

Applications of 3D Printing in the Automobile Industry: Technologies, Impacts, and Future Perspectives

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Abstract. 3D Printing, a technology that emerged in 1981, is a process of creating objects by adding layers of material. This technological advancement facilitates the production of intricate forms or configurations that are typically challenging or unattainable through traditional manufacturing techniques. There are multiple production methods available in the field of 3D Printing, each possessing distinct advantages and disadvantages. The automobile Industry has become a significant economic and industrial force over decades, using considerable materials, including iron, aluminum, and steel, to produce billions of vehicles. This article will delve into an in-depth exploration of various technological attributes, comparing their advantages and shortcomings. The central focus of this study revolves around understanding the application of three-dimensional (3D) printing in the automotive sector, pinpointing its existing limitations, and projecting its potential trajectory in the industry's future landscape. With the rapid development of materials science, new materials and production methods are widely used. 3D Printing is the rising star of these methods, and it has been applied extensively in the automobile industry to enhance prototyping, customization, and lightweight.

Keywords: 3D Printing; Automobile; Prototyping; Customization.

1. Introduction

3D Printing represents the process of creating physical objects from a three-dimensional digital model [1]. It is also known as additive manufacturing because this technology involves adding layers of material to each other according to the shape and size of the desired object, compared to traditional machining techniques that rely on removing material by cutting or drilling [2]. 3D Printing has a long history. The initial 3D printers were established in the 1980s [2]. In that model, a computer traces a pattern submerged in a liquid polymer. The laser causes the traced pattern to harden into a layer. Since then, the additive manufacturing industry has made tremendous progress. Presently, there exists a wide array of 3D printing techniques, and have already used in varies industries and has already significantly impacted those industries. Examples of 3D Printing include Fabrication of Heart Valve Scaffold, Drug Delivery, and Production of Patterns for Investment Casting [3]. A detailed analysis of the features of the different technologies and a comparison of their benefits and limitations will appear in this article. The primary aim of this research is to examine the utilization of three-dimensional (3D) printing technology within the automotive industry, identify the current weaknesses of this technology, and forecast the industry's future development.

2. The Fundamentals of Three-Dimensional Printing Technology

The 3D printing technology initializes by putting the 3D digital model made in CAD system into the 3D printing machine [1]. It could also be possible to obtain input data utilizing 3D scanners. Subsequently, the digital representation is transformed into a sequence of commands intended for the 3D printer, instructing it on the specific movements and precise locations for material deposition. The material used for 3D Printing can be plastic, metal, ceramic, resin, or even biological tissue, depending on the type and purpose of the object. The material is usually fed into the printer in the form of filament, powder, liquid, or pellets [4-7]. The following process varies when different technologies are applied. ASTM cataloged 3D printing technologies into seven groups, according to

ASTM Standard F2792 [8]. The three categories that occur most frequently are discussed in the following sections.

2.1. Binder jetting

The manufacturing process known as binder jetting has the characteristics of both rapid prototyping and three-dimensional printing in terms of its capabilities. Although there have been some adjustments made, it is founded on the fundamentals of the inkjet printing technology. When using this approach, a liquid binding agent is utilized in order to successfully link together individual particles of powder material [3]. Spraying the chemical binder that was previously dispersed on top of the powder causes the formation of the layer [9]. Binder jetting is a process that can be used to manufacture high volumes of a variety of goods, including casting patterns, sintered raw materials, and sand-based objects.

2.2. Directed energy deposition

Directed energy deposition (DED) is a sophisticated additive manufacturing technique utilized for the purpose of repairing or augmenting pre-existing components [10]. The manipulation of the grain structure and quality of the object is achievable through its control. The process uses a movable nozzle to extrude material, which can be ceramic, polymer, or metal-based. Some examples of this technology include laser deposition and laser-engineered net shaping (LENS) [10]. Laser deposition can make or repair large parts. It has many applications in the field of equipment, conveyance, aviation, and energy industries. The reasons for these applications are its ability to grow efficiently and a wide range of functionalities within a unified framework. Furthermore, laser LENS uses heat to melt and cast parts [11].

2.3. Fused deposition modeling

The 3D printing technology based on material extrusion has been widely adopted and is cost-effective [12]. This technology prints the object layer by layer using one of the several techniques available for 3D Printing. One prevalent approach in the 3D printing industry is Fused Deposition Modeling (FDM), which entails the application of heat to a plastic filament, followed by its extrusion through a nozzle onto a build platform. The nozzle exhibits movement along the X and Y axes, while the platform demonstrates movement along the Z axis. This coordinated motion facilitates the production of a three-dimensional object, commencing from its lowermost section [4-7].

3. Overview of the Automobile Industry

The automotive industry holds significant importance and exerts substantial influence within the global economy, significantly impacting society, culture, environment, and technology. The automotive industry encompasses a diverse array of corporations and entities engaged in multiple facets of motor vehicle design, development, production, promotion, sales, maintenance, and customization. The industry mostly consists of passenger automobiles, light trucks, and commercial vehicles. The industry also manufactures a diverse range of components and parts for automobiles, including engines, chassis, tires, batteries, and fuel systems.

The automotive sector possesses a lengthy and illustrious chronicle that can be traced back to the latter part of the 19th century, during which Karl Benz pioneered the initial automobiles in Europe. Subsequent to that period, the industry has experienced numerous transformations and developments, primarily propelled by technical progress, shifting consumer inclinations, environmental mandates, and competitive forces. The industry has faced many challenges and opportunities, such as economic cycles, globalization, market segmentation, and digital transformation. The sector has also shaped and been shaped by the social and political contexts of different regions and countries.

3.1. Current Trends and Challenges in the Automobile Industry

The automobile industry faces several trends and challenges that are influenced by or related to 3D printing, such as sustainability and digitization. The automobile industry is pressured to reduce its environmental impact by lowering emissions, improving fuel efficiency, and using renewable or recyclable materials. 3D Printing can contribute to sustainability by reducing material waste, optimizing weight and aerodynamics, and using bioplastics or biocomposites. For example, Liux produces electric vehicles with 3D-printed bioplastic parts [13-14]. The automobile industry is also undergoing a digital transformation involving data, connectivity, automation, and artificial intelligence integration. 3D Printing can facilitate digitization by enabling data-driven design and manufacturing, enhancing connectivity and communication between devices and systems, automating production processes, and incorporating intelligent features and sensors. For example, Tesla uses 3D printing to create intelligent components with embedded electronics [13-14].

Additionally, the automobile industry faces increasing competition from new entrants and disruptive innovations that challenge established players and business models. 3D Printing can create competitive advantages by enabling faster innovation and development, reducing production costs and time, increasing customer satisfaction and loyalty, and creating new markets and opportunities. For example, NIO is a Chinese startup that uses 3D printing to design premium electric vehicles with personalized features [13-14].

4. The Utilization of Three-Dimensional Printing in the Automotive Industry

4.1. Prototyping

The utilization of 3D printing for prototyping purposes is widely adopted and firmly established in the automotive sector. Prototyping is the process of creating physical models or mock-ups of a product or a component before mass production. Prototyping is essential for automotive design and development, as it allows engineers and designers to test and validate their ideas, improve functionality and performance, and detect and correct errors. 3D Printing can facilitate rapid prototyping for automotive design and development, producing prototypes faster, cheaper, and more accurately than traditional manufacturing methods. 3D Printing can enable more iterations, modifications, and more complex and detailed geometries.

Many car manufacturers use 3D printing to create prototypes for testing and validation. For example, Ford uses Formlabs 3D printers to prototype various parts of their cars, such as lettering, steering wheel trim, console detailing, and safety components. Ford claims that 3D Printing can reduce prototyping time from weeks to hours, saving up to \$493,000 per month in production costs. Another example is BMW, which uses 3D Printing to prototype metal parts for its engines, transmissions, and chassis [13]. BMW says using 3D Printing can improve their parts' quality, performance, and durability [13].

Using 3D Printing for prototyping has many advantages, such as speed, cost-efficiency, flexibility, and accuracy. However, it also poses challenges, such as scalability, reliability, standardization, and regulation. For instance, while 3D Printing can produce prototypes quickly and cheaply for small batches or individual parts, it may not be able to meet the high-volume and high-quality demands of mass production [15]. Moreover, while 3D Printing can produce accurate and consistent prototypes for testing purposes, it may not be able to guarantee the same level of quality and safety for final products [15]. Therefore, car manufacturers must carefully evaluate the suitability and feasibility of using 3D Printing for prototyping depending on their specific needs and goals.

4.2. Customization

Customization is another essential and emerging application of 3D printing in the automotive sector. Customization is tailoring a product or a service to meet a customer's or market segment's specific needs or preferences. Customization can enhance customer satisfaction, loyalty,

differentiation, and competitiveness. 3D Printing can enable customization and personalization for automotive products and services, as it can produce unique or customized cars or parts on demand, without requiring expensive tooling or inventory.

Some car manufacturers use 3D printing to create customized or personalized cars or parts. For example, Mini uses 3D printing to create customized customer accessories, such as side scuttles, dashboard trim, door sills, and LED door projectors. Mini says that 3D Printing can offer more than 100 million possible combinations for customers to customize their cars. Another example is Porsche, which uses 3D Printing to create spare parts for its classic cars, such as clutch release levers, crankshafts, and cooling ducts. Porsche says that using 3D Printing can ensure the availability and quality of their spare parts and reduce storage and transportation costs.

Using 3D Printing for customization has many benefits, such as customer satisfaction, differentiation, and innovation. However, it also has some drawbacks, such as complexity, cost, and regulation. For instance, while 3D Printing can produce customized or personalized cars or parts according to customer needs or preferences, it may also increase the complexity and variability of the production process and the product quality. Moreover, while 3D Printing can produce unique or exclusive cars or parts for premium customers or markets, it may also incur higher production costs and lower economies of scale than mass production. Furthermore, while 3D Printing can produce novel or innovative cars or parts for new customers or markets, it may also face legal or ethical issues regarding intellectual property rights, safety standards, or environmental regulations. Therefore, car manufacturers need to carefully assess the opportunities and challenges of using 3D Printing for customization depending on their specific needs and goals [16-17].

4.3. Lightweighting

The application of 3D printing in the automotive sector includes the significant and novel practice of lightweighting. Lightweighting is the process of reducing the weight of a car or a part by using less or lighter materials without compromising strength or performance. Lightweighting can improve the efficiency, fuel economy, emissions, and safety of cars. 3D Printing can reduce the weight and improve the efficiency of cars or parts, as it can produce hollow or lattice structures, use less material, and optimize designs for specific functions or conditions.

Some car manufacturers use 3D printing to create lightweight or optimized cars or parts. For example, Bugatti uses 3D printing to create a titanium brake caliper that weighs only 2.9 kg, compared to 4.9 kilograms of conventional aluminum. Bugatti claims that the 3D-printed brake caliper can withstand higher temperatures and pressures, and improve braking performance. Another example is Volkswagen, which uses 3D printing to create a bionic wheel rim that weighs 18% less than a conventional one. Volkswagen says that the 3D-printed wheel rim can reduce rolling resistance, fuel consumption, and CO2 emissions.

Using 3D Printing for lightweighting has many advantages, such as efficiency, sustainability, and performance. However, it also faces some challenges, such as cost, durability, and compatibility. For instance, while 3D Printing can produce lightweight parts using less material, it may also require more expensive materials or processes than traditional manufacturing methods. Moreover, while 3D Printing can produce strong and durable parts using advanced materials or techniques, it may also introduce defects or inconsistencies that affect the quality and reliability of the parts. Furthermore, while 3D Printing can produce optimized parts for specific functions or conditions, it may also create compatibility issues with other parts or systems in the car. Therefore, car manufacturers need to carefully balance the trade-offs and risks of using 3D Printing for lightweighting depending on their specific needs and goals.

5. Benefits and Limitations of 3D Printing in the Automobile Sector

5.1. Benefits of 3D Printing for the Automotive Industry

The utilization of 3D Printing technology in the automotive sector has numerous benefits, encompassing design innovation, customization capabilities, cost reduction potential, and sustainability enhancements. To begin with, it is feasible for 3D printing to generate elaborate and complicated designs that would otherwise be unattainable through conventional manufacturing techniques. This capacity is especially advantageous for generating personalized functional components. For example, 3D Printing can produce parts with organic geometries that reduce weight and improve performance, such as lattice structures or honeycomb patterns [18]. 3D Printing can also combine multiple elements into a single component, simplifying the assembly process and reducing material usage. This technology also enables a high level of personalization and differentiation for automotive products. Customers can choose from various options and features to create their own unique vehicles. For instance, luxury and motorsport vehicles can use 3D printing to produce personalized parts for the vehicle's interior and exterior [18]. 3D Printing can also create spare parts on demand, reducing inventory costs and lead times [19]. In addition, the utilization of 3D Printing technology has the potential to decrease production costs through the elimination of costly tooling, molds, and dies. 3D Printing can also reduce material waste by using only the amount of material needed for each layer. Furthermore, 3D Printing can enable localized production, reducing transportation costs and environmental impact [20]. Finally, 3D Printing can contribute to the sustainability of the automotive industry by reducing emissions, energy consumption, and waste. 3D Printing can create lighter parts that improve fuel efficiency and extend battery life for electric vehicles. 3D Printing can also use recycled or biodegradable materials to create eco-friendly products [20].

5.2. Limitations of 3D Printing for the Automotive Industry

Despite its benefits, 3D Printing also faces some challenges and limitations for the automotive industry. It is clear that 3D Printing still needs to meet the high standards of quality and reliability required by the automotive industry. 3D printed parts may have defects, such as porosity, cracks, or warping, that affect their mechanical properties and performance [21]. 3D printed parts may also have variations in dimensions, surface finish, or color due to different machines, materials, or settings. Therefore, 3D-printed parts need to undergo rigorous testing and inspection to ensure their safety and durability. Also, 3D Printing is still a relatively slow process compared to conventional manufacturing methods. The speed of 3D Printing depends on several factors, such as the size, complexity, and resolution of the part; the type and amount of material; and the technology and parameters of the machine [21]. Therefore, 3D Printing may not be suitable for mass production of large or simple parts that can be made faster and cheaper by other methods. However, 3D Printing can be used for low-volume or high-value production of complex or customized parts. Furthermore, 3D Printing lacks a clear and consistent regulatory framework and standardization for the automotive industry. There are no specific rules or guidelines for the design, production, testing, certification, or maintenance of 3D-printed parts. This creates uncertainty and confusion for both manufacturers and customers regarding the quality, safety, and legality of 3D-printed products. Therefore, there is a need for more collaboration and coordination among stakeholders to establish common standards and best practices for 3D printing in the automotive sector.

It is necessary to note that 3D Printing requires a different set of skills and knowledge than traditional manufacturing methods. Designers must acquire the knowledge and skills necessary to enhance the efficiency and effectiveness of their designs specifically tailored for 3D Printing technology. This entails considering various critical elements, including but not limited to the optimal orientation of the design, the appropriate utilization of support structures, the selection of suitable infill patterns, and other relevant considerations. Operators need to know how to operate and maintain 3D printers, as well as how to handle and store materials. Customers need to learn how to use online

platforms or software to customize their products. Therefore, there is a need for more training and education to develop the competencies and capabilities needed for 3D printing in the automotive industry.

6. Future Perspective

This article delves into the ways in which 3D printing technology is finding its place within the automobile industry. The author discusses various aspects, including the technologies themselves, their impacts, and the potential pathways they might take in the future. The introduction provides an overview of the basic principles behind 3D Printing, followed by an exploration of the importance and challenges that the automobile industry faces, encompassing topics like sustainability, digitalization, and competition.

Looking forward, there is the prospect of customization and personalization becoming more widespread due to lowered costs. This shift has the potential to significantly alter the automobile market by tailoring products to individual preferences. Furthermore, the potential for quicker prototyping processes is anticipated, enabling manufacturers to refine designs more rapidly and introduce new vehicles to the market more efficiently. In addition, advancements in materials are expected. As 3D printing technology advances, novel materials that work well with the process are being developed. These materials could have specific attributes, such as increased strength, flexibility, or resistance to heat, making them suitable for a wider variety of uses in the automotive domain.

7. Conclusion

3D Printing is an emerging technology that is developing rapidly, and its additive manufacturing method has the property of manufacturing complex shapes. Compared with traditional materials, 3D printing technology is lighter, cheaper, and the manufacturing process is more straightforward. These features allow it to be applied in the automobile industry for prototyping, customization, and lightweighting. Overall, the article provides insights into how 3D printing technology is being utilized in the automobile industry, its benefits, limitations, and the evolving landscape of additive manufacturing within this sector.

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