3D PRINTING AS A STRATEGIC TECHNOLOGY OF INDUSTRY 4.0: A SYSTEMATIC REVIEW OF THE MAIN APPLICATION AREAS

A IMPRESSÃO 3D COMO TECNOLOGIA ESTRATÉGICA DA INDÚSTRIA 4.0: UMA REVISÃO SISTEMÁTICA DAS PRINCIPAIS ÁREAS DE APLICAÇÃO

LA IMPRESIÓN 3D COMO TECNOLOGÍA ESTRATÉGICA PARA LA INDUSTRIA 4.0: UNA REVISIÓN SISTEMÁTICA DE LAS PRINCIPALES ÁREAS DE APLICACIÓN

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ABSTRACT
Three-dimensional printing (3D printing) is one of the key technologies of Industry 4.0, with increasingly diversified applications and significant impact on strategic sectors such as education, healthcare, engineering, sustainability, art. This article presents a systematic review of scientific literature published between 2020 and 2024, aiming to identify the main application areas of 3D printing and analyze the methodological and thematic contributions of the selected studies. The search was conducted in the Web of Science (WoS) database, using descriptors in Portuguese, English, and Spanish related to technology and its applications. After the screening and selection process, 26 articles were included in the qualitative analysis. Thematic categorization allowed for the organization of studies into seven main areas: education, engineering/industry, biomaterials/biofabrication, human health, veterinary health, energy/sustainability, and art and design. The results show a balanced distribution across fields, with emphasis on educational and industrial applications. The analysis was complemented by a comparative table and a word cloud, reinforcing the versatility and interdisciplinary nature of the technology. The evidence highlights the potential of 3D printing as an educational, technological, and socially transformative tool, especially when aligned with sustainable and accessible practices. This study contributes to understanding the strategic role of 3D printing in Industry 4.0, highlighting trends, gaps, and research opportunities aligned with the Sustainable Development Goals of the 2030 Agenda.

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Keywords: 3D Printing. Industry 4.0. Technological Applications. Sustainability. Innovation.

RESUMO

A impressão tridimensional (3D) é uma das tecnologias-chave da Indústria 4.0, com aplicações cada vez mais diversificadas e impacto significativo em setores estratégicos como educação, saúde, engenharia, sustentabilidade, arte. Este artigo apresenta uma revisão sistemática da literatura científica publicada entre 2020 e 2024, com o objetivo de identificar as principais áreas de aplicação da impressão 3D e analisar as contribuições metodológicas e temáticas dos estudos. A busca foi realizada na base Web of Science (WoS), utilizando descritores em português e inglês relacionados à tecnologia e suas aplicações. Após o processo de triagem e seleção, 26 artigos foram incluídos na análise qualitativa. A categorização temática permitiu a organização dos estudos em sete áreas principais: educação, engenharia/indústria, biomateriais, biofabricação, saúde humana, saúde veterinária, energia/sustentabilidade e arte e design. Os resultados indicam uma distribuição equilibrada entre os campos, com destaque para aplicações educacionais e industriais. A análise foi complementada por um quadro comparativo e uma nuvem de palavras, que reforçam a versatilidade da tecnologia e sua natureza interdisciplinar. As evidências apontam para o potencial da impressão 3D como ferramenta pedagógica, tecnológica e socialmente transformadora, especialmente quando associada a práticas sustentáveis e acessíveis. O estudo contribui para o entendimento do papel estratégico da impressão 3D na Indústria 4.0, destacando tendências, lacunas e oportunidades de pesquisa alinhadas aos Objetivos de Desenvolvimento Sustentável (ODS) da Agenda 2030.

Palavras-chave: Impressão 3D. Indústria 4.0. Aplicações Tecnológicas. Sustentabilidade. Inovação.

RESUMEN

La impresión tridimensional (3D) es una de las tecnologías clave de la Industria 4.0, con aplicaciones cada vez más diversas y un impacto significativo en sectores estratégicos como la educación, la salud, la ingeniería, la sostenibilidad y el arte. Este artículo presenta una revisión sistemática de la literatura científica publicada entre 2020 y 2024, con el objetivo de identificar las principales áreas de aplicación de la impresión 3D y analizar las contribuciones metodológicas y temáticas de los estudios. La búsqueda se realizó en la base de datos Web of Science (WoS), utilizando descriptores en portugués e inglés relacionados con la tecnología y sus aplicaciones. Tras el proceso de cribado y selección, se incluyeron 26 artículos en el análisis cualitativo. La categorización temática permitió organizar los estudios en siete áreas principales: educación, ingeniería/industria, biomateriales, biofabricación, salud humana, salud veterinaria, energía/sostenibilidad y arte y diseño. Los resultados indican una distribución equilibrada entre los campos, con énfasis en las aplicaciones educativas e industriales. El análisis se complementó con una tabla comparativa y una nube de palabras, que refuerzan la versatilidad de la tecnología y su carácter interdisciplinario. La evidencia apunta al potencial de la impresión 3D como herramienta pedagógica, tecnológica y socialmente transformadora, especialmente cuando se asocia con prácticas sostenibles y accesibles. Este estudio contribuye a comprender el papel estratégico de la impresión 3D en la Industria 4.0, destacando tendencias, brechas y oportunidades de investigación alineadas con los Objetivos de Desarrollo Sostenible (ODS) de la Agenda 2030.

Palabras clave: Impresión 3D. Industria 4.0. Aplicaciones Tecnológicas. Sostenibilidad. Innovación.

1 INTRODUCTION

Three-dimensional (3D) printing, also known as additive manufacturing, is one of the most emblematic technologies of the so-called Industry 4.0, alongside artificial intelligence, the internet of things, big data, and advanced automation. This new industrial revolution has been reconfiguring the productive logic, organizational models, and the worlds of work themselves, promoting the intensive digitalization of processes and the growing interaction between physical and virtual systems (PEROSINI, 2024). Industry 4.0 not only transforms material production, but also generates significant impacts on professional qualification, work organization, and the emergence of new fields of technological action, creating tensions and possibilities on the horizon of human development.

As highlighted by Gimenez and Santos (2021), Industry 4.0 represents a profound technological inflection, but its adoption occurs unevenly across countries and sectors, reflecting structural asymmetries and weaknesses in the industrial policies of peripheral countries, such as Brazil. The authors point out that, although these technologies increase productivity and innovation capacity in highly developed contexts, their introduction in unstructured economies tends to accentuate informality, technological unemployment, and labor market segmentation, making it difficult to build inclusive development trajectories.

In turn, Ferretti and Kroenke (2021) reinforce the need for a national innovation policy that not only stimulates cutting-edge sectors, but is guided by criteria of social inclusion, reduction of regional inequalities, and strengthening of endogenous capacities. The authors propose that innovation should be thought of as a socially constructed, interactive and context-dependent process, in which the State plays an irreplaceable role as an articulator of local innovation systems, promoter of technological infrastructure and mediator of relations between university, company and society. 3D printing, in this scenario, cannot be understood only as a technological tool for additive manufacturing, but as a potential vector of economic and social transformation, depending on how it will be incorporated into innovation policies, productive restructuring, and sustainable territorial development strategies.

However, the application of 3D printing in educational contexts has contributed to the enhancement of spatial visualization, active learning, and the development of creative thinking, especially in disciplines that require three-dimensional representation, such as

anatomy, chemistry, and engineering (TOLEDO-ORDOÑEZ et al., 2022; RAMIREZ-TAGLE, PINTO AND ANGULO, 2022). In healthcare, technology has made it possible from surgical planning to implant prototyping and the production of medical instruments, promoting greater precision and accessibility (GARAY et al., 2024; SILVA et al., 2020).

In this way, 3D printing stands out for its ability to materialize objects from digital models with precision, agility, and a high degree of customization, meeting complex demands in areas such as engineering, health, education, design, energy, and sustainability (MARTÍNEZ, GARCÍA, AND GONZÁLEZ, 2020; RODRIGUES et al., 2021). Such characteristics give technology a strategic role not only from a technical point of view, but also from a social and environmental point of view. This is in line with the precepts of the 2030 Agenda for Sustainable Development, whose central commitment is to "leave no one behind" through the promotion of sustainable, inclusive and economically viable innovations that favor equity and collective well-being (UN, 2015).

In this context, it is relevant to consider the contemporary debates on the limits of economic liberalization and the challenges for strengthening the national productive structure. Furtado (2023), when criticizing the conventional approach centered on economic freedom as an automatic path to innovation, argues that the absence of strategic coordination by the State results in productive asymmetries, concentration of economic power, and technological stagnation. In his analysis, the "freedom" promoted by the neoliberal reforms of the 1990s did not generate an environment conducive to innovation, but rather deepened the dependence on exogenous technologies, destructuring the Brazilian industrial base. In dialogue with this critique, Furtado (2023) argues that macroeconomic stability, in order to be functional to development, requires robust industrial foundations. The author argues that public and private investments in strategic sectors should be guided by integrated industrial policies, capable of promoting structural transformations and inducing sustainable technological trajectories.

Thus, by investigating the application of 3D printing in different fields, this article also contributes to a critical reflection on the directions of Industry 4.0 in Brazil and on how emerging technologies can be appropriated in a strategic, inclusive, and sustainable way. The analysis proposed here articulates the technical dimensions of additive manufacturing with broader debates on industrial policy, innovation and development, highlighting the central role of the State, science and society in the construction of fairer and more democratic technological futures.

2 METHODOLOGY

This systematic review of the literature was conducted with the objective of identifying, categorizing and analyzing the main areas of application of 3D printing technology in the context of Industry 4.0, considering scientific publications indexed between the years 2020 and 2024. The methodology adopted followed the principles established by Cassundé, Barbosa, and Mendonça (2018), based on systematic procedures for identifying, selecting, extracting, and categorizing data, in order to ensure transparency, reproducibility, and reliability of the results. The biblioFigureic search was carried out in the *Web of Science (WoS)* database, due to its relevance, multidisciplinary scope and rigor in the indexing of high-impact scientific journals. The descriptors used were: *"3D printing", "work", "technology",* "3D printing", "work" and "technology".

Searches were carried out between June 5 and 10, 2025, using terms combined with Boolean operators to include publications in Portuguese, English, and Spanish, in the period from 2020 to 2024. Initially, 103 articles were found. After screening titles, abstracts, removal of duplicates and application of the inclusion criteria, studies were selected that dealt with 3D printing as the main technology, with practical, methodological or theoretical application in specific areas, and that were fully available with access to methodological content.

As a result, 26 articles were selected for qualitative and categorical analysis. The thematic categorization was conducted based on the predominant area of application of the technology in the reviewed articles, originating seven analytical categories: Education, Engineering/Industry, Biomaterials/Biofabrication, Human Health, Veterinary Health, Energy/Sustainability, and Art and Design. Each article was classified according to its alignment with the predominant area of application, allowing a structured visualization of the contributions by thematic field.

3 RESULTS AND DISCUSSION

The quantitative analysis of the thematic areas reveals a relatively balanced distribution among the fields of application of 3D printing, with emphasis on the areas of engineering/industry, education, biomaterials/biofabrication and human health, each with four or five studies identified. Such data confirm the transversality of technology and its consolidated presence in strategic sectors of Industry 4.0. The area of energy and sustainability also stands out, with five articles, which reflects the growing interest in

technological solutions aligned with sustainable and low-cost practices. On the other hand, areas such as veterinary health and art and design showed a lower incidence in the studies analyzed, which may indicate both the incipience of these applications and an opportunity for further research

The panorama illustrated in Figure 1 reinforces the importance of the thematic categorization adopted to understand the multiple uses of 3D printing in science and society.

Figure 1

Frequency of studies by 3D printing application area.
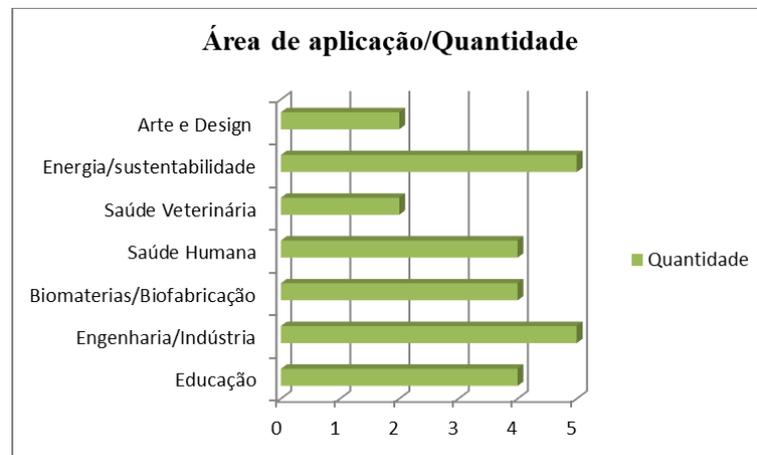
Source: prepared by the author (May, 2025).

From the classification presented, it is possible to deepen the analysis of the different approaches that have been developed in the field of 3D printing. The thematic and methodological diversity of the studies shows not only the versatility of the technology, but also its potential for transformation in different social, scientific and productive contexts. By exploring the specific contributions of each application area, it becomes possible to understand how 3D printing has been incorporated as a tool for innovation, process optimization, learning promotion, therapeutic support and sustainable development.

In order to systematize the main contributions analyzed in this review, Chart 1 was elaborated, which deals with the synthesis of the studies according to their areas of application, respective authors and central thematic focus.

Table 1

Applications of 3D printing by area, authors and main focus.

Application Area	Authors and Year	Main Focus
Education	Toledo-Ordoñez et al. (2022)	3D models for teaching Histology
	Ramirez-Tagle, Pinto and Angulo (2022)	"3D Chemistry" Platform for Molecular Manipulation
	Hecht-López, Maturana-Arancibia and Parra-Villegas (2023)	Digital resources and 3D models in the teaching of Anatomy
	Cabrera Frías and Córdova Esparza (2023)	Development of creative thinking in higher education
Engineering / Industry	Martínez, García and González (2020)	Influence of printing parameters on PLA, Nylon and HIPS flexing
	Rodrigues et al. (2021)	DLP Printing Ceramic Suspension with Zirconia
	Romero et al. (2021)	Adaptation of tensile standards for printed parts
	González-Sosa and Ávila-Soler (2023)	Mathematical modeling for print time optimization
	Silva et al. (2024)	Flexural strength in PLA with different filling patterns
Biomaterials / Biofabrication	Silva et al. (2020)	Printable composite with photoluminescent and biocompatible properties
	Ferrari et al. (2022)	Microstructure of 3D printed soils (MIP and SEM)
	Santo et al. (2022)	Bioprinting hydrogels with rheological properties
	González-González et al. (2023)	PLA Andamios with different topologies and permeability analysis
Human Health	Telich-Tarriba et al. (2020)	3D Printing in Reconstructive Plastic Surgery
	Oviedo-Quirós et al. (2021)	Open protocol for dental impression
	Crego-Vita et al. (2021)	Production of surgical instruments for military use
	Garay et al. (2024)	Orthopedic surgical planning with 3D models
Veterinary Health	Lyu et al. (2020)	Functional Prosthesis Paw for Amputee Dog
	Espín-Lagos et al. (2023)	Osseointegration of porous titanium implants in rabbits
Energy / Sustainability	Zambiazi et al. (2020)	Modified electrodes for water oxidation and hydrogen production
	Márquez-Herrera and Moreno-Palmerin (2022)	3D electrochemical cell for testing with boron-carbon coatings
	Márquez-Herrera, Zapata Torres and Montesinos (2022)	PLA/PTFE printed cell for electrochemical studies
	Silva et al. (2022)	Development of a low-cost centrifuge with PLA and Arduino
	Chinnathambi et al. (2024)	PLA Vertical Wind Turbine Blades with FEA Simulations
Art & Design	Morell i Rovira (2020)	3D printing as a conceptual element in contemporary art

Guillemot, Fernandes, and Pereira et al. (2022)	Sustainable DIW inks with natural materials

Source: prepared by the author (May, 2025).

Next, the content of the selected studies is discussed in more detail, organizing the analysis by thematic areas and highlighting the advances, limitations and perspectives identified in the literature.

3.1 EDUCATION: PEDAGOGICAL INNOVATION AND STIMULATION OF CREATIVITY

The application of 3D printing in education has been consolidated as an innovative strategy to enhance teaching in areas that require spatial understanding and three-dimensional visualization. Toledo-Ordoñez et al. (2022) used this technology to develop three-dimensional histological models, such as the glomerular filtration barrier and the epidermal strata, with the aim of facilitating medical education. These models, in addition to being accessible and low-cost, have contributed to a better understanding of microscopic structures by helping students transpose two-dimensional images into three-dimensional space.

In a complementary perspective, Ramirez-Tagle, Pinto, and Angulo (2022) created the interactive platform "3D Chemistry", aimed at teaching stoichiometry and molecular structures to engineering and science students. The initiative combined digital resources with 3D printing, allowing students to formulate balanced chemical reactions, visualize three-dimensional molecular models, and access printable files, promoting visual and interactive learning.

The importance of integrating digital technologies and traditional methods was also highlighted by Hecht-López, Maturana-Arancibia, and Parra-Villegas (2023), when they reported on the experience of a medical school in Chile and institutions participating in the "SECTRA Users Meeting 2019". The study highlighted the combined use of digital dissection tables, such as SECTRA, and 3D-printed anatomical models, indicating a growing trend in the adoption of technological resources in anatomical education.

Finally, Cabrera Frías and Córdova Esparza (2023) demonstrated that 3D printing in the field of design contributes to the development of creative thinking, motivation, and engagement of Industrial Design students. The authors defend the curricular reformulation based on the integration between technological innovation and critical training, in order to strengthen the professional qualification of students.

3.2 ENGINEERING AND INDUSTRY: MECHANICAL PERFORMANCE AND PROCESS OPTIMIZATION

3D printing has been widely explored in engineering and industry for material characterization, structural performance, and mathematical modeling aimed at process optimization. One of the main challenges addressed in the studies is the anisotropy of the parts, often evaluated by flexural, hardness, compression and tensile tests.

Thus, Martínez, García, and González (2020) investigated the impact of filament orientation, coloring additives, and printing speed on the flexural modulus of elasticity in parts produced by Filament Deposition Modeling (MDF), using polymers such as PLA, Nylon, and HIPS. The results revealed that all these factors significantly affect the stiffness of the parts, with the mechanical performance being superior when the filaments are aligned with the direction of the forces.

In the field of technical ceramics, Rodrigues et al. (2021) developed homogeneous suspensions with stabilized zirconia (3Y-TZP) for printing via DLP, facing the challenge of formulating stable suspensions with high solid loading and low viscosity. With the use of Disperbyk-111 and PEGDA 250, they obtained dense, detailed and viable ceramic bodies for sintering, demonstrating the potential of the bath light curing (VP) technique in the production of complex ceramic pieces.

Complementing this approach, Romero et al. (2021) compared tensile test methodologies on FDM-printed thermoplastic specimens, using ISO standards for injected plastics as a reference. They tested four materials in three types of machines and found that, even without strain gauges and with variations in the strain rate, it is possible to obtain reliable values for the modulus of elasticity, as long as the tests are conducted with proper care.

With regard to process modeling and optimization, González-Sosa and Ávila-Soler (2023) proposed the use of Lagrange integration to model the printing time of specimens used in impact tests. The proposal allows predicting and rationalizing resources, optimizing parameters such as filling, quality, and thickness of layers through polynomial functions.

Silva et al. (2024), in turn, focused on the flexural strength of PLA parts with different patterns and fill levels. They identified that the concentric pattern offers greater resistance and less variability than the ±45° line pattern, being more suitable for applications that require high mechanical performance.

3.3 BIOMATERIALS AND BIOFABRICATION: DEVELOPMENT OF FUNCTIONAL STRUCTURES

The area of biomaterials and biofabrication has benefited significantly from advances in 3D printing, allowing the construction of complex and functional structures with optimized properties for biomedical, geotechnical and tissue engineering applications. The studies analyzed reinforce the versatility of additive manufacturing in the formulation of innovative materials, in the control of microstructure and in the modeling of physicochemical and biological properties.

In this context, Silva et al. (2020) developed a poly(ε-caprolactone) (PCL)-based compound with upconversion nanoparticles (UCNPs)-apatite and photosensitizer, intended for photodynamic therapy (PDT)-assisted bone repair. The structure, produced by 3D printing, maintained the thermal and rheological properties of pure PCL, with superior mechanical performance due to the incorporation of UCNPs. The emission of visible light under NIR excitation (980 nm) allowed the generation of singlet oxygen, essential for PDT, and toxicological tests indicated safety at low concentrations of rare earth elements, expanding the prospects for clinical application.

At the interface between biofabrication and geotechnics, Ferrari et al. (2022) explored the effects of 3D printing on soil microstructure, using characterization techniques such as IPM and SEM. Macropores formed from the distortion and arrangement of the filaments were identified, especially under almost undrained conditions, in addition to internal anisotropy caused by the rotation of the extruder, evidencing the influence of the deposition process on the morphology and behavior of the printed soils.

In the field of tissue engineering, Santo et al. (2022) evaluated the feasibility of the PEG-Laponite-alginate (PL-Alg) hydrogel for 3D bioprinting, highlighting its pseudoplastic rheological behavior and its ability to cross-link with $CaCl_2$, crucial factors for extrusion and shape maintenance after printing. The stability of the hydrogel was affected by the Laponite content, and it was necessary to optimize the cross-linking of the PEG chain to improve mechanical strength and control degradation, key elements for future applications in tissue engineering.

Regarding the modeling of physical properties, González-González et al. (2023) investigated the relationship between porosity and permeability of porous PLA andomios, with different geometries based on triplicately periodic minimum surfaces (Diamond,

Gyroid, and Schwarz Primitive). Through FDM printing, experimental tests and polynomial modeling, correlations higher than 98% were obtained, confirmed by statistical tests of normality and homoscedasticity. The results validate the application of mathematical models to predict the permeability of structures with geometries optimized by computational design, which is highly relevant for applications in tissue regeneration and controlled release systems.

3.4 HUMAN HEALTH: DIAGNOSIS, PLANNING, AND REHABILITATION SUPPORT

3D printing has gained prominence in the area of human health, especially as an auxiliary resource for diagnosis, surgical planning, and functional rehabilitation. Telich-Tarriba et al. (2020) demonstrated its application in reconstructive plastic surgery, with a focus on the customization of anatomical models and implants. In the field of dentistry, Oviedo-Quirós et al. (2021) proposed an open and low-cost protocol for printing dental devices, validated by operators with no previous experience, highlighting the accessibility of the technology.

In military surgery, Crego-Vita et al. (2021) produced surgical instruments with PLA and ABS filaments, the latter being more reliable in terms of strength and performance. In orthopedics, Garay et al. (2024) reported clinical cases in which 3D printed models facilitated the visualization of fractures and the planning of osteotomies, benefiting medical performance and patient recovery.

3.5 VETERINARY HEALTH: PROSTHETICS AND IMPLANTS CUSTOMIZATION

Veterinary **medicine** is an emerging and promising field for the application of **3D printing**, especially in the development of **personalized prostheses and implants** aimed at animal welfare. In this context, *Lyu et al.* (2020) investigated the **osseointegration of porous titanium implants submitted to preload** in rabbits, observing an effective bone filling in the implanted regions, which suggests a satisfactory biomechanical performance and **feasibility of long-term clinical application**. In addition, *Espín-Lagos et al.* (2023) reported the development of a **functional prosthesis for the front leg of an amputee dog**, manufactured in PLA from **computer modeling (CAD)** and **mechanical resistance simulations**. The results indicated a high level of comfort and functionality for the animal, evidencing the potential of additive manufacturing in the **rehabilitation and improvement of the quality of life of veterinary patients**.

3.6 SUSTAINABILITY AND ENERGY: INNOVATION WITH LOW ENVIRONMENTAL IMPACT

Additive manufacturing has stood out as an ally in the development of sustainable and low-cost solutions, with promising applications in the areas of energy, materials science, and laboratory instrumentation. In the field of clean energy production, Zambiazi et al. (2020) explored the modification of electrodes with analogues of Prussian Blue, demonstrating the feasibility of using 3D printing in the production of hydrogen in a neutral medium, configuring itself as an affordable and environmentally sustainable alternative. In a complementary vein, Márquez-Herrera and Moreno-Palmerin (2022) applied the technology in the construction of 3D-printed electrochemical cells for corrosion testing on ASTM A-36 steel with boron-carbon coating, highlighting the potential of additive manufacturing in materials engineering and durability testing.

Also in this domain, Márquez-Herrera, Zapata Torres and Montesinos (2022) experimentally validated an electrochemical cell manufactured in PLA/PTFE, reinforcing the applicability of 3D printing in the construction of experimental devices with good performance and low cost. This perspective of accessibility is also reinforced by Silva et al. (2022), which developed low-cost laboratory centrifuges with PLA components, expanding the possibilities of using 3D printing in environments with budget constraints.

In the renewable energy generation sector, Chinnathambi et al. (2024) used the fused deposition modeling (FDM) technique in the manufacture of blades for vertical wind turbines, evaluating their performance through finite element simulations (FEA), which highlights the potential of additive manufacturing in the optimization of devices for wind energy harvesting.

3.7 ART, DESIGN AND TECHNOLOGICAL DEMOCRATIZATION

In the artistic and cultural field, 3D printing has expanded the expressive and conceptual possibilities. Morell i Rovira (2020) analyzed the use of technology in the creative process of artists such as Anna Dot and Mercè Casanovas, highlighting themes such as error, copying, and reproducibility in contemporary art. Guillemot, Fernandes, and Pereira (2022) proposed a simplified protocol for the formulation of extrusion inks (DIW), using natural materials such as clay and bamboo fibers, with the aim of democratizing access to technology in workshops and schools, without the need for sophisticated equipment.

This panorama reveals the wide versatility of 3D printing, whose application transcends disciplinary boundaries, incorporating technical innovation, sustainability and accessibility. The different approaches analyzed indicate that 3D printing not only transforms production and educational processes, but also contributes to facing social and scientific challenges. Thus, technology is consolidated as a strategic tool for the development of interdisciplinary, personalized solutions with relevant social impact.

The complementary analysis of the abstracts of the 26 selected articles was carried out through the generation of a word cloud (Figure 1), a visual resource that highlights, through the length and recurrence of the terms, the concepts most frequently used in the reviewed literature.

Figure 1

Word cloud of the 26 abstracts of the selected articles

Source: prepared by the author (May, 2025).

Among the most prominent words are "model", "property", "materials", "process", "teaching", "development" and "technology", evidencing the centrality of technical, pedagogical and applied elements in the approach to 3D printing.

This result corroborates the thematic categories already described and reinforces the transversality of technology, which ranges from the teaching of science and anatomy, where terms such as "model" and "teaching" appear prominently, to studies focused on the engineering of materials, biomaterials and industrial processes, in which words such as "property", "materials" and "development" emerge.

Furthermore, the recurrence of words such as "project", "application" and "implant" indicates the practical concern of research, aimed at solving real problems in clinical, educational and industrial contexts. The presence of terms such as "low cost", "accessible" and "sustainable", although less frequently, is in line with discussions about the democratization of technology and its relevance in scenarios with budget constraints, such as those observed in the categories of energy, art, design and public health.

In this way, the word cloud not only reinforces the thematic trends already identified, but also highlights the interdisciplinarity and methodological diversity of the analyzed research, strengthening the understanding of 3D printing as a multifaceted technology, with high potential for technical, social and educational impact.

4 FINAL THOUGHTS

This study carried out a systematic review of the recent literature on the applications of 3D printing, focusing on works published between 2020 and 2024, aiming to identify the main areas of activity, methodological approaches, and scientific contributions. From the thematic categorization adopted, it was possible to map a comprehensive and diversified panorama, evidencing the transversality and transformative potential of this technology in different contexts.

In the area of education, 3D printing has proven to be an innovative resource for teaching complex content, favoring active learning and the development of creative thinking. In the field of human health, the use of additive manufacturing for surgical planning, implant customization, and development of advanced biomaterials stands out, reinforcing its clinical and therapeutic relevance. Engineering and industry have directed efforts to the mechanical characterization of materials and the optimization of production processes, promoting gains in efficiency and quality. Additionally, veterinary medicine emerges as an emerging area, benefiting from the customization of prostheses and implants.

The survey also revealed the growth of 3D printing applications in materials sciences, laboratory devices and sustainable technologies, which reinforce the ability of additive manufacturing to contribute to low-cost innovation and sustainable development. Finally, artistic manifestations and design stand out for the incorporation of technology as a means of expression and democratization of access to creative resources.

The results point to 3D printing as a strategic tool for interdisciplinary innovation, capable of integrating technological advances, sustainability and social impact. However, it is important to emphasize the need to deepen aspects related to the standardization of methods, durability of materials and technological accessibility, in order to expand the potential for application and adoption of the technology.

In short, this work contributes to the consolidated understanding of the multiple facets of 3D printing, serving as a subsidy for researchers, professionals and managers interested in exploring the possibilities of this technology in different contexts, as well as to guide future investigations that expand its socially relevant applicability.

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