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ANALYSIS OF 3D-PRINTING TECHNOLOGIES AND THEIR IMPACT ON ADDITIVE MANUFACTURING PROCESSES

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The field of 3D printing technology has made tremendous progress in recent years, radically changing the design and prototyping methods using various 3D printing techniques such as FDM (Fused Deposition Modeling), SLA (Stereo Laser Lithography), SLS (Selective Laser Sintering), SLM (selective laser melting). There are also other methods and technologies such as DMLS (direct laser metal sintering), SHS (selective thermal sintering) and multilayer object modeling (LOM), multi-jet modeling (MJM), electron beam melting (EBM), color inkjet printing (CJP), digital light processing (DLP), etc. Thanks to these technologies, there are opportunities to create complex prototypes for various fields of application. The purpose of this scientific study is to conduct a detailed comparative analysis of these 3D printing technologies by studying the differences between 3D printing methods and types such as FDM, SLA and SLS, including also new printing methods such as DMLS and EBM, and studying their features and their application, effectiveness and materials used. It will also look at how new 3D printing technologies such as MJM and CJP are advancing the development of 3D printing, especially in areas such as manufacturing and prototyping, and future trends in 3D printing technology, as well as the applications of these technologies for different industries industry. It is also discussed how these technologies affect additive manufacturing processes. This study sheds light on the understanding of the differences in 3D printer technology and the active use and improvement of these technologies and the opening of new opportunities for the creation of new technologies. Understanding the differences in 3D printing technology will make it possible to choose one or another optimal technology for creating models. For example, the use of 3D printing technology to create 3D models with raised Braille dot may be the optimal selection of a technology such as SLA, FDM, DLP, while for other 3D models another 3D technology may be optimal. This article provides an opportunity to continue scientific research and conduct experiments on the use of different 3D printing technologies to reproduce different models, in order to sort out which 3D printing technology will be optimal for certain 3D models, and this will reduce time and costs production.

Keywords: *3D printing technology, SLA, FDM, DLP, LOM, MJM, DMLS, EBM, CJP, SLA, SLS, SHS, additive manufacturing.*

Introduction. The field of 3D printing technology has made tremendous progress in recent years, radically changing the design and prototyping methods using various

3D printing techniques such as FDM (Fused Deposition Modeling), SLA (Stereo Laser Lithography), SLS (Selective Laser Sintering), SLM (selective laser melting). There are also other methods and technologies such as DMLS (direct laser metal sintering), SHS (selective thermal sintering) and multilayer object modeling (LOM), multi-jet modeling (MJM), electron beam melting (EBM), color inkjet printing (CJP), digital light processing (DLP), etc. Thanks to these technologies, there are opportunities to create complex prototypes for various fields of application. The purpose of this scientific study is to conduct a detailed comparative analysis of these 3D printing technologies by studying the differences between 3D printing methods and types such as FDM, SLA and SLS, including also new printing methods such as DMLS and EBM, and studying their features and their application, effectiveness and materials used. It will also look at how new 3D printing technologies such as MJM and CJP are contributing to the development of 3D printing, especially in areas such as manufacturing and prototyping, and future trends in 3D printing technology, as well as the application of this technology for different industries industry.

Formulation of the problem. 3D printing is now becoming a part of various areas of production and industry more than ever, and its use is growing every year. 3D printing has different types of printing technologies, and researchers are discovering new printing methods and there are more and more of them. The use of certain types of 3D printing may be suitable for one area of production, while for, for example, medicine it will be necessary to use a different 3D printing method. In addition, each printing method in one way or another affects the additive manufacturing processes and, ultimately, the quality of creating a three-dimensional model, part or prototype. To understand how the choice of 3D printing method can affect the additive manufacturing processes and the final result of the model, it is necessary to conduct an analytical study, and how the choice of a particular 3D printing will affect the additive manufacturing processes and the quality of the finished model.

Analysis of recent research and publications. Recent research in the field of additive manufacturing is described in various scientific journals, such as “3D Printing and Additive Manufacturing: Principles and Applications”, where Prof. Dr. Jeng-Ywan Jeng talks about the latest achievements, research and applications in various industries such as medicine, etc. Also in the scientific journal “Performance evaluation of 3D printing technologies: a review, recent advances, current challenges, and future directions”, researchers Utkarsh Chadha and others studied the challenges 3D printing faces in production and material limitations. Moreover, Lawrence Berkeley Lab researchers have studied 3D printing and proven that inkjet 3D printers waste more material than Fused Deposition Modeling (FDM) printers and have a higher overall life cycle impact, as described in the company’s blog Autodesk. The researchers are also from Harvard University and are working on methods that make 3D printing truly three-dimensional, going beyond the traditional layer-by-layer approach. Back at MIT, researchers are exploring new 3D printing technologies, and Associate Professor John Hart has developed a special selective laser melting system, while Professor Emanuel Sachs is known for inventing binder jet printing, a process in which a liquid binder is selectively added to a powder. And the rest of the MIT team is focused on discovering new materials for 3D printing. Although scientists are making a great contribution, based on this, we see that it is necessary to continue research in the field of 3D printing, since there is not enough information and analyzes carried out for the development of 3D printing.

Aim. To conduct an analytical study of 3D printing methods and demonstrate how the selection of 3D printing method affects the additive manufacturing processes and the quality of creating three-dimensional models. A table will also be built comparing 3D printing based on the given mathematical calculation, considering the parameters, and for which areas of production and industry it is the most suitable.

Presentation of the main research material

In the field of 3D printing technology, it is of great importance to understand the unique diversity and capabilities of each type as they revolutionize manufacturing in various industries. Among the main types, Fused Deposition Modeling (FDM) stands out for its accessibility and compatibility with low-cost materials such as ABS and PLA, making it particularly attractive for entry-level applications and educational purposes [1]. This technique, along with stereolithography (SLA) and selective laser sintering (SLS), are fundamental methods for plastic part manufacturing [2], [3], each with unique advantages in material selection, surface finish, durability and cost efficiency. The ability of FDM to create low-cost and fast durable parts, the accuracy of SLA in creating smooth finished parts, and the ability of SLS to create complex geometries without the need for support structures represent a broad spectrum of available 3D printing technologies. This spectrum is further expanding as the industry continues to explore and adopt a growing list of materials, reinforcing 3D printing's role as a versatile additive manufacturing technology capable of supporting a wide range of engineering and design applications [4], [1].

To understand the applicability and versatility of known 3D printing technologies such as FDM, it is necessary to examine the materials used in these technologies. For example, in FDM (Fused Deposition Modeling), PLA (polylactic acid) and ABS (acrylonitrile butadiene styrene) are mostly used due to their ease of use and wide availability, making them ideal for hobbyist applications [1]. This is in contrast to more industrial 3D printing techniques such as SLS (selective laser sintering), which require materials with specific properties such as durability and heat resistance. For example, nylon 12 (PA12 or PA2200) is often used in SLS due to its strength and flexibility, meeting industrial needs where component flexibility is crucial [1][5]. In addition, SLS technology is suitable for the production of components that meet specific requirements, as it can process a wider range of materials, including specialty materials such as PA 3200 GF, a glass-filled polyamide to increase stiffness, and flame-retardant materials such as PA 2241 FR [5]. These differences in material requirements highlight the need for more thorough assessments when selecting 3D printing technology for a project where material selection plays an important role in achieving the desired outcome [5].

Relying on materials such as PLA and ABS in FDM 3D printing, it is important to understand the broader perspective and principles of 3D printing technology. These include freedom of customization and design, which facilitates the production of customized solutions such as hearing aids, especially in areas such as healthcare [1]. This principle is not limited to healthcare. In the aerospace and automotive industries, 3D printing can optimize topology, achieve high strength-to-weight ratios, and combine multiple parts into one complex component [1]. This is indicative of a broader trend where technological flexibility is allowing industry to push production boundaries while achieving overarching goals such as cost efficiency and speed. In addition, the main and widespread method of three-dimensional printing in additive manufacturing is the use of solid heat-resistant types of plastics for the production of inexpensive injection molds using a 3D printer instead of traditional methods of processing metal or wood [1]. This desire for innovative manufacturing approaches highlights a fundamental shift in product development and highlights the importance of matching the benefits and limitations of each 3D printing technology with the most critical application requirements [2].

Table 1

Types of 3D-printing technologies and their description

TECHNOLOGY OF 3D-PRINTING	DESCRIPTION
FDM	Fused deposition modeling involves heating and extruding a thermoplastic filament.
SLA	Stereolithography uses a laser to cure liquid resin into hardened plastic and a laser to cure liquid resin into hardened plastic.
SLS	Selective laser sintering fuses powder particles using a laser.
SLM	Selective laser melting completely melts metal powders to form solid parts.
DMLS	Direct metal laser sintering is similar to SLM, but usually refers to a different laser sintering process.
SHS	In selective thermal sintering, a thermal print head is used to sinter the thermoplastic powder.
LOM	The production of laminated products combines layers of material and cuts them into shape.
MJM	Multi Jet Modeling distributes droplets of UV cured material.
EBM	Electron beam melting uses an electron beam to melt metal powder.
CJP	ColorJet Printing creates full-color concept models by applying a colored binder to a layer of powder.
DLP	Digital Light Processing uses a digital light projector to cure the photopolymer resin.

A comparative analysis of FDM, SLA and SLS 3D printing technologies shows that each offers its own strengths and applications and meets different needs in additive manufacturing FDM has a wide range of applications due to its simple process of melting thermoplastic filaments to form layers. Despite its widespread use, FDM has been criticized for its low resolution and accuracy, especially compared to SLA and SLS, making it an ideal choice for early prototyping and educational purposes [6]. This limits its application to components [7]. SLA technology, on the other hand, shines with its ability to produce parts with the highest resolution and precision, providing crisp details and smooth surface finishes unmatched in plastic 3D printing technology [7].

Table 2

Materials and applications in each type of 3D printing technology

TECHNOLOGY TYPE	MATERIALS	APPLICATIONS
FDM	Thermoplastics (ABS, PLA, PETG).	Prototyping, educational models, functional parts.
SLA	Photopolymer resins.	High-detail models, dental applications, jewelry.
SLS	Nylon, polystyrene, metals, ceramics.	Functional parts, complex geometries, no support structures needed.
SLM	Stainless steel, titanium, aluminum.	Aerospace, automotive, medical implants.
DMLS	Metals - stainless steel, titanium.	Aerospace, automotive parts, durable prototypes.
SHS	Thermoplastic powders.	Prototypes, fit/form testing, desktop applications.
LOM	Paper, plastic, metal laminates.	Rapid prototyping, patterns for casting, large models.
MJM	Thermoset photopolymers, acrylics.	Detailed models, prototypes, automotive and aircraft industry.
EBM	Titanium alloys, cobalt chrome.	Medical implants, aerospace components.
CJP	Gypsum-based powders.	Concept models, architectural visualization, educational aids.
DLP	Photopolymer resins.	Detailed prototypes, dental applications, jewelry.

Based on basic research on the materials PLA and ABS, which are predominantly used in FDM 3D printing, do not forget to consider how other 3D printing methods, such as MJM and CJP, and others, contribute to progress, especially in the areas of creating complex objects and the use of multiple materials. MJM (multi-jet modeling) and CJP (color inkjet printing) stand out for their unique ability to create highly detailed, color-accurate prototypes. Unlike FDM, which is known for its simplicity and cost-effectiveness, MJM and CJP offer a limited selection of materials and colors. MJM in particular enables the printing of parts with complex shapes and smooth surfaces and is ideal for applications where aesthetic and functional details are important [9]. CJP, on the other hand, is known for its ability to produce high-resolution color models, which is particularly useful in industries where visual expression and accuracy are important, such as architecture and healthcare [10]. Furthermore, the development of 3D printing technologies, including MJM and CJP, has not only increased the capabilities of 3D printing in terms of material versatility and print accuracy, but has also pushed the boundaries of what can be achieved with rapid prototyping, leading to innovation in various fields, including biomedical applications [11].

3D printing technology is becoming increasingly common across a number of different sectors and is having a significant impact on innovation, productivity and the democratization of manufacturing. Over the past few years, major innovations in 3D printing have laid the foundation for significant progress in various sectors [12]. In manufacturing in particular, 3D printing has brought about a remarkable revolution, providing unprecedented flexibility, design freedom, and the ability to reduce time to market for new products [13]. This shift to additive manufacturing has made manufacturing processes more flexible, enabling mass customization, and significantly reducing the risks and costs associated with traditional manufacturing methods [14]. In addition, 3D printing technology has further accelerated the innovation process by facilitating collaboration and co-creation between designers, engineers, and end users, allowing the development of new products and services [14].

Future developments in 3D printing, building on the foundations of existing 3D printing technologies and materials, have the potential to revolutionize many industries and all aspects of daily life. The overall outlook for 3D printing technology is very optimistic, with 97 percent of manufacturers expecting an increase in applications [13]. This growth is more than speculation; it is based on the practical and almost limitless possibilities that 3D printing offers. From the creation of small parts to the construction of entire buildings and the production of transplantable organs, the possibilities of 3D printing are limited only by the limits of the imagination [15]. In particular, the impact of 3D printing on medicine and healthcare is expected to be enormous, providing cost-effective solutions for the production of accessible prosthetics and haptic models for people with disabilities [15]. This personalization trend, which is gaining momentum across various industries, fits perfectly with the capabilities of 3D printing technology, allowing companies to offer unprecedented flexibility and personalization in their products without significant additional costs [15]. As a result, potential future developments in 3D printing are expected to not only increase the efficiency and personalization of manufacturing processes, but also significantly improve the quality of life of people around the world.

Conclusion. Advances and applications of 3D printing technology are changing manufacturing processes in various industries. This comparative analysis of 3D printing methods and technologies highlights the various capabilities inherent in fused deposition modeling (FDM), stereolithography (SLA), selective laser sintering (SLS), and so on. Each method offers unique advantages in the material selection, surface finishing, durability and cost-effectiveness, meeting different additive molding needs. FDM is different in that it is affordable and also has greater compatibility with inexpensive materials such as

ABS and PLA plastic, making it almost ideal for entry-level prototypes and educational purposes, also capable of being used in more complex models. SLA, on the other hand, is characterized by precision and surface smoothness, while SLS has demonstrated the ability to create complex geometries without the need for support structures. Continued research and the introduction of different materials will further increase the versatility of 3D printing technology to support a variety of engineering and design applications. Future advances in 3D printing will provide unprecedented flexibility, efficiency and customization and are poised to revolutionize several industries. Additionally, advances in new technologies such as DMLS (direct metal laser sintering) and EBM (electron beam melting) are pushing the boundaries of rapid prototyping and innovation in areas such as biomedical applications. The flexibility of 3D printing technology allows manufacturers to optimize designs or combine multiple parts into complex individual components to achieve high strength-to-weight ratios. Overall, the transformative impact of 3D printing on manufacturing and prototyping is clear, and significant advances are laying the foundation for future developments that are expected to increase efficiency and customization and improve the quality of life for people around the world.

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АНАЛІЗ ТЕХНОЛОГІЙ 3D-ДРУКУ ТА ЇХ ВПЛИВ НА ПРОЦЕСИ АДДИТИВНОГО ВИРОБНИЦТВА

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Сфера технологій 3D-друку досягла величезного прогресу за останні роки, радикально змінивши методи проектування та виробництва прототипів, використовуючи різні методи технологій 3D-друку, такі як FDM (моделювання плавленого осадження), SLA (лазерна стереолітографія), SLS (селективне лазерне спікання), SLM (селективне лазерне плавлення) . Також існують й інші методи та технології, таких як DMLS (пряме лазерне спікання металу), SHS (селективне термічне спікання) і багатошарове моделювання об'єктів (LOM), багатострументеве моделювання (MJM), плавлення електронним променем (EBM), кольоровий *струменевий друк (CJP), цифрова обробка світла (DLP) тощо. Завдяки цим технологіям, існує можливості для створення складних прототипів для різних сфер застосування. Метою цього наукового дослідження є проведення детального порівняльного аналізу цих технологій 3D-друку шляхом вивчення відмінностей між методами та типами 3D-друку, такими як FDM, SLA та SLS, включаючи також нові методи друку, такі як DMLS та EBM, і вивчення їх особливостей та їх застосування, ефективність і використані матеріали. Також буде розглянуто, як нові технології 3D-друку, такі як MJM і CJP, сприяють розвитку 3D-друку, особливо в таких сферах, як виробництво та прототипування, та майбутні тенденції в технологіях 3D-друку, а також застосування цих технологій для різних галузей промисловості. Також обговорено, як такі з технології впливають на процеси адитивного виробництва. Це дослідження проливає на світ розуміння відмінностей технології 3D-принтерів та активне використання і покращення цих технологій і відкриття нових можливостей для створення нових технологій. Розуміння відмінностей технології 3D-друку, дасть можливість обирати ту чи інші оптимальні технології для створення моделей. Для прикладу, використання технології 3D-друку, для створення 3D-моделей з рельєфно-крапковим шрифтом Брайля, може бути оптимальним вибором такої технології, як SLA, FDM, DLP, в ой час як для інших 3D-моделей може бути оптимальним інша технологія 3D-друку. Ця стаття дає можливість в продовженні наукових досліджень та проведення експериментів з використання різних технології 3D-друку з відтворення різних моделей, для того щоб виконати сортування, яка технологія 3D-друку буде оптимальним, для певних 3D-моделей, а це дозволить скоротити час та витрати виробництва.*

Ключові слова: *технологія 3D-друку, SLA, FDM, DLP, LOM, MJM, DMLS, EBM, CJP, SLA, SLS, SHS, адитивне виробництво.*

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