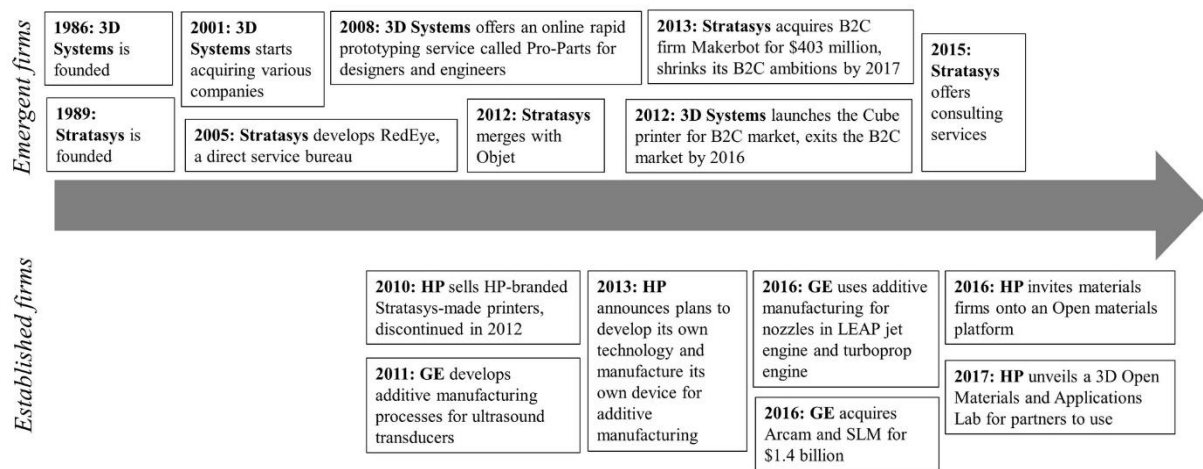


Figure 2: A timeline of Stratasys, 3D Systems, HP and GE in additive manufacturing sector

3. Discussion

3.1 Comparison of business models of the four cases

Additive manufacturing has grown from an initial prototyping application into a core production technology. Such growth and acceptance of additive manufacturing as a core technology is in part to do with the design of appropriate business models to create and capture value from the technology. Our case vignettes show that the delivery of the customer value proposition of additive manufacturing technology informs the design and evolution of the business models. We studied two emergent firms and two established firms and how they adopted additive manufacturing technologies and designed and evolved their business models. We next compare and contrast their respective approaches and discuss why the business model lens is important to better understand how, and why, new technologies such as additive manufacturing come to be adopted as a core technology. We first compare the business models of the emergent firms with the established firms. Then, we compare the business models of the two emergent firms and then the established firms among themselves. Table 1 provides the summary of the business models of these four firms.

Let us first compare the business models of the emergent firms with the established firms. The emergent firms, Stratasys and 3D Systems, were start-ups from the very beginning of the

development and commercialisation of additive manufacturing. Hence, their business model design had two principal phases. The first phase was the market awareness phase, and the second was the market maturation phase. Both Stratasys and 3D Systems had to develop their business models in the market awareness phase, where the principal objective was to educate the market about the benefits of additive manufacturing. This took the form, for example, of Stratasys opening high-street branches through its Makerbot subsidiary, where customers could learn and use additive manufacturing technologies. 3D Systems and Stratasys also pivoted their business model from merely selling printer equipment to a bureau model whereby 3D printers are rented to third-party firms to deliver printing services to their customers. For example, Stratasys rented additive manufacturing machines at UPS and then FedEx stores in order to entice customers to use the service to print and send objects to friends and family. The business model for such awareness-building activities often did not generate sufficient income to be viable on its own, and they were eventually closed down, although they did help to educate the market about the benefits of the technology. On the other hand, both HP and GE entered the market for additive manufacturing in a more mature phase when customers were more aware of the benefits of the technology. In the case of GE this was driven by the needs of its own aviation and health care businesses, while for HP the stagnating revenue from its core printing business prompted the firm to build a business to disrupt the manufacturing sector, as it was beginning to embrace industrial digital technologies.

Table 1 Comparison of business models

Firm	Value Proposition	Value Creation	Value Capture	Value Network
Stratasys	Customers can install additive manufacturing capability at their site or digitally order parts to be printed and shipped to them.	Stratasys develops technologies, produces machines and manages the online platform for direct digital manufacturing.	Stratasys generates revenue from equipment sales and shipping printed parts and through support services.	Collaboration with design software firms.
3D Systems	3D Systems offers an additive manufacturing platform, including hardware, materials and software support.	3D Systems develops the technologies and maintains online platforms for support.	Revenue is from printer sales and services, with an emphasis on services.	Collaboration with design software firms, materials firms and customers through on-demand manufacturing.
HP	Manufacturing clients derive better design capability through the installation of additive manufacturing capacity at their site.	HP is developing its Multi Jet Fusion technology, which is the basis for its hardware products. These hardware products are a platform upon which other companies – such as material developers and software developers – provide their offerings.	Revenue is generated from the sale of hardware and through a 3D-as-a-service model.	HP concentrates on hardware while collaborating with materials companies through an open platform, partnering with software companies for CAD and product lifecycle software.
GE	Clients of GE benefit from parts that are more durable, lighter and efficient.	GE is developing in-house equipment that it uses to make advanced components for its clients.	Additive manufacturing improves production efficiency and reduces production costs within GE's factory when making parts for clients. This offers cost savings for GE.	GE leveraged the network of collaborators through its acquisition of Arcam and SLM.

We now compare the business models of the two emergent firms between themselves. Stratasys and 3D Systems initially focused their business model design on addressing market awareness. Subsequently, the firms went on to develop their business models to cater for their relevant customer segments. For example, 3D Systems had more revenue from services compared to Stratasys [37]. To gain competitive advantage, Stratasys decided to acquire Econolyst, an additive manufacturing consultancy and research firm, to complement the sales of additive manufacturing machines. In addition, the distribution of the machines was an important aspect of Stratasys's business model. The importance of distribution, together with the complementary nature of the technologies and customers, prompted Stratasys to integrate with Objet through a reverse takeover in 2012.

Comparing the business models of the two established firms among themselves also provides some interesting lessons for business model design. GE was driven primarily by the need to build internal capability for using additive manufacturing technology that was becoming core to its aviation and health-care businesses. For example, in aviation, because of the increasing pressure to reduce costs in a competitive marketplace, GE needed to make its engines cheaper and also more reliable. Additive manufacturing provided the core technology to make more efficient parts, such as fuel nozzles, and also to reduce the number of parts in the engine to increase its efficiency and reduce maintenance costs. GE's increasing reliance, in terms of the provision of maintenance services, on a subscription model for its engine meant that having more reliable engines would increase the firm's profitability. Hence, the purchase of Arcam brought with it a network of complementary partners in its value network, which in turn complemented GE's capabilities in design engineering. HP, meanwhile, intended to disrupt the manufacturing industry with an industrial additive manufacturing proposition. Since HP did not have core capabilities in the production process itself, it had to build relationships with other complementary providers such as materials and software design capabilities.

3.2 Value network as investor community

There are also other emerging companies in additive manufacturing that adopt different business models, including Desktop Metal, Ultimaker, Prusa, and Carbon. Founded in 2015, Desktop Metal is one of the more recent start-ups in additive manufacturing. With deep links to research conducted at MIT, it is an American company that has long focussed on the printing of metals. Metal printing has typically been unsuited for office spaces where engineering and

design teams work; apart from the cost being prohibitively high, the process is potentially dangerous when lasers are used to melt metals at high temperatures. Desktop Metal overcomes these challenges to make metal 3D printing affordable and accessible [38]. Desktop Metal offers two different technologies - one for desktop prototyping in the office, and one for shopfloor production. Its office-friendly offering [39] does not use lasers or hazardous materials and is compatible with standard wall outlets. It is based on a proprietary technology where the printer extrudes a mixture of metal powder and polymers to build up a shape, which is then placed in a furnace to burn away the polymers and compact the metal particles together. The metal is fused into shape without reaching its melting point [40]. This desktop office offering has been shipped since 2017 [39]. Its offering for the shopfloor was launched in 2019, to enable high volumes of affordable production [41]. While GE prioritised high-end machines, Desktop Metal did not pursue the same market. Its competition was more from established metal-processing technologies. Desktop Metal's technology can print steel, aluminium, copper, and even alloys. It has now expanded beyond metals and into materials such as carbon fibre, photopolymers – through its acquisition of EnvisionTec - and even wood [42]. Given the company's focus on metals, it is unsurprising that its customers are from the automotive and aerospace sectors. Its customers include BMW, Honda, and Lockheed Martin [43]. However, this might be set to change in the future. In 2021, Desktop Metal acquired EnvisionTEC and gained a foothold in the healthcare space for dental, orthodontic and otolaryngology applications where EnvisionTec has strengths [44]. The revenue streams are from the sale of hardware, materials, and software-as-a-service that helps design optimal parts. The sale of the printer hardware opens the recurring revenue stream from materials and SaaS. A key highlight of Desktop Metal is that its investor community is also its value network. When it was still a private company, its investors include potential customers and other technology companies such as Ford Motor Company, BMW iVentures, Stratasys and Google Ventures. Ford's engineering team started working with Desktop Metal in 2016. Ford became an investor in 2018 and was among the first customers for Desktop Metal's office-friendly version [45]. Similarly, BMW became an investor in 2017. Stratasys, which was an investor since 2015, became a distributor of Desktop Metal in 2017. In December 2020, Desktop Metal was publicly listed on the New York Stock Exchange through a Special Purpose Acquisition Company [46].

Another company that merits attention for a similar reason is Carbon3D Inc. Carbon is a Silicon Valley-based company founded in 2013 which again illustrates an overlap between its value network and its investor community. Carbon employs a layerless 3D printing

technology called Continuous Liquid Interface Production. This polymer-focussed technology employs light and oxygen to grow shapes from a pool of resin. It uses a photosensitive resin which reacts to ultraviolet light and oxygen, thus growing the solid object out from the liquid bath of resin [47]. This printing technique has often been compared to imagery from the Terminator movie franchise [48]. Carbon supplies the liquid resins needed for using its technology. Carbon has also partnered with other firms such as Kodak to jointly develop materials for this purpose. In the strictest sense, such a production technology would not be adding multiple layers of material. Conventional layer-upon-layer additive manufacturing takes many hours to produce parts and are mechanically weak. Carbon's technology can draw complex solid parts from the resin at rates of hundreds of millimetres per hour, which is faster than its competitors. Carbon offers 3D printing of high resolution at a speed 25-100 times faster than traditional stereolithographic printers and other processes of its competitors [49]. The materials compatible with this production technique include stretchy elastomers and high-temperature-resistant resins [50]. Given the uniqueness of its technology, Carbon provides the hardware, software, and the materials to its customers. All Carbon materials are sold as liquid resins. Its digitally manufactured polymer parts have been adopted by various companies. For example, Ford has used this technology to make brake brackets, auxiliary plugs [51]. Another key market for Carbon has been in dental healthcare. Carbon has a presence in the dental market through its partnerships with denture providers to produce customised parts. Key collaborators are Dentca, Dreve, and Core3d. Carbon has also developed new dental resins to support its customers. As was the case with Desktop Metal, the value network of Carbon overlaps with its investor community. Carbon remains a venture-capital backed company and has not been publicly traded as of 2021. Its investors include Sequoia Capital, Google Venture, GE, Autodesk, Fidelity Management & Research, Adidas, BMW, and Johnson & Johnson [52,53]. Adidas and Johnson & Johnson are also partners in other ways to Carbon – the first 3D printed midsole by Adidas is one such example [54].

3.3 Open source design as business strategy

By adopting the business model of open source, source code is open to the public, so that individuals and companies could review, modify, enhance, and use. Increasingly companies have adopted the value proposition to introduce open design projects in promoting the engagement of online user communities, and also to accelerate the transition to local

manufacturing and digital distribution [55]. Ultimaker is a Dutch 3D manufacturing company founded in 2011. The products of Ultimaker are manufactured in the Netherlands, the US and Singapore. In its business model, Ultimake creates its value via providing products with open design projects in automotive, architecture, healthcare, education, and small scale manufacturing. Unlike in-house design, Ultimaker captures its value by combining open design in the process of making FFF 3D printers, developing additive manufacturing software, and selling branded additive manufacturing materials. With a distinctive characteristic that allows printers to move the print platform rather than the nozzle in the vertical movement, and also allows users to back up their files to the cloud, Ultimaker could make additive manufacturing easy and hassle-free. Although Ultimaker has a relatively shorter history, it has developed a value network that allows companies and individuals to participate in the design process, and design information can diffuse both inward and outward within a project management team or the user community [56]. Prusa is another newly established company that has a business model based on open innovation with source files being publicly available. Prusa is a Czech company started back in 2009, Prusa Research, which consists of open-source fused deposition modelling 3D printers. Its design files are publicly available through Prusa Research, and GitHub. Prusa's business model creates value by introducing an open-source philosophy that leads to a whole wave of clones with a significantly reduced price. Prusa delivers its service with comparable low-cost, and its open design approach allows for broad co-creation, which attracts a large number of users in education and also small-business ventures [57]. In its value networks, companies and individuals can easily use Prusa for their construction and modification of products and services. With the support of an open source architecture, enthusiasts and professionals from the manufacturer or the community can collaborate with ease, making troubleshooting simpler and allowing DIY enhancements in both hardware and software of additive manufacturing [58].

3.4 Managerial implications

There are a number of managerial implications for incumbent and emergent firms. First, for emergent firms, the need to build business models to increase market awareness is critical. In the case of both Stratasys and 3D Systems, this involved adopting business models, which enabled customers to obtain the benefits of additive manufacturing by de-risking the technology for them. This was done by enabling customers to solve particular problems such

as the design of bicycle parts through retail additive manufacturing stores without having to own the machine but using it on a pay-as-you-go basis. Such gradual use of additive manufacturing enabled 3D Systems and Stratasys to help build the market for the underlying machines. Once the market became aware of the benefits of additive manufacturing, customers began to demand solutions based on their experience of adopting the technology. Hence, both 3D Systems and Stratasys decided to build their capabilities both organically and through acquisitions across the spectrum of the product-services architecture needed to serve their customer base. Second, the two incumbent firms followed a wait-and-learn approach to their additive manufacturing strategies. In the case of GE, it was increasingly evident that additive manufacturing could provide the basis for not only reducing the costs of production but also become a key differentiator for its aviation and health-care businesses. For example, in aviation, the purchase of Avio Aero by GE, together with its increasing use of additive manufacturing technology, prompted its strategic move to acquire Arcam. GE's acquisition of Arcam as a basis for entering the additive manufacturing market was crucial to building the key capability to both differentiate its existing products and develop new products with unique functionalities. Building its own capabilities organically would have been too slow. Moreover, GE and Avio Aero were already customers of Arcam, which gave the firm the insights and technological knowhow it needed on the usefulness of the underlying additive manufacturing technology of Arcam and its network. In contrast, HP had knowledge of the printing business and needed to diversify into what it perceived to be an adjacent market, as it knew the principles of the printing business well. Hence, after a period of learning about the additive manufacturing industry through its alliance with Stratasys, HP decided to embrace the manufacturing industry with its own additive manufacturing offering. However, in order to be credible, it had to offer an integrated product-service offering to the market; hence, it needed a whole network of other firms such as BASF and Siemens to be able to provide complementary products and services. Third, the four more-recent emerging firms, Desktop Metal, Carbon, Ultimaker, and Prusa, demonstrate more diverse business models. These firms run different business models in order to compete with the established firms and emergent firms. While Stratasys and 3D Systems spent much of their efforts on educating the market, consumers, manufacturers, students, and investors, this was not a major focus for Desktop Metal and Carbon. There was little need to convince the investors about the potential of the technology and the applicability to their industry – Desktop Metal and Carbon could instead use their value network as their investor community as well. An innovative approach to the value network is also seen with Ultimaker and Prusa, which are exploring value co-creation in additive manufacturing, through open-

source design. As the additive manufacturing industry matures, one can expect continued innovation with business models, from both emergent and established firms alike.

4. Conclusion

This chapter has provided an overview of case vignettes to illustrate the rationale behind additive-manufacturing-based business model design. We have shown how the strategies of firms to create and deliver customer value proportions helped them to develop their business models accordingly across the key components of value proposition, value creation, value capture and value network, respectively. There were differences between the established and the emergent firms in terms of business model design strategies. The emergent firms had to develop their business model to help develop the market before redesigning them to make them economically viable. The established firms were able to wait and learn and develop their business models to complement and extend their existing businesses. The research in additive manufacturing and business model design is very much at a nascent stage, with much more still to be investigated regarding how, when and why business model innovation is required for additive manufacturing technology-based strategies to contribute to creating competitive advantage. Also, our focus of this chapter is primarily on the B2B sector although we mention some aspects of the B2C sector, while the differences between the B2B and B2C markets still needs more investigation in the future studies. We hope that our chapter provides some of the principles for scholars and managers to think about business model design and evolution as firms adopt new technologies.

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