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Extent of 3D Printing Use in Manufacturing and Service Sector: A Literature Review

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Abstract

This study focuses on identifying the adoption and scalability of 3D printing technology in modern-day industries across the manufacturing and service sectors, tracing its evolution from early stereolithography patents in the 1980s to its current role as a cornerstone of Industry 4.0. Employing a systematic literature review guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, the study addresses three research questions concerning the historical evolution of 3D printing, its technological advancements in these sectors, and how those advancements compare to traditional manufacturing. The review draws on peer-reviewed articles, conference proceedings, and authoritative industry reports retrieved from Scopus, ScienceDirect, PubMed, and ProQuest. Findings reveal that 3D printing has gained ground in several manufacturing industries, including aerospace, automotive, food, and pharmaceuticals, by enabling complex geometries, reducing material waste, and accelerating prototyping cycles. In the service sectors, healthcare, education, hospitality, and entertainment have similarly benefited through enhanced customization, reduced lead times, and cost efficiencies. Though 3D printing offers distinct advantages over traditional subtractive manufacturing, challenges remain in quality assurance, material costs, and industrial scalability. This study concludes that 3D printing is best understood not as a replacement for conventional manufacturing, but as a complementary technology that expands production capabilities and unlocks new possibilities across both sectors.

Keywords
3D printing, manufacturing, service, additive manufacturing, traditional manufacturing.

1. Introduction
Additive manufacturing, also known as 3D printing or rapid prototyping, has been around for over four decades. According to the American Society of Mechanical Engineers (ASME), the first patent was filed in the 1980s, and since then, different companies have fought to become the first brand name in 3D printing. In the 1980s, Hideo Kodama filed the first 3D printing patent application describing a polymer rapid prototyping system which uses UV light to harden the material. However, it was not until 1983 that Charles Hull invented the first stereolithography apparatus (SLA) machine; hence, he is widely recognized as the father of 3D printing. Since then, significant technological development has occurred, and as patents expire and become more widely available, almost anyone can

go online, purchase a home 3D printer, and start printing objects within minutes (*Timeline of the 3D Printing History - ASME*, 2020). Recent reviews of the technology underscore that additive manufacturing has transitioned from a niche prototyping tool to a strategic enabler of digital production within Industry 4.0 (Ngo et al., 2018; Tofail et al., 2018).

For over four decades, 3D printing has gained recognition in both the manufacturing and service sectors. The United States Department of Labor defines a manufacturing division as one engaged in the mechanical or chemical transformation of materials or substances into new products (*U.S. Department of Labor*, n.d.). Accordingly, manufacturing companies can be categorized into the following key sectors: automotive; aerospace and defense; electronics and semiconductors; pharmaceuticals and life sciences; chemicals and petrochemicals; food and beverage; machinery and industrial equipment; textiles and clothing; and wood and paper. With respect to service sectors, the Department of Labor identifies a primary engagement in providing a wide variety of services for individuals, businesses, government establishments, and other organizations (*U.S. Department of Labor*, n.d.), including financial services, healthcare and social assistance, education, hospitality and tourism, information technology (IT) and communication, transportation and warehousing, entertainment and recreation, and personal services. For the purposes of this study, attention is directed to a representative subset of these sectors in which 3D printing adoption has been most pronounced.

Statement of the Problem

This study focuses on identifying the adoption and scalability of 3D printing technology in modern-day industries across the manufacturing and service sectors. Although prior reviews have examined individual application domains in isolation, comparatively few have synthesized evidence across both manufacturing and service sectors while explicitly contrasting these advances against traditional subtractive manufacturing (Attaran, 2017; Gibson et al., 2021). To gain a concise understanding of the extent of 3D printing in the manufacturing and service sectors, the following research questions were proposed.

Research Questions

1. RQ1: What are the historical evolutions of 3D printing?
2. RQ2: What are the technological advancements of 3D printing in the manufacturing and service sectors?
3. RQ3: How does the advancement of 3D printing in the manufacturing and service sectors compare to traditional manufacturing?

2. Methodology

This study is based on a literature search conducted using available online databases, search engines (Google Scholar and Zotero), and the university library (Minnesota State University, Mankato). The review was guided by the PRISMA framework (Page et al., 2021), which provides a transparent and replicable approach to identifying, screening, and synthesizing relevant scholarly evidence. Searches were performed across Scopus, ScienceDirect, PubMed, and ProQuest using Boolean combinations of terms including "3D printing," "additive manufacturing," "rapid prototyping," "manufacturing sector," and "service sector." Inclusion criteria comprised peer-reviewed articles, conference proceedings, and authoritative industry reports published primarily within the last two decades, with seminal earlier works retained for historical context. Records were excluded if they lacked data on either of the two sectors, contained insufficient methodological detail, or did not include comparative information relevant to the research questions. Figure 1 below is a PRISMA flow diagram of how the articles were selected and narrowed down.

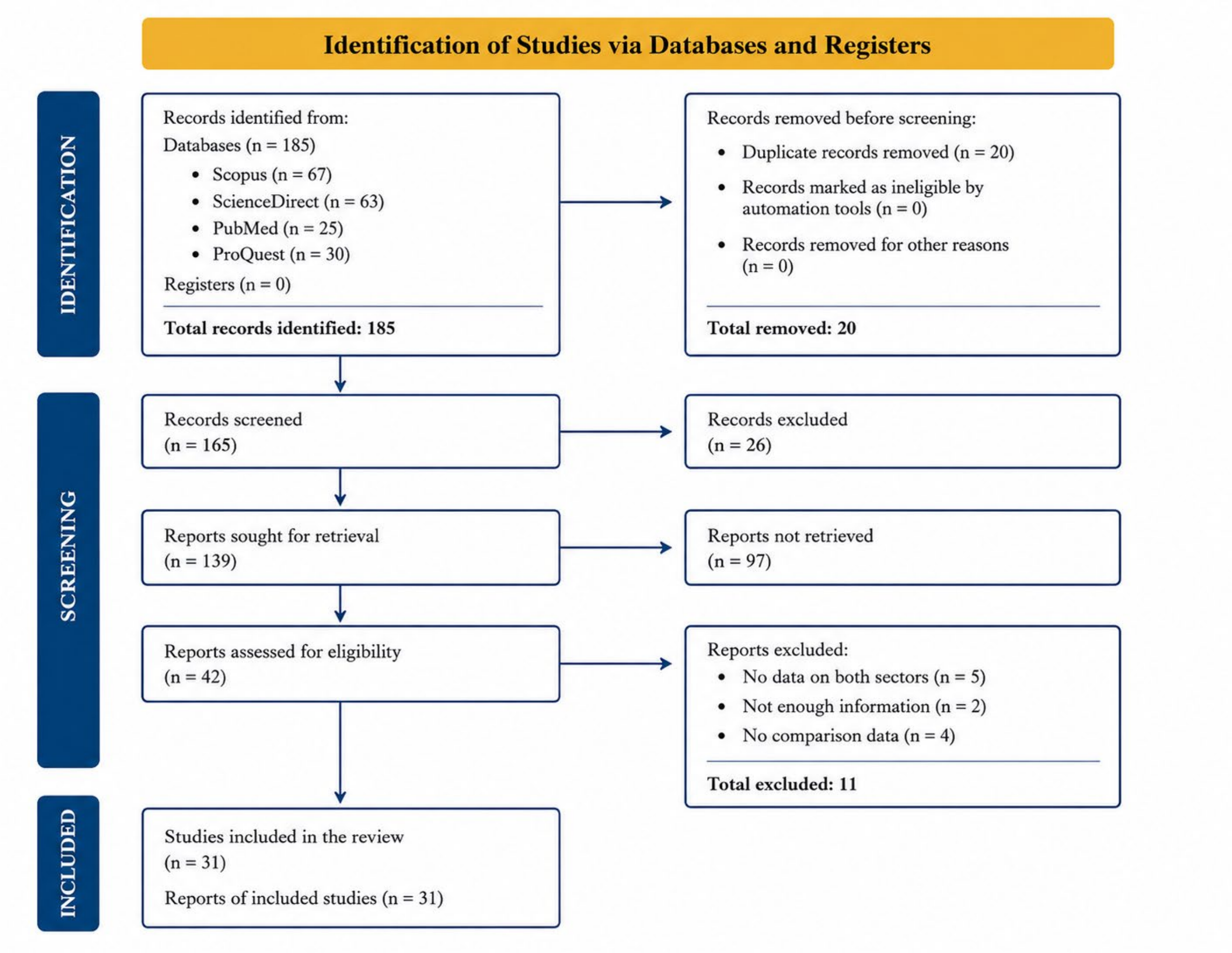

Figure 1. PRISMA 2020 flow diagram for study identification, screening, and inclusion (adapted from Page et al., 2021).

3. Findings

Findings are presented in response to the three research questions and are organized into three subsections that address (a) the historical evolution of 3D printing, (b) technological advancements in the manufacturing and service sectors, and (c) a comparative perspective against traditional manufacturing.

3.1 Evolution of 3D Printing

In response to RQ1, 3D printing is historically best understood as a series of overlapping technological waves that have enabled successive innovations. Since the 1980s, the field has undergone significant technological advances, largely defined by competing polymer-hardening approaches (Savini & Savini, 2015; Horvath, 2014).

Since the 1990s, 3D printing has undergone significant technological advances. Most of these advancements were driven by the material extrusion process, which Scott Crump developed and patented in 1989. The method marked a major departure from traditional manufacturing and set the stage for the commercialization of 3D printing. The implementation of 3D printing in the aerospace and automotive sectors revolutionized how components were designed, with a focus on reducing weight while maintaining and improving strength (*The History of 3D Printing*, 2025).

With the invention of stereolithography by Charles Hull—a process in which liquid polymers harden under ultraviolet light—a method and apparatus for making solid objects by depositing layer upon layer of this material were patented (Savini & Savini, 2015). 3D printing has since moved from producing a 5 cm-tall cup over the course of months to fabricating sophisticated prototypes such as cervical spine implants and 3D-printed robot skin equipped with integrated sensors.

Towards the end of the 1980s, Laminated Object Manufacturing (LOM) technology was developed. Next, Selective Laser Sintering (SLS) was invented at the University of Texas; the process melted powder particles with a laser beam and was patented by C.R. Deckard in 1989. In the early 1990s, the Massachusetts Institute of Technology developed 3D printing technologies inspired by Canon Co.'s ink-jet technology, originally developed in 1979. C.S. Crump developed Fused Deposition Modelling (FDM) technology in the 1980s, based on the layer-by-layer deposition of thermoplastic material using a three-axis robot. He patented the method and apparatus in 1992 and founded Stratasys Inc. FDM subsequently became the fabrication process on which most desktop printers rely (Savini & Savini, 2015). 3D printers were expensive machines, typically used in industry for prototyping, in the early 2000s. In 2005, Adrian Bowyer, a senior lecturer in mechanical engineering at the University of Bath, published the designs for the parts of his 3D printer on the Internet and encouraged others to improve them and post their improved versions. He called the open-source effort the RepRap (Replicating Rapid Prototyping) project (Horvath, 2014). In 2008, Bowyer released Darwin, a self-replicating printer. In 2006, the first SLS machine became commercially viable, which opened the door to on-demand manufacturing of industrial parts. MakerBot subsequently provided open-source DIY kits for makers to build their own 3D printers and products. At this point, the barriers to entry for designers and inventors were falling every day (Goldberg, 2014).

Fast forward to today, 3D printing has evolved from rapid prototyping to industrial manufacturing, driven by advancements in Multi Jet Fusion (MJF), Laser Profusion Technology, High-Speed Metal 3D Printing, High-Speed Fused Deposition Modeling (FDM/FFF), bioprinting, and construction 3D printing, to name only a few. 3D printing has become one of the leading emerging technologies of Industry 4.0. Using and implementing additive manufacturing in combination with other technologies is driving an evolution towards intelligent production, where machines, systems, and networks can exchange information and respond to production management systems. 3D printers eliminate the need for expensive tools and fixtures, reducing post-processing, material waste, and human intervention—characteristics that define the industry of the future (H, 2021). Comprehensive accounts of contemporary additive manufacturing processes further document the maturation of metal-based approaches such as Direct Metal Laser Sintering (DMLS) and Electron Beam Melting (EBM), which now support certification-grade production in aerospace and biomedical applications (Frazier, 2014; Murr, 2016; Gibson et al., 2021).

3.2 Technological Advancements in the Manufacturing and Service Sectors

In response to RQ2, the technological advancement of 3D printing has had a significant impact on the manufacturing and service industries over the years. The initial adoption of 3D printing was for prototyping, and it later moved towards end-user part production; the pace and depth of this transition, however, vary across sectors. The most significant progress has been observed in healthcare, aerospace, and manufacturing.

Manufacturing Industries

In the aerospace industry, 3D printing has been used to produce products such as jigs and fixtures, surrogates, mounting brackets, and prototypes ("3D Printing In the Aerospace Industry," 2019). Boretti (2024) describes the enhancement of aerospace through design freedom, lightweight structures, rapid prototyping and iteration, supply-chain optimization, customization and personalization, maintenance, repair, and overhaul (MRO), material innovation, complex single-component design, integration of different structures, and ultimately the performance of the system and the component, as well as cost reduction for research and development of novel solutions. This enhancement has led to the production of complex engine components such as turbine blades, combustion liners, and engine brackets (Boretti, 2024). NASA astronauts also use 3D printers aboard the International Space Station (ISS) to manufacture tools and spare parts on demand, thereby reducing dependency on Earth-based resupply missions and providing a practical solution for space maintenance ("3D Printing in Aerospace Industry," n.d.). Collectively, these developments indicate that the trajectory of 3D printing in the aerospace sector has shifted from ancillary toolmaking to critical flight hardware, with major implications for quality assurance (Murr, 2016; Salmi, 2021). Figure 2 below presents representative examples of 3D-printed aerospace components.

Figure 2. Representative 3D-printed aerospace components: (a) copper chromite custom heatsinks; (b) Hx ring; (c) Glidcop reinforced copper combustion chamber; (d) Scalmalloy satellite bracket. Images courtesy of 3D Systems. Adapted from Boretti (2024).

In the automotive industry, the growth of 3D printing has been driven by the considerable increase in the demand for reduced vehicle weight, lower production costs, and shorter development times, leading to a more attractive shift in the initial phase of low-volume electric vehicle production (*The Worldwide Automotive 3D Printing Industry Is Projected to Grow to $7.9 Billion by 2027 - ProQuest*, n.d.). Xue (2025) reports that Honda's 3D-printed crankshaft achieves a 50% weight reduction, and that Italdesign has utilized 3D printing to produce seats for the Climb-E concept car—observations that point to a common trend toward light-weighting that mirrors aerospace priorities. Abdallah (2021) carried out qualitative research on the importance of 3D printing in the vehicle production process. The results indicated that 3D printing reduces the per-unit cost of each car manufactured by the auto manufacturer and increases the net revenue and profitability of the overall car industry market (*Advanced Manufacturing Student Conference (AMSC)*, 2021). Table 1 below presents data collected from various automobile companies.

Table 1. Data collection from different companies showing the influence of 3D printing on the automotive sector (*Advanced Manufacturing Student Conference (AMSC)*, 2021).

Element of 3D Researched / Company	**Volkswagen**	**Toyota**	**Ford**	**Kia**	**Honda**	**Mercedes**
Facilitate customization of car parts	97%	98%	99%	94%	96%	98%
Cost of manufacturing savings	97%	96%	95%	99%	99%	98%
Allowance for the creation of complex parts	99%	99%	99%	99%	99%	99%
Revenues and profitability from using this technology	99%	99%	99%	99%	99%	99%
Enhance the manufacturing cost/unit	97%	98%	96%	98%	99%	99%
Average	97.8%	98%	97.6%	97.8%	97.5%	98.6%

Due to social distancing during COVID-19, the demand for personalized 3D food printing services increased. Some countries use 3D food printers to produce combat food, space food, and food for the elderly. Companies such as

FoodInk launched the first 3D pop-up store to serve meals from 3D food printers; Blue Rhapsody, a spinoff, introduced customized pasta made based on customer preferences; and in 2017, BeeHex developed a 3D printer called "Chef 3D" that can make a pizza in six minutes. Food manufacturing using 3D printers is advantageous in precisely creating and controlling the desired shape, color, scent, texture, and nutrients, from small and personalized orders to food industry–scale manufacturing processes (Lee, 2021). Waseem et al. (2024) discuss several physics-related challenges, including the quality of materials used in the printers, the ability to precisely control the temperature and heat-transfer management systems to ensure good texture and taste of the food, and material selection and formulation.

Dating back to the 1960s, the pharmaceutical industry experienced limited manufacturing advancements, but in recent years, 3D printing has revolutionized the industry, creating numerous opportunities. 3D printing has been instrumental in various drug development phases, including early-phase screening, testing, manufacturing, and dispensing. Figure 3 presents a comparison chart of the production cost of an object manufactured using injection molding, stereolithography, fused deposition modelling, and selective laser sintering (Awad et al., 2018). 3D printing has now been applied in the personalization of drugs, the production of complex drug delivery systems, and manufacturing techniques. Fused deposition modeling (FDM), semisolid extrusion (SSE), stereolithography (SLA), and material jetting (MJ) have been the main additive manufacturing approaches in pharmaceutical sciences. Spritam (Levetiracetam), marketed by Aprecia Pharmaceuticals for epilepsy in 2015, was approved by the U.S. Food and Drug Administration as the first 3D-printed drug. To date, oral formulation has been the most extensively investigated product in this area, leading to the production of solid oral dosages with a demonstrated ability to encapsulate multiple drugs at varying dosages, to print shapes with complex internal structures, and to regulate the delivery rate of each discrete component. These advances have led to the proposition of a polypill—a tablet that contains customized doses of different medicines and can be produced to meet each patient's needs in response to physical attributes, metabolic activity, and severity of disease. Additionally, to commercially scale 3D-printed personalized tablets, existing pharmaceutical companies will have to move from mass production to individualized production, which is likely to lead to an increase in expenditure (Liang et al., 2019). The future of 3D printing in the pharmaceutical industry leans towards integrating neurological treatments with 3D bioprinting. Technologies such as patient-specific neural implants and biosensors for real-time feedback promise more accurate, adaptive, and treatment-oriented interventions while focusing on each patient's needs (Saleh-Bey-Kinj et al., 2025). Complementary work on bioprinting further situates these advances within a broader trajectory toward functional tissue and organ fabrication (Murphy & Atala, 2014; Vyavahare et al., 2020).

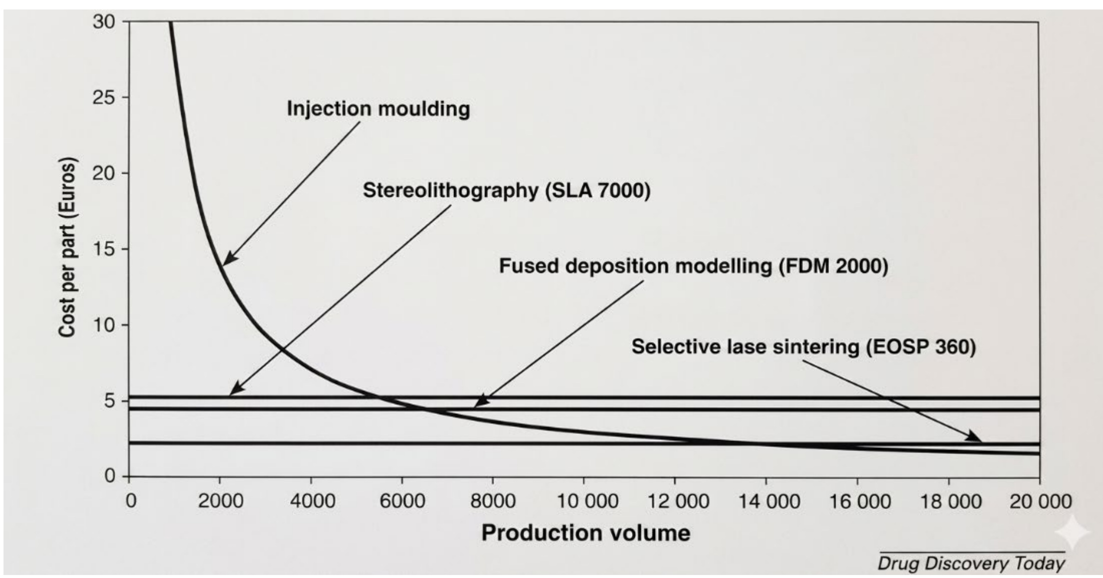

Figure 3. Production cost chart of an object when manufactured using injection molding, stereolithography, fused deposition modelling, and selective laser sintering (Awad et al., 2018).

Service Industries

In 2020, the Veterans Health Administration (VHA) collaborated with 3D Systems to train VHA staff in point-of-care 3D printing and to improve patient care through its use. As of November 2020, more than thirty VHA medical centers were able to print personalized prosthetics (Coe, 2021). 3D printing has been used in healthcare for the creation of customized prosthetics, implants, and anatomical models; tissue and organ fabrication; the manufacturing of specialized surgical instruments; and the production of medical devices (Dodziuk, 2016). As 3D printing continues to be adopted in healthcare, more items will be manufactured at the point of care, potentially expediting therapy and reducing patient visits (Javaid et al., 2022). Figure 4 below shows examples of patient-specific prosthetic parts.

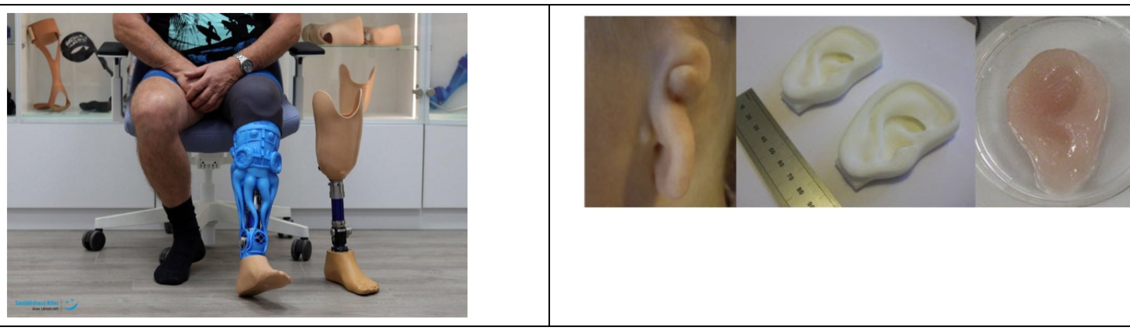

Figure 4. (a) Customized bath prosthetic leg used for showering and swimming in the ocean (Saunders, 2021); (b) Prosthetic ear device printed from medical-grade silicone with the correct color and texture to match a patient with microtia (Thomas & Singh, 2020).

The integration of 3D printing into education has been somewhat limited; nonetheless, applications have been documented in subjects such as mathematics, biology, chemistry, art education, graphic design, engineering, and early childhood education (Üçgül & Altıok, 2023). Üçgül and Altıok conducted a study by introducing an elective course for senior students entitled “3D Modeling and Printing” and found that most of the students were satisfied with the course and reported that it met their expectations. 3D printing has also enhanced active learning by bringing digital design projects to life and encouraging participation through hands-on experience. Pupils with mild disabilities have benefited from 3D-printing models that help address their learning challenges (Dosedla et al., 2023). Figure 5 shows examples of 3D printing projects completed with students.

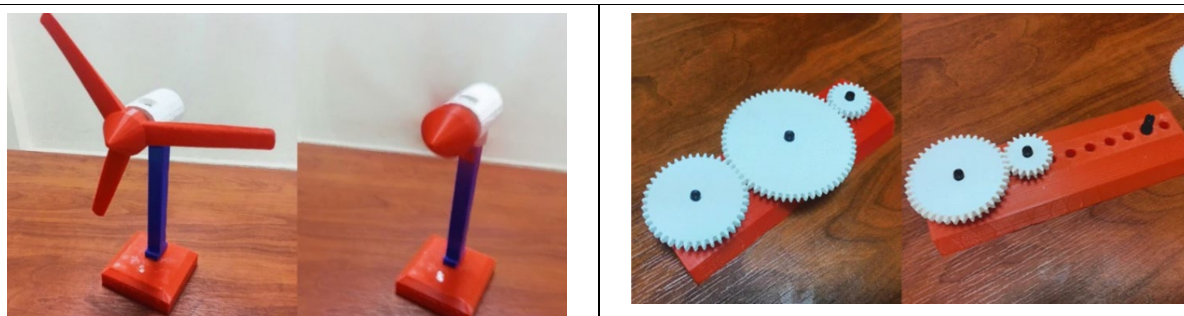

Figure 5. (a) Wind turbine; (b) Cogwheel assembly—student-produced classroom artifacts (Dosedla et al., 2023).

The hospitality and tourism industry has seen the implementation of the world’s first 3D-printed hotel room at the Lewis Grand Hotel in the Philippines. It was constructed entirely from a blend of sand and volcanic ash and required over 100 hours to 3D-print the 130-square-metre extension (Javaid et al., 2022). In Mexico, hotels are being built within six to nine months with a return on investment in as little as two years, surpassing the timelines of traditional hotels. Tourists can now receive or create on-demand souvenirs such as replicas of landmarks or artifacts. In Australia, a life-sized replica of a dinosaur was produced based on the significant discovery of *Rhoetosaurus* fossils near Roma nearly a century ago—the oldest dinosaur skeleton ever unearthed in Australia—with the aim of inspiring continued exploration of fossils and the history of millions of years ago (S, 2023). Figure 6 shows examples of hospitality infrastructure produced through additive construction.

Figure 6. (a) Grand Hotel in the Philippines; (b) El Cosmico hotel project (S, 2023).

3D printing has driven significant development in the entertainment industry by enabling the rapid, cost-effective creation of props and armor for movies, the customization of realistic special effects and body prosthetics for actors, and the design of intricate miniature and large-scale set elements that are often cheaper to produce than through traditional methods. Some props from major motion pictures are shown in Figure 7 below.

Figure 7. (a) Hela's headpiece from *Thor: Ragnarok*; (b) Full-scale dinosaur replica for *Jurassic World: Fallen Kingdom*; (c) Thor's iconic hammer; (d) Queen Ramonda's extraordinary costume from *Black Panther* (P, 2023).

3.3 Technological Advancements in 3D Printing in the Manufacturing and Service Sectors Compared to Traditional Manufacturing

In response to RQ3, 3D printing has evolved into a vital production tool within the manufacturing sector, supported by significant advances in materials and scalability. Aerospace and automotive companies using Direct Metal Laser Sintering (DMLS) now produce structural components—such as turbine blades, engine brackets, and spare parts—that outperform comparable components manufactured by traditional methods. A major trend in manufacturing has been the application of 3D printing to eliminate assembly steps, reduce part count, and enable geometric designs that are impossible to achieve with subtractive methods (Frazier, 2014; Ngo et al., 2018).

In the service sector, 3D printing is more strongly associated with customization, speed, and rapid access. Healthcare has experienced the most pronounced transformation through 3D printing, including the customization of prosthetics, dental aligners, and hearing aids, all produced to individual specifications. Hospitality has also benefited from large-scale concrete printing of buildings and on-demand printing of customized souvenirs in micro-batch production. The education sector has integrated 3D printing into its curriculum to facilitate learning. With many professional platforms now combining multiple manufacturing capabilities, customers have access to extensive manufacturing systems, transforming how they view the production and procurement of parts (Plica, 2025).

The manufacturing sector mainly prioritizes throughput, material properties, and cost per part as its benchmarks. It requires industrial reliability, repeatability, and certification, particularly in aerospace and medical devices. The service sector, on the other hand, focuses on customization, processing time, and accessibility. These differing priorities also imply distinct quality-management requirements, with the manufacturing sector emphasizing process capability and statistical control and the service sector emphasizing user experience and turnaround time (Tofail et al., 2018; Salmi, 2021).

Both sectors share similar challenges, such as quality assurance, owing to variations in surface finish, accuracy, and tolerance between prints. Operational costs are driven by the high cost of materials, which can range from $25 to $45 per kilogram (Attaran, 2017), as well as by equipment and maintenance expenses, making it difficult to compete with traditional manufacturing on a purely cost basis.

4. Discussion and Conclusion

This review set out to address three research questions concerning the historical evolution of 3D printing, its technological advancements in the manufacturing and service sectors, and how those advancements compare to traditional manufacturing. With respect to RQ1, the evidence indicates that 3D printing has matured through a series of overlapping technological waves—from early stereolithography and selective laser sintering to contemporary multi-material and metal-based systems—establishing the foundation for its current role in Industry 4.0 (Savini & Savini, 2015; Gibson et al., 2021). With respect to RQ2, the technology has matured massively in the manufacturing sector into a more scalable and reliable technology. Sectors such as aerospace, pharmaceuticals, and electronics now rely heavily on this technology due to its reduced material waste, rapid prototyping, and ability to create complex geometries on demand. Healthcare, as a service sector, has increasingly adopted 3D printing technology. According to a report published by Allied Market Research, the global 3D Printing in Healthcare Market generated $1.03 billion in 2020 and is estimated to reach $5.84 billion by 2030, with a CAGR of 20.1% from 2021 to 2030 ("Global 3D Printing in Healthcare Market to Reach $5.84 Billion by 2030," 2021). With respect to RQ3, the evidence indicates that 3D printing complements rather than displaces traditional manufacturing: while subtractive and formative methods retain advantages in high-volume, cost-sensitive production, additive techniques offer unmatched capability for geometric complexity, customization, and on-demand fabrication (Attaran, 2017; Ngo et al., 2018). 3D printing is expected to experience significant growth in the coming years as the technology continues to develop.

Experts do not expect 3D printing to replace traditional manufacturing processes or render them obsolete. Instead, it is best viewed as a complementary technology whose unique capabilities can be exploited alongside conventional methods (Attaran, 2017). Future research should examine the standardization of materials and processes, the development of harmonized quality-assurance frameworks across regulatory environments, and the integration of additive manufacturing with digital-twin and Industry 4.0 platforms to enable closed-loop quality control (Tofail et al., 2018; Salmi, 2021).

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