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APPLICATIONS OF 3D TECHNOLOGY IN INNOVATION AND DEVELOPMENT OF TEXTILE MATERIALS

APPLICATIONS OF 3D TECHNOLOGY IN THE INNOVATION AND DEVELOPMENT OF TEXTILE MATERIALS

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SUMMARY: This paper is a systematic review of the scientific literature published between 2019 and 2024, which investigates the impact of 3D printing technology on the textile industry. The analysis covered the contributions of additive manufacturing in several dimensions, including design, functionality, sustainability and product customization. The study explored the principles of 3D printing and its main methods – Fused Deposition Modeling (FDM), Selective Laser Sintering (SLS), Direct Ink Writing (DIW), Stereolithography (SLA) and Digital Light Processing (DLP) – as well as the materials most commonly used in textile production. The analysis detailed the advances enabled by technology, such as innovation in design, fabric functionality, optimization of production efficiency, reduction of waste, and transformation of sectors such as fashion and the production of technical textiles. The study also assessed the potential of 3D printing for more sustainable production, considering the circular economy, mitigation of environmental impacts and support for local production. In addition, the research identified the challenges and limitations of the technology. It is concluded that 3D printing has transformative potential for the textile sector, despite the existing barriers. Therefore, investments in research and development of materials and processes, as well as in professional training, are recommended to accelerate the adoption and advancement of technology in the industry.

Keywords: Textile 3D Printing, Additive Manufacturing, Apparel 3D Printing, 3D Printing Design.

ABSTRACT: This work, a systematic review of the scientific literature published between 2019 and 2024, its investigates the impact of 3D printing technology on the textile industry. The analysis encompassed the contributions of additive manufacturing across several dimensions, including product design, functionality, sustainability, and personalization. The study explored the principles of 3D printing and its main methods—Fused Deposition Modeling (FDM), Selective Laser Sintering (SLS), Direct Ink Writing (DIW), Stereolithography (SLA), and Digital Light Processing (DLP)—as well as the materials most commonly employed in textile production. The analysis detailed the advancements enabled by the technology, such as innovation in design, enhanced fabric functionality, optimization of production efficiency, waste reduction, and transformation of sectors like fashion and technical textiles production. The study also evaluated the potential of 3D printing for more sustainable production, considering the circular economy, the mitigation of environmental impacts, and the support of local production. Furthermore, the research identified the challenges and limitations of the technology. It concludes that 3D printing presents transformative potential for the textile sector, despite existing barriers. It is therefore recommended that investments be made in research and development of materials and processes, as well as in professional training, to accelerate the adoption and advancement of the technology in the industry.

Keywords:3D printing textile, Additive Manufacturing, 3D printing clothing, 3D printing design.

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1. INTRODUCTION

The textile industry is one of the pillars of the global economy and has been characterized by its dynamism and capacity for innovation (CHATTERJEE, GHOSH, 2020). From the production of fibers, yarns, fabrics, nonwovens, knitwear, and basic clothing to applications in technical areas such as health, sports, and transportation, the textile sector has proven to be quite adjusted to social and economic demands. However, given the growing concern about environmental impact and the demand for customized products, the textile industry faces the challenge of reinventing itself. In this context, 3D printing technology emerges as a promising transformation tool, offering a path to innovation and sustainability (MANAIA, CEREJO, DUARTE, 2023).

Additive manufacturing, also known as 3D printing, refers to processes that build three-dimensional objects from digital models, adding material layer by layer (FRANCO URQUIZA, 2024). This technology, which began its journey in the prototyping sector, has evolved into a means of production in several areas, such as aerospace, automotive, health and, more recently, textiles (XIAO, KAN, 2022). In the textile industry, 3D printing has enormous potential to revolutionize how textiles are produced, designed and customized (ZHANG, DENG, 2021).

The overall objective of this study is to analyze the contributions of 3D technology to textile production, identifying and evaluating advances in design, functionality, sustainability and customization. Specific objectives include: exploring 3D printing principles and methods relevant to the textile sector; investigating the materials used in textile printing; analyzing the contributions of the technology to innovation, functionality and sustainability; evaluating the challenges and limitations of 3D printing in textile production; and identifying future trends for the technology.

1.1 Methodology

This study is a review of the scientific literature, focusing on the analysis of the contributions of 3D technology in the textile area. The research covered scientific articles published in the last 5 years (2019 to 2024), seeking to identify the main advances, challenges and trends in the application of 3D printing in the textile sector.

The search for articles was carried out in scientific databases relevant to the area, such as Web of Science, Scopus, ScienceDirect and Google Scholar, using a combination of keywords.

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keyword and search terms. A total of 358 articles were found, 97 of which were selected for full reading after analyzing the titles and abstracts. The following inclusion and exclusion criteria were applied:**-Inclusion Criteria:**a) Original scientific articles, published in indexed and reviewed journals; b) With the theme of 3D printing technology in the textile industry; c) Focusing on textile production, functionality, design, sustainability and customization; d) Published between 2019 and 2024, in English, Portuguese or Spanish.**-Exclusion Criteria:**a) Articles on 3D printing in other sectors; b) Other production technologies; c) Articles without results and empirical data; d) Conference abstracts, book reviews, notes, opinion pieces, editorials or similar.

After applying the inclusion and exclusion criteria, 29 articles were selected and analyzed in depth for the preparation of this work. The analysis of the articles included the identification of the main 3D printing methods used in the textile area, the materials used, the contributions of the technology to innovation, functionality and sustainability and the main limitations and challenges of the technology.

The structure of the work comprises this introduction, followed by sections that address the fundamentals of 3D printing, its contributions to fabric production, the impact on sustainability, and the challenges and limitations of the technology. Finally, conclusions and recommendations for future research will be presented.

2. FUNDAMENTALS OF 3D TECHNOLOGY AND ITS APPLICATION IN THE TEXTILE AREA

2.1 Principles of Additive Manufacturing (3D Printing)

Additive manufacturing, or 3D printing, has revolutionized the way objects are produced, based on three-dimensional construction through the sequential addition of material (FRANCO URQUIZA, 2024). Unlike subtractive processes, which remove material from a solid block, 3D printing deposits material layer by layer, from a digital model, allowing the creation of complex and customized geometries. This process not only eliminates material waste, but also offers unprecedented flexibility in terms of design and production.

The 3D printing process begins with the creation of a three-dimensional model using computer-aided design (CAD) software. This model is then

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divided into two-dimensional layers, which guide the printer during the sequential deposition of the material (HUNDE, WOLDEYOHANNES, 2022). Using an extrusion nozzle, a laser or another mechanism, the printer applies the material according to the model's guidelines, allowing the final object to be built layer by layer, as illustrated in Figure 1. This approach makes it possible to create complex structures that would be difficult or even impossible to manufacture using traditional methods.

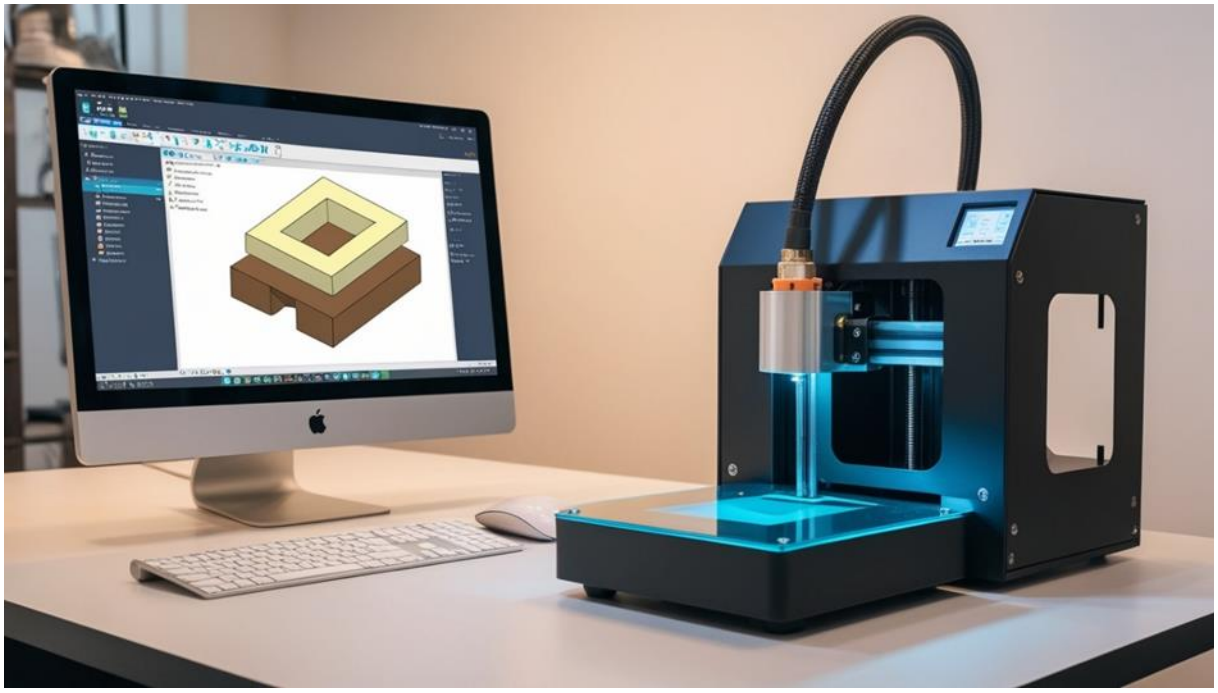

Figure 1. Generic 3D printing system (authorial).

2.2. 3D Printing Methods Relevant to the Textile Sector

Several 3D printing techniques have demonstrated relevance for the textile sector, each with its own particularities and specific applications. The most widely used include:

- **Fused Deposition Modeling (FDM):**This technique is the most accessible and the most used; it uses thermoplastic filaments that are heated and extruded through a nozzle, depositing their material in layers, as shown in Figure 2. It is suitable for more rigid and semi-rigid structures and, in general, used in the construction of prototypes and garments with complex geometric topologies (ALI, DEIAB, PERVAIZ, 2024). The accuracy and speed of deposition can be adjusted to the specific needs of the project.

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Figure 2: Images of the FDM printing process (authorial).

• **Selective Laser Sintering (SLS):**The SLS technique employs a laser to fuse powdered polymer particles, creating objects layer by layer, as illustrated in Figure 3. This methodology is suitable for the process of obtaining complex and resistant structures, avoiding the need for additional supports (ZHANG, ZHOU, FENG, 2025). SLS is used to manufacture technical and functional parts, such as footwear and accessories with high mechanical resistance.

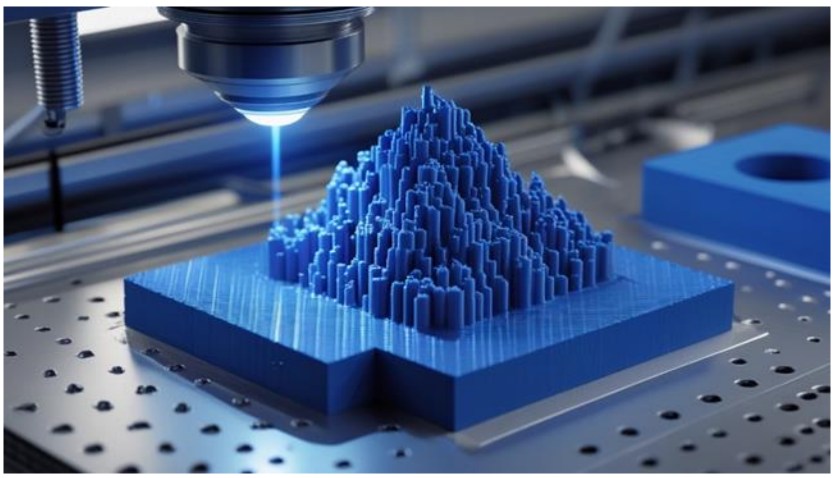

Figure 3. Image of SLS printing process: laser fusing polymer powder particles creating an object (authorial).

• **Direct Ink Writing (DIW):**DIW consists of the extrusion of materials in paste form or gel, depositing them in layers to form the object, figure 4. This technique is suitable for the production of flexible and adaptable fabrics, and for the integration of electronic components in

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textile structures (SAADI et. al., 2022). The versatility of DIW allows the use of different materials, from polymers to conductive materials.

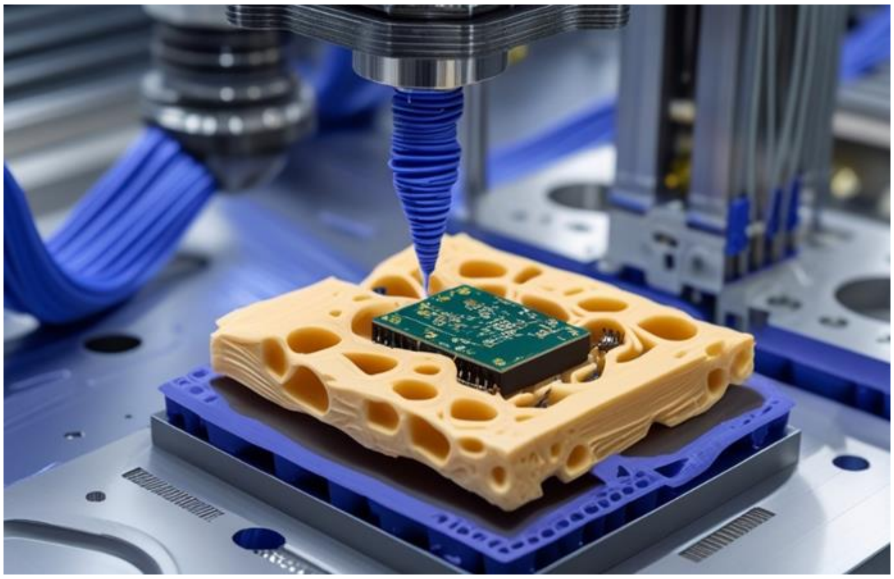

Figure 4. Image of the DIW printing process: extrusion of ink with graphene creating an electronic circuit (authorial)

• **Stereolithography (SLA) and Digital Light Processing (DLP):**These techniques use photosensitive liquid resins, hardened by ultraviolet light, figure 5. SLA uses a laser to solidify the resin, while DLP uses a projector. Both techniques are suitable for creating parts with high precision and resolution, being used in the production of accessories and components with intricate details (LI et. al., 2024).

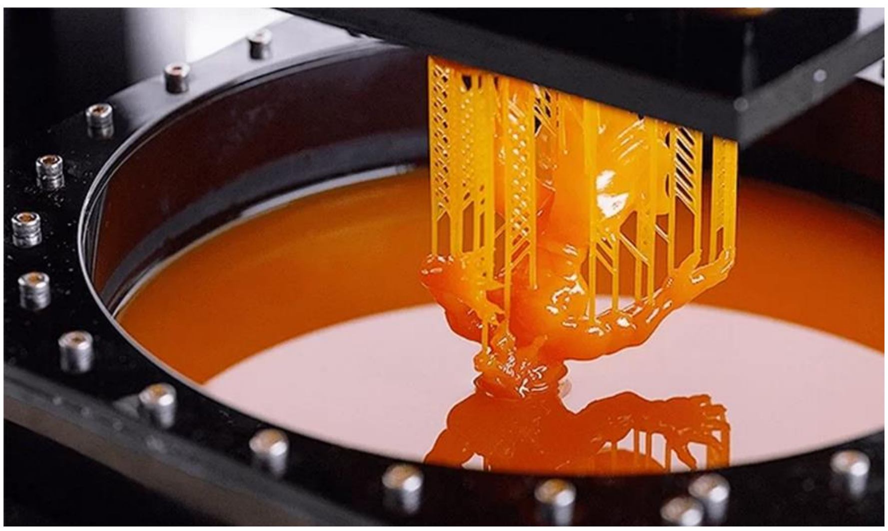

Figure 5. Image of the SLA printing process (WISHBOX, 2024).

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In addition to these, others such as PolyJet, a Material Jetting technique that prints drops of photopolymerizable material, and printing with binders Binder Jetting, based on the use of a binder that joins powder particles, also have potential in textile applications, although less so.

2.3. Materials for 3D Textile Printing

Material choice is crucial to the success of 3D printing, and a variety of materials have been explored for fabric production, including:

• **Polymers**: Polymers are the most widely used materials in 3D printing, due to their versatility and ease of processing. Among them, the following stand out: PLA (polylactic acid), a biodegradable polymer derived from renewable sources; TPU (thermoplastic polyurethane), known for its flexibility and resistance; ABS (acrylonitrile butadiene styrene), a resistant and durable material; Nylon, a strong and flexible polymer; and other polymers with specific properties (SHIVA, et. al., 2023), see Table 1. Each polymer offers different advantages in terms of resistance, flexibility, durability and cost, allowing designers to choose the most suitable material for each application.

• **Resins:**They are polymers or mixtures of viscous polymers that can be molded. Photosensitive resins are used in techniques such as SLA and DLP, and offer high precision and detail. These resins can be formulated with different properties, from rigid resins to more flexible resins with different mechanical strengths, making them suitable for creating complex accessories and details.

• **Composites:**Composites are materials formed by the combination of two or more materials, usually a polymer matrix reinforced with fibers. The fibers can be natural, such as cellulose, flax and hemp, or synthetic, such as carbon and glass. The use of composites allows the creation of materials with improved mechanical properties, offering greater strength, rigidity or flexibility, in addition to being more sustainable options when using natural or recycled sources (CHAKRABORTY, BISWAS, 2020).

• **Functional Materials:**In addition to structural materials, 3D printing allows the use of materials with functional properties, such as graphene, which provides electrical conductivity to fabrics, allowing the integration of electronic components. Thermoresponsive materials, which change their properties in response to temperature variations, have also been used to create fabrics with special properties.

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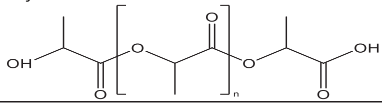
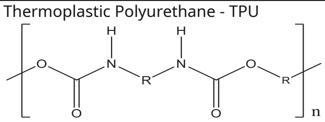
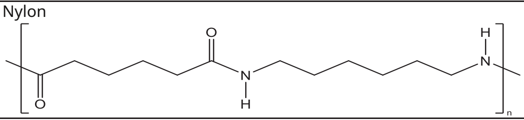
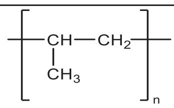
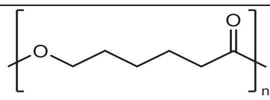
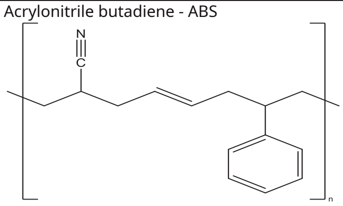
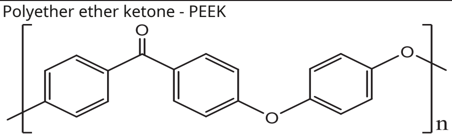
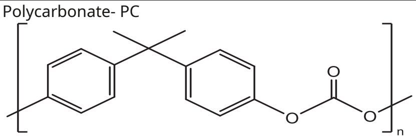
Table 1. Structural molecular formula of some polymers (SHIVA, et al, 2023).

Polylactide - PLA 	Applications in engineering tissue, treatment bone, packaging, implants cardiovascular and orthopedic devices.
Thermoplastic Polyurethane - TPU 	Vacuum foams, mattresses and dressings
Nylon 	Wound closure materials, cardiovascular catheter balloons, cotton swabs.
 Polypropylene – PP	Sutures, prostheses, syringes, inhalation systems, containers, drug delivery systems of
 Polycaprolactone - PCL	Scaffold, drug delivery systems, bone healing
Acrylonitrile butadiene - ABS 	Load-bearing applications such as bone implants, medical masks, valves for ventilators
Polyether ether ketone - PEEK 	Orthopedic implants, application in bone tissue engineering
Polycarbonate- PC 	Drug delivery devices of (nebulizers, dialysis machines and syringes), patient safety barrier

The choice of material for textile 3D printing must take into account not only its mechanical and functional properties, but also its sustainability, cost and suitability for the chosen printing process.

3. CONTRIBUTIONS OF 3D TECHNOLOGY TO TISSUE PRODUCTION

3.1. Innovation in Textile Design

Three-dimensional (3D) technology is transforming textile design, enabling the configuration of pieces with innovative and complex geometries, which would previously be impractical or excessively complex to be produced using traditional methods (MANAIA;

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CEREJO; DUARTE, 2023). Designers began to work with new shapes, textures, and patterns, in cooperation with three-dimensional modeling software that offers unprecedented creative freedom. In addition, three-dimensional printing allows the production of fabrics with three-dimensional structures, ensuring greater volume and depth for the pieces.

Customization is another aspect that has been enhanced. Designers have the opportunity to create custom pieces, adapting their design and measurements to the taste and needs of their clients. Thus, three-dimensional scanning technologies associated with parametric modeling software establish the possibility of developing prototypes and final pieces that fit the body perfectly, with a level of customization previously unimaginable, figure 6.

Figure 6. Clothing items produced with 3D technology (ZHANG; DENG, 2021. SEWING TIPS, 2020. FERNANDA, 2021. LUANA SILVA, 2022. LIVIA, 2021. AUNGKH, 2020).

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3.2. Advances in Tissue Functionality

3D printing enables the creation of fabrics with advanced functionalities, integrating different materials and components into the same structure. The incorporation of conductive materials, such as graphene and carbon nanotubes, allows the creation of special fabrics capable of monitoring vital signs, regulating body temperature or interacting with electronic devices, figure 7 (WANG et. al., 2023).

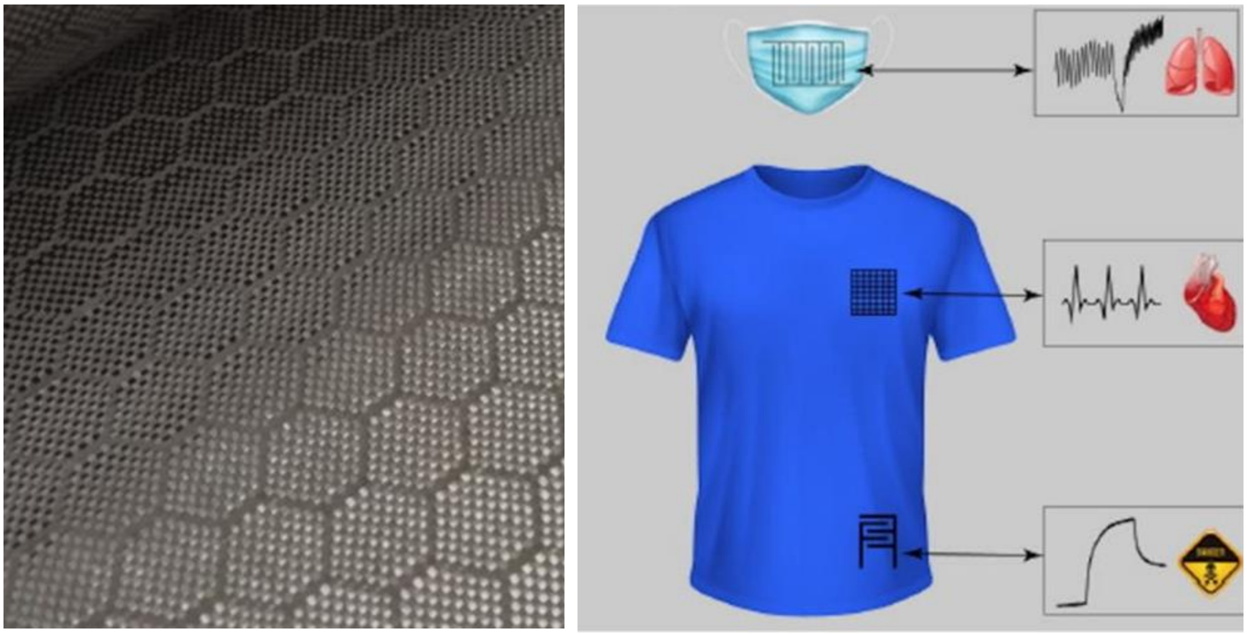

Figure 7. The image on the left is of an electrically conductive fabric made with carbon nanotubes (GLOBAL SOURCES, [sd]). The shirt on the right has sensors for breathing, heart rate and exhaled gases (DIÁRIO DA SAÚDE, 2020).

The integration of sensors and actuators into fabrics enables the development of clothing with functions for monitoring body signals, interacting with the environment and other devices. These applications open up a range of possibilities for the development of specialized workwear, clothing for athletes and clothing for people with special needs, protective masks, orthoses, etc. figure 8 (LI, 2023).

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Figure 8. Wrist immobilization mask and orthosis: 3D printing (DONE 3D, 2024; GALANTA, 2024).

The inclusion of thermal regulation elements, such as thermo-responsive materials, allows fabrics to adapt to temperature variations, providing greater comfort and protection. In addition, 3D printing makes it possible to create fabrics with antibacterial properties, through the integration of biocidal materials or through the creation of structures that hinder the growth of microorganisms (CHEN et. al., 2023).

An example of personal cooling technology that directs body heat to the external environment is fabric produced using boron nitride (BN)/polyvinyl alcohol (PVA) composite fibers. These fibers are manufactured using a fast and scalable three-dimensional (3D) printing method. The uniform dispersion and high alignment of BN nanosheets (BNNSs) result in a combination of mechanical strength and high thermal conductivity.(GAO et. al., 2017).

3.3. Increased Efficiency and Reduced Waste

3D printing enables more efficient production, as it enables the manufacture of parts on demand and without excess, minimizing waste and reducing environmental impact, eliminating the need for large inventories and reducing material waste. On-demand production allows companies and designers to produce only what is needed, which prevents overproduction and the dumping of unsold parts (AGNUSDEI; DEL PRETE, 2022). Another advantage of 3D printing is the reduction in production time, as 3D printing allows complex parts to be produced in a few hours, as opposed to the days or weeks required to produce conventionally.

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3.4. Personalization and Customization

Personalization and customization are fundamental aspects of the impact of 3D printing on textile production. 3D body scanning technology allows the creation of virtual models and then the creation of tailored pieces, adapted to each customer's preferences, with ergonomic adjustments that better align with the body and provide greater comfort. This offers a more personalized and satisfying consumer experience. In addition, 3D printing makes it possible to create exclusive pieces, with designs, colors and textures chosen by the customer, offering a high level of customization (JIANPING, FEIFEI, 2023).

3.5. Contributions to Specific Sectors

3D printing has impacted several sectors of the textile industry, such as:

• **Fashion:**3D printing has been used by designers to create conceptual and innovative clothing pieces, exploring new shapes, textures and materials. Thus, it is possible to create unique pieces for special customers, who are willing to pay a high price for the exclusivity of their pieces, serving a market that demands exclusivity and customization, figure 9 (GIGLIO, PAOLETTI, CONTI, 2022).

Figure 9. Dresses produced with 3D technology (PEOPLE, 2023).

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• **Technical Textiles:**In the technical textiles sector, 3D printing has been used to produce personal protective equipment (PPE), healthcare products, athletic apparel and other specialized applications. The technology allows the creation of parts with specific properties, such as abrasion resistance, thermal insulation and impact protection (XIAO, KAN, 2022).

• **Home Textiles:**3D printing has been applied to the production of curtains, rugs, upholstery and other household items, offering greater creative freedom and customization. The technology allows for the creation of pieces with unique designs, innovative textures and functionalities adapted to the needs of each environment, see figure 10 (MANAIA, CEREJO, DUARTE, 2023).

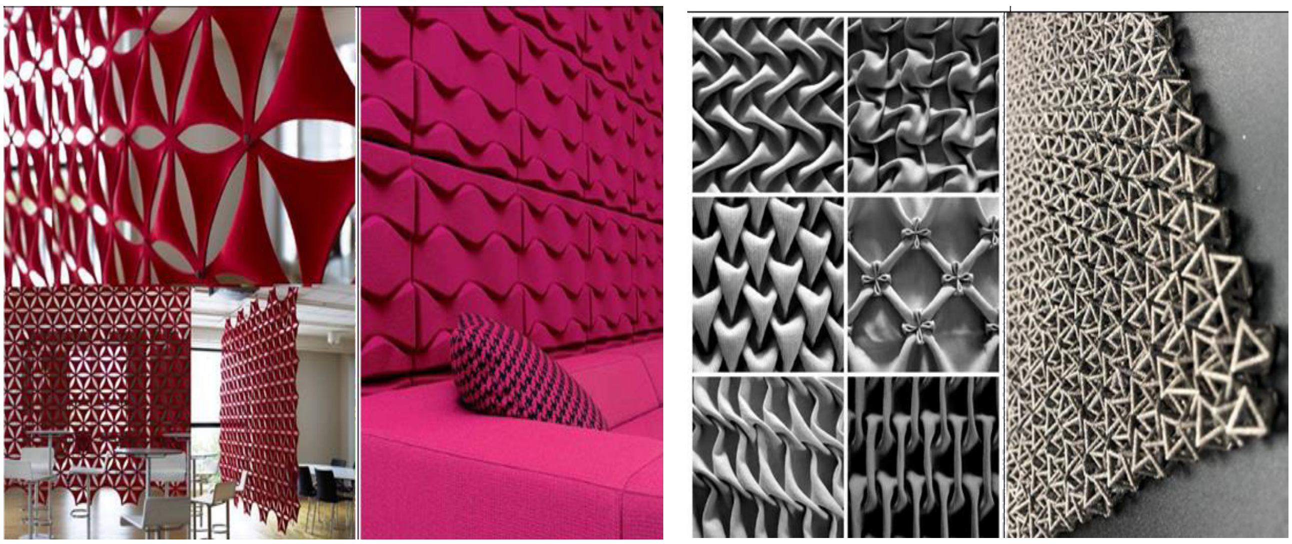

Figure 10. Images of curtains and partitions, wall decorations, cushion covers (TECHNICAL TEXTILES (2024). PINTEREST, 2024).

• **Accessories and Footwear:**3D printing has been used to produce accessories such as bags, belts, jewelry and footwear with innovative and personalized designs. The technology enables the creation of complex pieces, with intricate details and ergonomic adjustments, meeting an increasingly demanding market for exclusive products, figure 11 (SAXENA, 2023).

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Figure 11. Bags and shoes produced with 3D technology (ZHANG; DENG, 2021. PHROZEN, 2022. ARCHDAILY BRASIL, 2015. TECMUNDO, 2021).

4. IMPACTS OF 3D TECHNOLOGY ON THE SUSTAINABILITY OF THE TEXTILE INDUSTRY

4.1. Reducing Environmental Impact

The textile industry is known for its high environmental impact, due to the excessive consumption of water, energy and raw materials, in addition to the generation of waste and polluting emissions (SANTOS et. al., 2023). 3D printing emerges as a promising solution to mitigate these impacts, offering a path to more sustainable production.

3D printing allows for the reduction of water and energy consumption through on-demand production and the optimization of material use (GOPAL; LEMU; GUTEMA, 2023). By using only the necessary amount of material, the technology eliminates waste and reduces the need for resource-intensive processes, as well as the emission of polluting gases in the transportation of products.

4.2. Circular Economy

3D printing is a technology that can be integrated into circular economy models, with the reuse of printing materials and the creation of parts with recycled materials (SINGH; AHN, 2024). Materials such as regenerated cellulose, which can be produced from renewable sources

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renewable and biodegradable, and other recycled polymers, can be used in 3D printing, reducing dependence on virgin raw materials.

3D printing also offers the possibility of repairing and updating parts, extending their useful life cycle and avoiding premature disposal (MANAIA; CEREJO; DUARTE, 2023).

4.3. Sustainable Materials

The development of sustainable materials is a crucial aspect for reducing the environmental impact of 3D printing in the textile industry. PLA, produced from renewable sources such as corn and sugarcane, emerges as an alternative to petroleum-derived polymers. The use of composites with natural fibers, such as cellulose, flax and hemp, is also an alternative to reduce dependence on synthetic materials. Research into new materials with lower environmental impact and greater biodegradability is fundamental for the future of 3D printing in the textile industry (KUMAR et. al., 2024).

4.4. Local and On-Demand Production

3D printing enables local production, eliminating the need for large production chains and reducing the environmental impact associated with transporting products. Local and on-demand production makes it possible to create parts adapted to the needs and preferences of each region, using materials and techniques that take into account climatic and cultural conditions. Local production also boosts the regional economy by supporting small producers and local businesses.

4.5. Comparative Sustainability Analysis

Comparative analysis of the economic sustainability between traditional textile production models and additive manufacturing by 3D printing is essential to assess the long-term viability of this technology in the sector. A careful assessment of costs throughout the entire product life cycle, from the acquisition of raw materials to marketing and disposal, allows us to identify the economic advantages and challenges inherent to each production method.

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The preliminary cost-benefit analysis indicates that 3D printing, under certain conditions, can offer a more economically advantageous model for the textile industry. On-demand production, a characteristic of additive manufacturing, significantly reduces the costs associated with excess inventory and losses due to obsolescence, which are common in traditional production models. In addition, the ability to customize products through 3D printing opens up new market opportunities and increases the value perceived by consumers, resulting in potentially higher profit margins. The possibility of using recycled or sustainably sourced materials can also reduce raw material costs and position the company as environmentally responsible, a factor increasingly valued by consumers. However, it is crucial to consider the investment costs in 3D printing equipment and software, as well as the energy costs of operation. Optimizing the production process, reducing printing time and using materials efficiently are key factors in ensuring the economic competitiveness of additive manufacturing in textiles. A careful cost-benefit analysis, including return on investment (ROI) assessment, is essential for a successful economic transition to this production model. Therefore, the focus should be on management that balances economic and environmental aspects, so that 3D printing consolidates itself as an economically viable and sustainable alternative for the textile industry (SHAH et. al., 2024).

5. CHALLENGES AND LIMITATIONS OF 3D TECHNOLOGY IN THE TEXTILE AREA

5.1. Technical Challenges

Despite its transformative potential, 3D printing in the textile industry faces some technical challenges that need to be overcome. Production and equipment costs are still high, limiting the adoption of the technology by small businesses and producers (DHIWAR, AMBTKAR, BEDARKAR, 2024). The scalability of large-scale production is another challenge, as manufacturing large quantities of parts with 3D printing is still slower and more expensive than traditional methods.

The finish and texture of printed fabrics also have some limitations, as printed materials tend to be stiffer and less malleable than traditional fabrics. The durability and resistance of printed materials also need to be improved, so that the pieces produced can withstand wear and washing. Comfort properties, such as flexibility,

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breathability and moisture absorption also need to be optimized so that printed fabrics can be used in apparel and other applications that require comfort and functionality.

5.2. Material Limitations

The availability of materials with suitable properties for textile 3D printing is another limitation. The variety of materials that meet the requirements of flexibility, durability, comfort and functionality is still limited, which makes it difficult to create parts with the same characteristics as traditional fabrics (ALI; DEIAB; PERVAIZ, 2024). In addition, the cost of more advanced materials with specific properties can be high, limiting their use on a large scale.

Research and development of new materials for textile 3D printing is essential to overcome these limitations. Biodegradable, recycled materials with functional properties and improved performance in terms of comfort and durability are needed to drive the adoption of the technology in different sectors of the textile industry.

5.3. Design and Adaptation Challenges

Adapting product designs for the 3D printing process also poses a challenge. Designers need knowledge and skills in 3D modeling, CAD software, and printing techniques to create parts that are suitable for 3D production (XIAO; KAN, 2022).

Creating accurate molds that fit the user's body also requires knowledge and experience in design, modeling, and adaptation to the printing process. The need for technical expertise in 3D modeling and CAD software can represent a barrier to the adoption of the technology by small businesses and independent designers.

5.4. Economic Barriers

Economic barriers represent a major obstacle to the large-scale adoption of 3D printing in the textile industry. The high cost of equipment, the need for investment

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in research and development, and competition with traditional production methods make the technology less accessible to many producers (MANAIA; CEREJO; DUARTE, 2023).

The difficulty in achieving economic viability in large volumes is another challenge, as mass production with 3D printing is still more expensive than conventional methods. Acceptance of the technology by the consumer market is also important, as many consumers are still unfamiliar with 3D printed products and are unaware of their advantages and benefits.

6. FUTURE PROSPECTS AND TRENDS

6.1. 4D Printing

4D printing, which combines 3D technology with smart materials that transform over time, is emerging as a promising trend in the textile industry. This technology allows the creation of adaptable and responsive fabrics that change their properties in response to variations in temperature, humidity, light and other stimuli (MANAIA; CEREJO; DUARTE, 2023).

4D printing opens up a range of possibilities for the creation of multifunctional and adaptable fabrics that can be used in a variety of applications, from clothing that adapts to climate conditions to healthcare products that respond to the user's needs. The development of materials with shape memory and transformation capabilities is essential for the advancement of 4D printing in the textile industry.

6.2. Smart Materials and Nanotechnology

The integration of smart materials and nanotechnology into 3D textile printing offers possibilities for creating fabrics with advanced properties. Nanomaterials such as carbon nanotubes and graphene can be used to create fabrics with electrical conductivity, allowing the integration of electronic components. Antimicrobial and UV-protective materials can also be integrated into 3D printed fabrics, offering greater functionality and protection (LI, 2023).

Nanotechnology can also be used to create materials with greater resistance, flexibility and durability, optimizing the properties of 3D printed fabrics. In addition,

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Nanomaterials can be used to improve the finish and texture of fabrics, making them more comfortable and pleasant to the touch.

6.3. Artificial Intelligence and Automation

Artificial intelligence (AI) and automation have the potential to revolutionize the production of 3D printed fabrics. Through AI, it is possible to create innovative designs more quickly and accurately, optimizing printing parameters and ensuring material quality. Automation, in turn, speeds up the production process, enabling the manufacture of customized parts on a large scale. This synergy between AI and automation not only reduces costs and production time, but also makes it possible to create fabrics with unique properties tailored to different applications, as shown in Figure 12, an example of a fabric developed with the help of these technologies.

Figure 12. AI-created and 3D printed dress (FREEPIK, 2024).

6.4. Collaboration and Innovation Ecosystems

Collaboration between designers, engineers, materials scientists and companies is key to accelerating innovation in the area of textile 3D printing. The creation of innovation ecosystems, where different professionals and companies work together on the development of new technologies,

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materials and products, can boost the adoption of 3D printing in different sectors of the textile industry.

The exchange of knowledge, collaboration in research and development projects and the creation of contact networks between companies, research institutions and designers are important for the advancement of technology and for the training of professionals qualified to work with 3D textile printing (MANAIA; CEREJO; DUARTE, 2023).

7. CONCLUSION

3D printing is emerging as a technology with great transformative potential in the textile industry, offering new and innovative possibilities for the creation of products, especially in areas such as fashion and technical textiles. Although it still faces challenges and limitations in terms of production scale and costs, the technology has already demonstrated its effectiveness in several segments of the sector, providing a series of advantages, such as the optimization of production processes, the reduction of logistics costs and the minimization of waste, which contributes to environmental sustainability. In addition, 3D printing makes it possible to create textile materials and parts with specific and personalized properties, allowing for a huge variety of applications that meet different market needs and demands.

Recommendations

Future research should focus on developing biodegradable and recyclable materials for 3D textile printing, as well as optimizing the properties of printed fabrics, such as flexibility, breathability, durability, and touch. It is essential to investigate the application of nanomaterials and smart technologies in the creation of functional and adaptable fabrics, capable of meeting the growing market demands for innovative and sustainable products. In addition, it is crucial that companies and governments invest in training and development in the use of 3D printing and modeling software, ensuring that they can apply the technology appropriately.

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