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HOW 3D PRINTING TRANSFORMS EXISTING BUSINESS MODELS: A LITERATURE REVIEW

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This study explores the transformative impact of 3D printing technology on existing business models. Through a comprehensive literature review, the research identifies how 3D printing reshapes core business model elements, value creation, value capture, and value proposition, by facilitating customization, enabling decentralized production, and simplifying supply chains. A conceptual framework is presented to map the unique characteristics of 3D printing (e.g., additive manufacturing, rapid prototyping, and digital transferability) to these business model elements, providing a roadmap for understanding the interplay between technological innovation and strategic adaptation. The findings suggest that while 3D printing offers firms greater flexibility and innovation potential, challenges such as high initial costs, slower production speeds, and regulatory concerns require continuous strategic adaptation. This review contributes to the emerging literature on the economic implications of 3D printing by highlighting the need to align technological advancements with dynamic business models to secure sustained competitive advantage. Future research should employ empirical investigations to deepen understanding of 3D printing's impact across diverse industrial contexts. In addition to operational impact, 3DP enables strategic positioning options for firms to support hybrid approaches that combine cost leadership with differentiation through personalisation. This evolution reflect digitalisation, which requires firms to rethink traditional business assumptions. Furthermore, the integration of 3DP with other digital technologies, such artificial intelligence, may create even greater disruptions to business models in an area that requires further exploration. The framework proposed in this study offers a foundation for such future inquiry.

Keywords: **Business model, 3DP business model, Business model change, 3DP business model change framework.**

JEL Classification: **Q32, L86, M11, Q33**

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1. Introduction

The world of manufacturing is facing transformation by the rise of 3D printing (3DP) technology. Industries from automotive to healthcare adopt 3DP technology. As example, automotive manufacturers use 3DP to reduce lead times in tooling and die production, increase design flexibility, and streamline manufacturing workflows (Asnafi *et al.*, 2019). Healthcare providers use 3DP to produce patient-specific implants and prosthetics, reshaping supply chains and cost structures (Sandström, 2016; Verboeket *et al.*, 2021). Recent research shows 3DP development into novel domains such as food sustainability and personalized medicine. In the food industry, 3DP has potential to support long-term sustainability goals, reduce waste, and enable customized nutrition and packaging solutions (Thorakkattu *et al.*, 2025). According to Rodriguez-Pombo *et al.* (2024) , 3DP in healthcare show its application in producing chewable, personalized medicines for children with rare metabolic disorders, enhancing treatment adherence and dose precision. Consequently, such transformation challenges the traditional business models. Recent studies in clothing industry highlight that 3DP faces challenges of digital transformation which create a need for innovative business models. Deep mass customization and distributed manufacturing are emerging as key solutions to these challenges (Jin *et al.*, 2024). 3DP technology change production logic: processes that were costly under centralized mass production are now being transformed by 3DP's decentralization, which enables greater customization, supports premium pricing, and increases accessibility.

This shift raises important questions: What does this shift mean for existing business models? This article explores how 3DP is reshaping the business operations, present opportunities and challenges for companies that rely on traditional manufacturing methods.

Implications of 3DP expected from supply chain transformation to the potential disruption of entire industries. Research is needed to evaluate whether it represents a shift or a simply temporary technological disruption. Despite the growing 3DP adoption, research on the economic and business implications of 3DP remains limited. Most academic studies focus on technical aspects such as material science, engineering, and process optimization, with little emphasis on the broader implications for business models. This leaves gaps in understanding how 3DP reshapes value proposition, value creation, and value capture as key elements of sustainable business models (Oberg *et al.*, 2018; Rayna & Striukova, 2016).

This review aims to bridge the gap in the literature by systematically examining the impact of 3DP on traditional business models. As 3DP challenges traditional business structures, compelling companies need to rethink where and how to manufacture products in order to remain competitive (Despeisse & Ford, 2015). The more disruptive the technology, the greater the need for business model change that should ensure value creation, value capture, and long-term sustainability (Chesbrough & Rosenbloom, 2002; Teece, 2010). This review addresses two key research questions: how does 3DP influence the core elements of business models, including value creation, value proposition, and value capture? And, what challenges and opportunities do the adoption of 3DP present across different industries? By focusing on these questions, the review not only synthesizes current knowledge but also highlights areas where further empirical research is needed, thereby contributing a structured framework for future studies and strategic decision-making."

By analyzing the existing literature and identifying areas for further research, this review contributes to an improved framework for understanding how emerging manufacturing technologies can reshape business strategies and secure a long-term competitive advantage.

2. Methodology

This study uses a structured literature review to analyze the impact of 3DP technology on business models. The methodology follows a systematic approach to ensure a comprehensive understanding of how 3DP affects the core business model elements: value proposition, value creation, and value capture.

The literature review was conducted using academic databases Web of Science and Google Scholar, focusing on peer-reviewed articles published in English, and considering all relevant articles. The search strategy included keywords such as "3D printing," "additive manufacturing," "business models," "business model change," and "technological innovations" (Snyder, 2019). Articles that were not published in English were excluded, as well as those focusing solely on technical aspects, as well as studies without full-text access. The final selection consisted of studies addressing the economic and business implications of 3DP, with particular emphasis on manufacturing optimization, customization, and supply chain transformation.

The literature review approach was chosen due to the limited availability of empirical data on 3DP's business model implications (Oberg *et al.*, 2018). By synthesizing existing research, this study provides a foundational understanding of 3DP's transformative potential, bridging theoretical insights with practical applications.

3. Business models

3.1. Business models as drivers for innovation in the digital age

It is essential to review business model origin so that to get better understanding of the significance of the business model, especially in the context of innovation, The term "business model" emerged in 1957. It appeared in the context of constructing business games for training purposes as a simulation of real-world operations for educational objectives (Dasilva & Trkman, 2014). In 1960, it appeared in discussions on business education, but it remained relatively uncertain until the early 1990s, when the rise of the Internet brought new digital possibilities. During the dot-com era, the concept gained significance as disruptive digital technologies forced companies to rethink how they delivered and captured value (Teece, 2010). In the traditional Industrial Age, companies primarily packaged their technology and intellectual property into products, selling them individually or as bundled packages (Dasilva & Trkman, 2014; Škerlavaj *et al.*, 2007). During the dot-com era, many technology-based firms adopted new, web-focused business models grounded in untested assumptions, promising high profits without necessarily establishing a clear customer base or sustainable strategy (Foss *et al.*, 2023). However, this approach contributed to the failures of numerous high-profile e-tailers when the dot-com bubble burst, underscoring the essential role of well-designed business models in changing market conditions (Thornton & Marche, 2003). With continued technological advances and the emergence of electronic business, the concept of the business model evolved into a comprehensive framework that not only guides operational decisions but also serves as a strategic asset. Today, business models are recognized as the drivers of innovation, they provide the mechanism by which firms align their resources, capabilities, and revenue strategies with emerging technological opportunities (Wirtz *et al.*, 2016).

In conclusion, the dot-com era highlighted how technology-driven changes demand more than just innovative products or services. Technological changes also require robust business models. This highlights the need for a sustainable mechanism to deliver and capture value in rapidly evolving technological landscapes. As Teece (2010) highlighted, sustainable competitive advantage depends on an effective business model that enables the successful commercialization of innovation. Therefore, technological adaptation, whether in the dot-com era or in current digital transformations, demands that firms develop well-structured business models that not only accommodate innovative technologies but also ensure long-term success. For instance, 3D printing presents a novel production method that can challenge traditional manufacturing firms to rethink their approaches to value creation, delivery, and capture.

3.2. Business model framework and core elements

Due to the inconsistent use of the term business model, there are no commonly accepted definitions. Scholars approach the concept from diverse theoretical perspectives. Some emphasize the firm's value creation process, while others focus on strategic decision-making or transaction efficiency (Wirtz *et al.*, 2016). Magretta (2002) adopts a narrative approach by describing a good business model as one that tells a compelling story about how an enterprise operates and creates value. Casadesus-Masanell and Ricart (2009) offer another perspective by defining a business model as a system of strategic choices and consequences that determine how a firm operates and competes. According to Teece (2010), every business, whether explicitly or implicitly, operates according to a business model which articulates how a company identifies customer needs, creates and delivers products or services, and ensures profitability or sustainability in doing so. By emphasizing these three dimensions, the business model as a framework clarifies how firms achieve competitive advantage and successfully commercialize innovations (Teece, 2010). In the technological innovations context, business models serve as an explanatory and a managerial function, helping firms understand the economic rationale behind innovation and guiding strategic decisions during times of rapid technological change. This perspective emphasizes that, especially in the context of disruptive technologies, a firm's business model must be continuously refined to effectively bridge the gap between technological potential and market value (Baden-Fuller & Morgan, 2010). Teece (2018) further highlighter the importance of dynamic capabilities, arguing that successful firms continuously refine their models to adapt to evolving market conditions and competitive pressures.

Following the definition of Teece (2010), three key elements within a business model: value proposition, value creation, and value capture, not only define a firm's operational activities but also underpin its competitive advantage in dynamic markets.

The value proposition of a company refers to the products and services it offers to customers, which aim to address specific needs or solve problems (Demil *et al.*; Osterwalder *et al.*, 2005). It defines the unique value created for users through its offerings, often leveraging technology to reduce costs, introduce new solutions, or enhance existing possibilities. The business model identifies the target market or users for whom these value propositions are designed, thereby structuring how value is delivered to customers (Chesbrough & Rosenbloom, 2002). The goal is to innovate and enhance the benefits of consumption for customers, making them willing to pay for these enhanced or novel benefits (Priem, 2007).

Value creation refers to how organizations generate value through the entire value chain by leveraging their resources and capabilities (Achtenhagen *et al.*, 2013). These resources include assets such as people, equipment, facilities, channels, brands, and technologies, which are important for delivering the value proposition to the target customer (Priem, 2007). Successful companies develop operational and managerial processes that enable them to deliver value efficiently, repeatedly, and at scale. These processes include essential activities like training, development, manufacturing, budgeting, planning, sales, and service. Moreover, key processes also encompass a company's rules, metrics, and norms, which collectively guide and sustain value creation (Johnson *et al.*, 2008).

Value capture is the process of turning created value into revenue and ensuring profits from it (Baden-Fuller & Haefliger, 2013; Teece, 2010). Central concept is the profit formula, which defines how a company generates value for itself while delivering value to its customers. The revenue model is determined by price multiplied by volume. The cost structure includes direct and indirect costs and benefits from economies of scale, influenced by the resources essential to the business model. The margin model outlines the contribution needed from every transaction to achieve the desired profits, based on the expected volume and costs. Additionally, resource velocity measures how efficiently resources, such as inventory and assets, are utilized to maintain the desired volume and achieve profitability (Johnson *et al.*, 2008). A successful business model ensures that the price charged for the value proposition not only covers costs but also generates the profits necessary for sustainable operations and long-term growth (Teece & Linden, 2017).

Together, these three elements, value proposition, value creation, and value capture, form any business model. Their interdependence means that a change in one element often necessitates corresponding adjustments in the others (Teece & Linden, 2017; Zott & Amit, 2010).

3.3. The interplay of technological innovation and business models

Technological innovations often force firms to reexamine how they create, deliver, and capture value (Chesbrough & Rosenbloom, 2002; Teece, 2010). While traditional economic theories often assume that improved products or services naturally lead to higher profits (Baden-Fuller & Morgan, 2010), research-driven innovations often produce spillover technologies that lack a clear market application, making commercialization challenging (Chesbrough & Rosenbloom, 2002). Commercial success hinges on aligning the new technology with an effective business model (Baden-Fuller & Haefliger, 2013). For example, Zott and Amit (2010) describe how friction-reduction technologies may be commercialized through varied approaches: in-house manufacturing, service-based production, or technology licensing. Each path entails distinct business activities, partnerships, and financial outcomes, demonstrating that successful innovation requires more than technical skills, it demands a coherent business model. Firms must configure their resources, capabilities, and cost structures in ways that support the new technology's advantages, which may entail adopting new revenue streams, creating different supply-chain relationships, or designing more agile production processes.Illustrative example is Xerox's Model 914, where the company moved from simply selling an expensive copier to leasing the equipment under a usage-based fee. By realigning its business model with the copier's technology, Xerox made high-quality copying affordable and accessible, driving market adoption and establishing industry leadership (Chesbrough & Rosenbloom, 2002).

Furthermore, the relation between technological innovation and business models is two-way. While new technologies can invalidate or diminish existing models, a well-structured business model can also shape technologies development and how they can be deployed (Baden-Fuller & Haefliger, 2013). Firms that use effective dynamic capabilities, the ability to sense opportunities, seize them, and reconfigure operations, are more likely to adopt emerging technologies effectively (Teece, 2018). In conclusion, technological breakthroughs challenge companies to rethink core assumptions about who their customers are, how they deliver value, and how they structure revenue. Those that adjust all three dimensions, rather than focusing solely on product-level improvements, get the best chance of capturing long-term competitive gains.

4. Understanding 3DP technology

4.1. 3DP process

3DP, also known as additive manufacturing, is a process that creates three-dimensional objects by adding material layer by layer, based on a digital model or computer-aided design (CAD) file (Tofail *et al.*, 2018). The process begins with design of an object by using CAD software, which generates a digital model (see Figure 1). This model is sliced into thin horizontal layers to prepare it for printing. The 3D printer follows the instructions from the sliced model: adding material layer by layer to build the object from the bottom up (Berman, 2012). Once printing is complete, the object may require post-processing steps such as cleaning, curing, or finishing to achieve the desired final product (Tofail *et al.*, 2018).

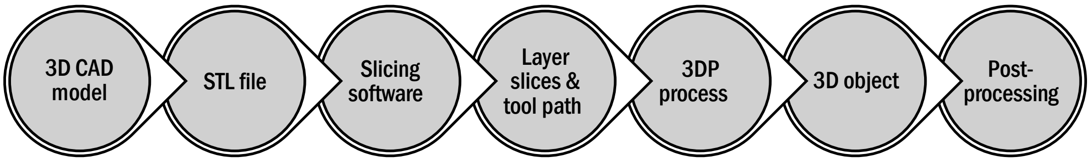

Figure 1. 3DP process

Source: Adapted by author from Berman (2012) and Tofail et al. (2018)

The term 3DP encompasses many technologies including rapid prototyping, direct digital manufacturing, layered manufacturing, and additive manufacturing. 3DP and additive manufacturing terms have become interchangeable. Additive manufacturing is the industrial version of 3DP technologies that are used across various industries (Attaran, 2017).

3DP processes are classified into several categories: material extrusion, powder bed fusion, vat photopolymerization, material jetting, binder jetting, sheet lamination, and directed energy deposition (Gao *et al.*, 2015). Each category utilizes different techniques and materials, depending on the technology and the specific application. Common materials used in 3DP include plastics, resins, metals, ceramics, composites, powders, paper, and bio-inks like hydrogels and living cells for medical applications, reflecting 3DP's versatility across industries (Balletti *et al.*, 2017). 3DP processes vary in how layers are deposited, in operating principles, and in the usage of materials. Some 3DP processes melt or soften materials to build layers, while others cure liquid materials through different techniques (Bikas *et al.*, 2015). Raw materials can come in the form of liquids, powders, or sheets (Ford, 2014). The main differences between 3DP processes lie in the specific technologies employed to build objects layer by layer. Manufacturers need to select the most suitable 3DP process by considering factors such as material properties, part complexity, production volume, desired outcomes, as well as printing and machine costs and color capabilities to ensure requirements are met (Bikas *et al.*, 2015; Tofail *et al.*, 2018).

4.2. 3DP applicability

The versatility of 3DP can be classified into several key uses (Gupta *et al.*, 2012):

- Prototyping. 3DP is widely used for rapid prototyping, allowing engineers and designers to quickly create, test, and revise physical models during the design process.
- Tooling. 3DP is used for creating casting patterns, primarily as prototypes, but also as parts that may end up in final products.
- Direct goods production. 3DP is increasingly being applied in the production of end-use parts and finished products, creating final goods for sale or use.
- Repair and maintenance. 3DP is employed in the repair of damaged parts, particularly in situations where replacing parts would be costly or time-consuming, such as in specialized machinery.

The growing range of 3DP applications is driven by the introduction of new materials, incremental improvements in process control, speed, accuracy, and cost efficiency (Weller *et al.*, 2015).

4.3. Digital transformation and 3DP

Digitization is about converting analog information into digital form. Looking from the perspective of the organization, digitalization describes the broader organizational changes and business model adaptations by using digital technologies that to enhance performance and expand business opportunities (Brennen & Kreiss, 2016). Changes arising from digitalization are often disruptive, leading to the transformation of existing industries and market structures (Rachinger et al., 2019).

3DP can be viewed as a new digital manufacturing solution that reshapes traditional business operations by introducing flexible and decentralized production capabilities (Jin *et al.*, 2024). As part of digital transformation, 3DP enables deep mass customization, distributed manufacturing, and closer customer integration. Distributed manufacturing supports this shift by allowing production to occur at geographically dispersed, small-scale facilities close to end users, enhancing agility and enabling greater product personalization (Moreno & Charnley, 2016).

Additionally, digital transformation also enables the rise of more sustainable and circular business models where 3DP contribute to reducing waste and supporting eco-friendly production practices (Huynh, 2021). These developments challenge existing business models and require firms to rethink how they create, deliver, and capture value (Jin *et al.*, 2024). Digitization and servitization are increasingly putting pressure on established business models, making incremental adjustments insufficient. Innovation competition has shifted from technology and process improvements toward business model innovation, as new entrants such as startups and SMEs now have the means to challenge incumbents with relatively limited investment (Linz *et al.*, 2020).

Digitalization affects all industries by pressuring companies to adapt their business models (Linz *et al.*, 2020). However, the degree and speed of business model innovation differ across industries, as business models are often more dependent on company-specific resources and capabilities than on technology itself (Teece, 2018). This highlights the strategic importance for firms to align 3DP adoption with their unique capabilities and competitive positioning to fully realize the potential advantages offered by digital manufacturing. There is a need first to examine the technological foundations of 3DP and its capabilities that better understand how these strategic opportunities arise.

5. Findings

5.1. 3DP impact on value proposition

Customization and personalization

3DP enables customization by integrating product design and manufacturing processes, allowing the creation of tailored offerings that involve customers at one or more stages (Berman, 2012; Simpson, 2004). As 3DP use digital model, it can make design modifications quickly and eliminate retooling. This capability makes the process particularly suited for frequent design changes (Holmström *et al.*, 2010). As defined by Spring and Dalrymple (2000), flexibility is the ability to adapt and modify products to meet specific customer needs without compromising efficiency or quality. 3DP supports flexibility by enabling quick design changes without significant additional costs. Building on this foundation, products customized based on customer preferences provide clear and tangible benefits to consumers (Franke *et al.*, 2009). In practice, 3DP's flexibility for customization means each product can be tailored to specific requirements without incurring major setup costs or delays (Berman, 2012). This expanded design freedom is especially advantageous for highly customized or specialized products. By enabling on-demand production of one-off or small-batch designs, 3DP allows businesses to differentiate offerings in crowded markets. Such personalization to reinforce customer loyalty and support premium pricing opportunities.

Sustainability

The layer-by-layer additive manufacturing approach generates little, or no waste compared to subtractive methods. On-demand production helps minimize inventory, improving working capital and reducing scrapping risks for unsold products (Attaran, 2017; Despeisse & Ford, 2015; Tofail *et al.*, 2018). Additionally, manufacturing closer to end-users reduces transportation routes and associated carbon emissions (Kietzmann *et al.*, 2015). Furthermore, 3DP's ability to produce lightweight structures lowers material usage (Thompson *et al.*, 2016). On-demand printing of spare parts can also prolong product lifecycle, contributing to a more circular production model

(Tofail *et al.*, 2018). Recent studies emphasize that 3DP adoption supports sustainable value creation through localized, resource-efficient production (Huynh, 2021). All these factors address eco-conscious consumer demands. Also help businesses increase sustainability on focused markets by delivering tailored and eco-friendly solutions.

5.2. 3DP impact on Value Creation

Process efficiency and resource use

The main difference between 3DP and traditional manufacturing processes is that 3DP use additive approach rather than subtractive. 3DP enables the direct transformation of digital 3D models into physical objects by adding material layer by layer. 3DP allows to build complex geometries and intricate designs that are difficult or impossible with traditional methods (Berman, 2012; Weller *et al.*, 2015). 3DP process eliminates the need for specialized tooling and reduces material waste or preformed materials in standardized sizes, and shapes as the basis for further manufacturing (Kietzmann *et al.*, 2015; Tofail *et al.*, 2018). As a result, resources utilization becomes more efficient, lowering both operational costs and environmental impact. 3DP integrates CAD software directly into manufacturing workflows, reducing the need for manual oversight and minimizing errors (Berman, 2012; Feldmann & Pumpe, 2017). Unlike traditional labor-intensive manufacturing methods, the 3DP automated process ensures designs are reproduced exactly as intended, enhancing production accuracy and consistency (Feldmann & Pumpe, 2017).

Rapid prototyping is another contributor to process efficiency. As 3DP relies on digital design data, firms can quickly produce and test prototypes without incurring substantial setup expenses. This agility shortens design cycles and enable faster innovation (Holmström *et al.*, 2010). Consequently, organizations can respond more faster to market feedback, refine product features and bring new offerings to market in significantly less time.

Decentralized production

As 3DP is based on digital files that make them to be easy transferred. The easy transferability approach allows manufacturing to occur closer to end-users and the additive process does not require physical molds or tooling. Moreno and Charnley (2016) introduced the distributed manufacturing concept that presents a shift from the centralized to decentralized production, aiming to build a more resilient and connected system by leveraging digital technologies. It enables an agile, user-driven approach that supports personalization and customization of products for local markets. Therefore, 3DP significantly influences global value chains: they can become shorter and more dispersed, production shifts closer to end-users (André O. Laplume *et al.*, 2016). This decentralization reduces the need for centralized manufacturing and extensive logistics by cutting transportation costs and time-to-market (Attaran, 2017; Gebler *et al.*, 2014). Decentralized production advantages:

- mitigates logistical complexities,
- reduces transportation costs,
- lowers lead times.

Businesses can manufacture volumes in a just-in-time approach by minimizing inventory, quickly responding to local market demands.

Product design and complexity

3DP impacts value creation by expanding design possibilities. Product performance improvement by complex geometries and intricate internal structures reduce weight, enhance structural integrity and enable novel functionalities. Such feasibility reshapes how firms approach R&D and product engineering (Thompson *et al.*, 2016). Previously impossible or expensive design features can now be integrated into finished goods, often improving performance, reducing weight or adding new functionalities.

Despite the 3DP's innovative potential, technology faces several limitations that impact its performance and applicability in manufacturing. One significant issue is the printing speed, which is slower compared to traditional manufacturing methods, leading to longer production times and affecting throughput and lead times (Nyman & Sarlin, 2014; Thompson *et al.*, 2016). The build volume of 3DP limits the size of parts that can be produced, posing challenges for scalability in manufacturing larger components (Attaran, 2017). Some 3D printing processes can only use specific types of materials, limiting the range of material properties available (Thompson *et al.*, 2016). The precision and quality of 3DP parts often fall of those produced by traditional methods, requiring additional post-processing to achieve the desired surface finishes and resolution (Berman, 2012; Thompson *et al.*, 2016).

5.3. 3DP impact on Value Capture

Cost structures

3DP significantly reshapes cost structures by reducing or eliminating many of the expenses related with traditional manufacturing. As 3DP uses additive process that builds items layer by layer, expensive tooling and molds are not necessary (Thompson *et al.*, 2016). This approach minimizes material waste, overproduction, and lowers storage costs by enabling on-demand production and decentralized manufacturing (Attaran, 2017; Despeisse & Ford, 2015; Kietzmann *et al.*, 2015; Tofail *et al.*, 2018). In addition, reliance on digital 3D data streamlines supply chains, reducing logistical overhead and environmental impact (Berman, 2012). 3DP enhances profitability and value capture through a leaner, more flexible model that better aligns production with actual market demand.

Revenue models

3DP opens multiple possibilities to generate revenue by expanding how products and services are monetized. One of its most significant contributions is customization and personalization, which allows businesses to offer customer's tailored solutions at premium prices (Weller *et al.*, 2015). Because 3DP is fit for small batches and on-demand manufacturing, companies can target niche markets. As 3DP can quickly create prototypes, this significantly shortens time-to-market for new products (Berman, 2012; Weller *et al.*, 2015). This flexibility reduces the risk of holding large inventories and empowers firms to pursue low volume or one-off production runs. 3DP feasibility attracts clients who seek highly specialized or limited-edition items (Attaran, 2017).

Digital transferability opens new opportunities for business. By selling or licensing digital product files, businesses enable customers to print products locally, reducing both shipping costs and turnaround times (Attaran, 2017).

3DP facilitates the development of innovative product designs that were previously impossible to manufacture due to the limitations of traditional processes (Berman, 2012). This feature expands potential product offerings to new customer segments and differentiating brands in markets.

All these capabilities foster new revenue streams, whether through premium customized products, digital file sales, or on-demand printing services, enhancing how firms capture value in the evolving manufacturing landscape.

The initial investment in 3DP equipment is high, and the cost per part remains too high to be competitive for high-volume production (Nyman & Sarlin, 2014). Regulatory and social implications also present challenges. The ease of digital reproduction of CAD designs raises concerns over intellectual property security and the potential for unregulated printing of hazardous items, such as plastic guns (Attaran, 2017; Berman, 2012; Gebler *et al.*, 2014).

5.4. 3DP impact on business models across industries: benefits and challenges

The following case studies illustrate how 3DP is reshaping traditional manufacturing processes and driving changes in business models across diverse sectors (see Table 1).

The study by Asnafi *et al*. (2019) examines the impact of 3D metal printing on the automotive industry, particularly for stamping tools and dies. The findings reveal that the lead time can be halved, significantly improving production efficiency. Additionally, the quality of 3D printed tools and dies matches conventional methods meeting industry standards. Technological capabilities include the ability to eliminate the casting pattern, since the mold box can be 3D printed directly, reducing material usage and streamlining processes. However, the technology is limited by the maximum size of a metal piece that can be 3D printed by Powder Bed Fusion. Economic challenges include higher costs compared to traditional methods, scalability issues, and the need for significant adjustments in production processes. Despite these limitations, the study emphasizes the transformative potential of 3DP, particularly in reducing lead times and enabling innovative manufacturing approaches.

Table 1. Comparative overview of 3DP adoption: key findings and limitations across industries

Source	Industry	3DP usage	3DP Technology Unique Characteristics	Business Model Element	Economic Output	Limitations
Asnafi et al. (2019)	Automotive (Stamping Tools & Dies)	Stamping tools and dies	Additive Manufacturing & Digital Integration; elimination of casting patterns	Value Creation: Process Efficiency & Resource Use	Halved lead times, improved production efficiency, reduced material usage	High initial costs; maximum printable size limitations; scalability issues; need for process adjustments
Verboeket et al. (2021)	Medical (Localized Medical Parts)	Medical parts	Decentralized Production; high customization via digital design	Value Proposition: Tailored, On-Demand Offerings & Immediate Part Availability	Enhanced responsiveness, reduced supply chain lead times, improved crisis readiness	Higher per-unit cost; facility adaptation costs; increased training and staffing needs
Sandström (2016)	Hearing Aid Manufacturing	Hearing aid shells	Digital workflows; automation for custom shell production	Value Creation: Improved Efficiency & Cost Reduction	Faster production, enhanced product quality, reduced return rates	Technological uncertainties; need for staff retraining; early adopter challenges
Rylands et al. (2016)	SMEs (Filter Manufacturing & Wallpaper Production)	Filters and roller sleeves for wallpaper production	Ability to produce complex geometries; design customization & co-creation	Value Creation & Value Proposition: Enhanced Agility and Customization	Reduced lead times, lower production costs, improved competitiveness	High investment costs; design complexity; technical limitations

Source: Author's own analysis

Verboeket *et al*. (2021) explore the impact of 3DP on localized medical parts production. The main benefit is its ability to significantly improve responsiveness and reduce supply chain lead times, especially during emergencies. Localized production mitigates risks related with supply interruption by offering significant value during crises. 3DP facilitates localized production by bypassing physical distribution challenges and reducing dependence on centralized supply chains. It enables the creation of complex, patient-specific shapes without the need for molds or tooling. In this case 3DP offers high levels of personalization. However, the study also identifies challenges associated with localized 3DP such as higher costs per unit compared to the centralized production, primarily due to facility adaptation costs and the lack of economies of scale. Additionally, personnel training and the need for staffing across multiple locations further increase costs. Despite these challenges, localized 3DP justifies its higher costs in scenarios where rapid delivery is essential, ensuring quicker responsiveness compared to centralized setups.

The study by Sandström (2015) examines the adoption of 3DP technology in the hearing aid industry between 2000 and 2006, highlighting its transformative impact on production processes without significantly altering the competitive landscape. All major hearing aid manufacturers transitioned to 3DP during this period to improve efficiency, reduce costs, and enhance product quality. 3DP technology allowed for better customization of hearing aids, ensuring a tighter fit and improved acoustic performance, while digital storage of ear impressions streamlined the production of replacement shells. 3DP replaced manual, labor-intensive processes that resulted into faster production with fewer errors, and created a cleaner production environment. Significant cost reductions were achieved, and the business got improved product reliability and lower return rates. Additionally, the digital workflow opened new opportunities for product differentiation and optimization. Despite its benefits, the adoption of 3DP faced several challenges. Early adopters encountered technological uncertainties, such as material compatibility and printer selection, and had to retrain staff to use new software and equipment. The study characterizes 3DP in the hearing aid industry as a competence-destroying but sustaining innovation, offering clear economic incentives for adoption without disrupting the established industry structure (Sandström, 2016).

The study by Rylands *et al.* (2016) investigates the adoption process of 3DP and its business impact within two SMEs, specifically in the filter manufacturing and wallpaper production industries. Findings revealed that 3DP allowed the companies to produce geometrically complex parts and offered design customization capabilities. The filter manufacturing industry adopted 3DP enhanced agility and reduced lead times, leading to more competitive offerings and improved customer satisfaction. The wallpaper production industry integrated 3DP into roller sleeve design, significantly reduced lead time and production costs while enabling customization. The study highlighted 3DP role by enabling co-creation with customers and compressing product development cycles. However, challenges included high investment costs, design complexity, and technical limitations of 3DP systems. Overall, the study demonstrated that 3DP adoption contributes to business performance improvements, increased customization, and enhanced market competitiveness, while maintaining traditional manufacturing methods for broader operational flexibility.

5.5. Conceptual framework explanation: mapping 3DP's impact on business models

In order to examine systematically how 3DP transforms traditional business models, the author proposed a conceptual framework (see Table 2) that aligns the unique characteristics of 3DP with three core business model elements: value proposition, value creation, and value capture (Teece, 2010). This framework is like a roadmap for understanding the transformative influence of 3DP on firms' strategies and operations.

The main attributes of the framework are additive manufacturing process, decentralized production capabilities, advanced design flexibility, and potential for customization. For example, because 3DP builds objects layer by layer directly from digital models, it eliminates the need for physical molds or tooling. This not only minimizes material waste and reduces production costs but also accelerates the prototyping process, thereby enhancing value creation (Berman, 2012; Holmström *et al.*, 2010; Weller *et al.*, 2015).

Table 2. Conceptual framework for the impact of 3DP on business models

3DP Unique Characteristic	BM Element	Outcome/Impact	Strategic Advantage	References
Process Efficiency &Resource Use	Value Creation	Eliminates the need for specialized tooling; reduces material waste; enhances production accuracy; enables rapid prototyping that lowers operational costs and environmental impact	Cost Leadership	Berman (2012); Weller *et al.* (2015); Holmström *et al.* (2010); Feldmann & Pumpe (2017)
Decentralized Production	Value Creation	Enables manufacturing closer to end-users, shortening global value chains, reducing transportation costs and lead times, and lowering carbon emissions	Cost Leadership / Focus Strategy	Laplume et al. (2016); Attaran (2017); Gebler *et al.* (2014); Kietzmann *et al.* (2015)
Product Design &Complexity	Value Creation	Allows creation of complex geometries and intricate internal structures, fostering innovation and product differentiation	Differentiation	Thompson *et al.* (2016)
Customization &Personalization	Value Proposition	Supports on-demand, tailored production that meets individual customer needs, enhancing product uniqueness and enabling premium pricing	Differentiation / Focus Strategy	Berman (2012); Simpson (2004); Holmström *et al.* (2010)
Sustainability	Value Proposition; Value Capture	Minimizes waste and inventory, reduces environmental impact through localized production, and supports eco-friendly consumer demands	Differentiation	Attaran (2017); Despeisse & Ford (2015); Kietzmann *et al.* (2015)
Revenue Innovation	Value Capture	Opens new revenue streams via digital file licensing, pay-per-print services, and premium customization options, boosting overall profitability	Focus Strategy	Attaran (2017); Berman (2012); Weller *et al.* (2015)

Source: *Prepared by author*

The digital nature of 3DP enables manufacturing to be localized and decentralized. By allowing production to occur closer to end-users, 3DP shortens supply chains, reduces transportation costs and lead times. It's also diminishing the environmental impact associated with long-distance logistics (Attaran, 2017; Laplume *et al.*, 2016). This shift directly strengthens the value proposition, as firms can offer more agile, customized, and eco-friendly solutions to their customers.

3DP's ability to produce complex geometries and intricate designs, features that are often unachievable with traditional manufacturing, drives innovation in product design. This capability expands the range of products that can be offered. Also, this allows for tailored solutions better meet customer needs, thereby enhancing both the value proposition and value capture.

The emergence of novel revenue models, such as digital file licensing and pay-per-print services, further illustrates how 3DP reshapes cost structures and creates new profit opportunities (Attaran, 2017; Berman, 2012).

By resuming, the conceptual framework explains 3DP impacts to business models in the ways: 1) it improves operational efficiency and innovation (value creation), 2) enhances customer engagement and product's differentiation (value proposition), 3) fosters new revenue opportunities while reducing costs (value capture).

The adoption of 3DP technologies not only transform business model's elements but also generates strategic advantages for firms. According to Porter, firms can achieve advantages to pursue different strategies: cost leadership by minimizing operational costs, differentiation by offering customized, high-quality products, or a focus/hybrid strategy by targeting specific market niches with a combined cost and differentiation advantage (Porter, 1998).

As illustrated (see figure 2), 3DP technology characteristics impact business model elements, leading to strategic advantages. 3DP enables cost reduction through localized and resource-efficient production, improves product quality by enabling production according to exact specifications, shortens delivery times through distributed manufacturing models, and enhances customization capabilities, offering personalized solutions to customer needs (Jin *et al.*, 2024). These operational improvements strengthen a firm's competitive positioning.

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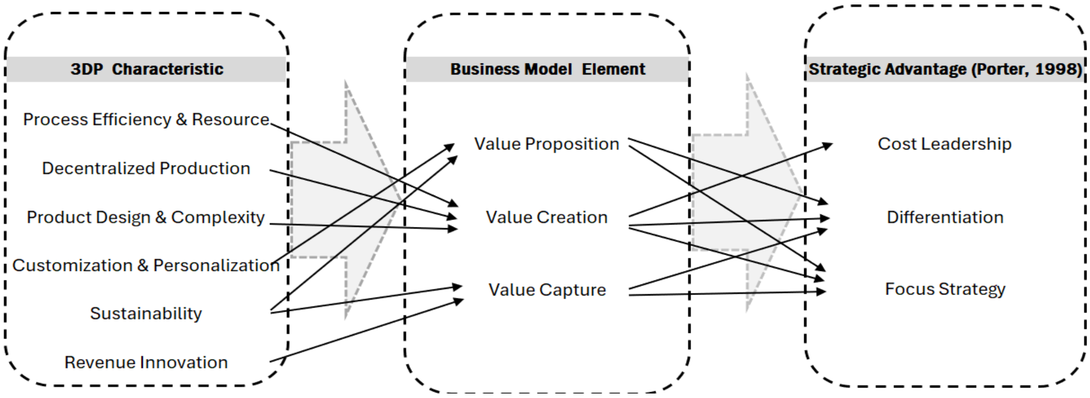

Figure 2. Framework linking 3DP technology, business model and strategic advantage

Source: Prepared by author

By integrating these dimensions, the framework provides a comprehensive perspective on how firms can strategically adapt to and benefit from the transformative potential of 3DP technology.

The following conceptual schema illustrates how the unique technological characteristics of 3DP influence key business model elements and enable firms to achieve strategic advantages consistent with Porter's (1998) framework. The model traces the pathway from technology adoption to business model transformation and competitive positioning.

6. Discussions

This literature review demonstrates that 3DP has potential to transform traditional business models by influencing how firms create, deliver, and capture value. The additive manufacturing process of 3DP characterized by its elimination of specialized tooling and reduction of material waste, enhances process efficiency and resource utilization, thereby lowering operational costs and environmental impact. The ability to rapidly prototype enables faster innovation cycles, allowing firms to respond quickly to market feedback and refine product features. The digital nature of 3DP facilitates decentralized production by enabling manufacturing to occur closer to end-users. This approach shortens global supply chains, reduces transportation costs, and minimizes lead times. 3DP technology's capability for high customization and personalization further strengthens the value proposition by allowing firms to offer tailored products that meet specific customer needs by premium pricing. Simultaneously, 3DP opens innovative revenue models, such as digital file licensing and pay-per-print services that enhance value capture while lowering traditional costs. Therefore, digitalization is increasingly challenging traditional business models across industries. As demonstrated in the case of 3DP, digital technologies drive shifts toward distributed production, personalization, and sustainability. Firms need not only to adopt new technologies but also to rethink their approaches to value creation, value proposition, and value capture to maintain competitiveness in a digitally transformation (Huynh, 2021).

Despite these advantages, significant challenges remain. Slower printing speeds, limited build volumes, material constraints, and regulatory and intellectual property concerns can impact scalability and broader adoptions possibilities. Moreover, the shift toward decentralized, digital manufacturing requires substantial organizational changes, including workforce retraining and process reconfiguration. These findings underscore that while 3DP offers considerable potential to disrupt and improve business models, firms must develop dynamic capabilities to continuously adapt to these technological advancements.

The proposed conceptual framework maps how key components of 3DP technology (see Table 2), such as additive manufacturing, decentralized production, customization, sustainability, digital transferability, and optimized cost structures, drive changes in core business model elements: value creation, value proposition, and value capture. This approach leads to economic outputs like lower production costs, premium pricing, and new revenue streams. This framework illustrates that 3DP not only enhances process efficiency and innovation (value creation), but also enables firms to offer tailored, eco-friendly products that meet specific customer needs (value proposition), while simultaneously reducing fixed costs and opening novel revenue models (value capture).

The findings also highlight that 3DP adoption supports firms to achieve strategic advantages by improving operational efficiency, enhancing customization capabilities, and enabling faster responsiveness to market demands. These advantages align with Porter's (1998) strategies framework, where firms seek cost leadership, differentiation, or focus on strategies depending on their market positioning and resource configurations. 3DP technologies offer firms strategic flexibility to adapt following dynamic and competitive environments.

The analysis of case studies illustrates common benefits across industries, and also indicates industry-specific challenges. For instance, the automotive industry benefits from reduced lead times and improved material efficiency but must manage high capital investments and process integration issues. In the medical field, localized production improves responsiveness in emergencies yet faces scalability and cost hurdles. Similarly, in hearing aid manufacturing and SME contexts, the balance between technological innovation and traditional production methods highlights both the promise and limitations of 3DP adoption.

Future research directions

Most studies are conceptual or with a limited number of empirical investigations examining outcomes of 3DP integration. Future research should focus on longitudinal studies to evaluate the sustained impact of 3DP on business models, take industry-specific adaptations, and address the challenges of scalability, workforce retraining, and regulatory implications in a more systematic approach. Such empirical investigations will provide deeper insights and gives guidance for seeking 3DP impact for a sustainable competitive advantage.

Future research should also investigate how the distinct applications of 3DP, such as rapid prototyping, tooling, direct goods production, and repair and maintenance, affect specific elements of the business model. For example, rapid prototyping may drive innovation and value creation by accelerating product development cycles, tooling applications might enhance production efficiency without altering value capture. Research should explore whether firms in different industries tailor their strategic responses based on the 3DP application they adopt, and how these variations influence competitive advantage. By incorporating these dimensions into empirical studies, future research can provide insights into the interplay between technological applicability and business model transformation (Gupta *et al.*, 2012; Weller *et al.*, 2015).

Future studies should also explore deeper integration of Artificial Intelligence (AI) with 3DP technologies. Recent advances highlight the transformative potential of AI in additive manufacturing, particularly in design optimization, material innovation, real-time process control, and quality assurance (Gu *et al.*, 2023). Empirical investigations remain underexplored regarding how AI-driven design processes influence specific elements of business models, such as value creation through accelerated product innovation and enhanced customization. Future studies should clarify how AI guided material development affects key business model components, particularly value proposition by offering unique materials and value delivery through improved production flexibility.

Limitations

This methodology is based on secondary data, which may not capture emerging trends or provide detailed firm level insights. Future research should address this limitation through empirical studies to validate and expand the findings.

In summary, the literature shows 3DP advantages in enhancing production efficiency, customization, and revenue generation. The full potential will be realized through continued research and strategic 3DP adaptation.

More comprehensive empirical studies on the impact of 3DP on business models are essential to better understand how this transformative technology contributes to sustainable competitive advantage.

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