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Review

Global Trends and Practices of Industry 4.0 Applications in the Clothing Sector: A Systematic Literature Review

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Abstract: The potential of Industry 4.0 enabling tools is emerging as a strategic factor for the adaptation and innovation of companies in the clothing sector. Thus, the aim is to identify global trends and practices in I4.0 applications in the clothing sector based on a systematic literature review. From the systematic literature review, 11 articles were selected from the Scopus and Web of Science databases. The results showed global trends in the application of I4.0 enabling tools, such as the Internet of Things, Cybersecurity and Additive Manufacturing, in addition to the benefits that I4.0 can provide in manufacturing, such as the possibility of efficient processes with lower operating costs. When studying the perception of businesspeople, the most critical dimensions were: vertical integration, flexibility, data analysis, supply chain integration, traceability, remote production monitoring, strategy, organizational culture and people. The originality of the paper is highlighted by its specific sectoral focus, emerging applications of Industry 4.0 and holistic approach to the value chain. In addition to the academic contribution in terms of mapping key global trends, identifying challenges and opportunities and providing a basis for future research, the results can provide practical recommendations for companies in the apparel sector seeking to start or accelerate their digital transformation journey.

Keywords: Industry 4.0; clothing; industrial automation; enabling technologies; digital transformation

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1. Introduction

The engagement of the digital era with the production process resulted in a change in the current paradigm: the emergence of smart factories, which can connect machines with people through the integration of wireless systems and sensors. The enabling tools for this include Cyber-Physical and the Internet of Things (IoT), in which devices can share information autonomously. In this way, products are affected when innovative tools are adopted concerning production, sales, and logistics to their destination (Sarı et al. 2020).

Throughout history, abrupt changes in the production process can be observed, such as the phases of the industrial revolutions, with the First Revolution marked by the mechanization of steam engines, with the positive effect of reducing the manual effort of workers (Bataglini 2021; Kusi-Sarpong et al. 2022).

The Second Revolution was enhanced using electricity, allowing the modernization and standardization of the production line, providing leaner production concerning waste. The Third Industrial Revolution was responsible for the computerization of factory machines, enabling the generation of information in real-time, in which production began to be managed by a minority receiving information quickly. Thus, decision-making became more assertive (Kusi-Sarpong et al. 2022).

The modernization of the industry continued to advance when, in April 2011, the Hannover Conference addressed the development of autonomous robots that were similar in appearance and decision-making to humans, beginning the fourth phase of the industrial revolution or Industry 4.0 (I4.0), in which its arrival and its enabling tools not only impacted the industry but also reached the political, economic, business and social layers (Kusi-Sarpong et al. 2022).

According to Sarı et al. (2020), the digital transformation of a traditional industry to an intelligent format is achieved through the massive production of data emitted by things in real time through automated intelligent technologies and convergence between the physical and digital worlds. This digitalization effect is possible and viable, intending to adopt much faster and more efficient routines and operational practices through one of the nine relevant support bases for technological advancement for industrial activity, in which data are obtained in real-time in the entire value chain through tools. Big data, additive manufacturing, cloud computing, information security, IoT, systems integration, artificial intelligence, augmented reality, and autonomous robots will provide benefits after the adoption of these applications, causing positive changes for intelligent production. The process of digitizing manufacturing requires skills and resources to be fully implemented. On the other hand, this digitalization will boost production and make the manufacturing industry more competitive.

The presence of I4.0 in the textile and clothing sector is mainly characterized by the connectivity of wireless sensors and devices connected to the internet, integrated with production control, through bar codes, RFID tags, sensors, global positioning system (GPS), and Bluetooth. The consequence is a fusion of the natural world with the virtual environment, which creates cyber–physical systems. It allows networked manufacturing technologies, innovation and practical applications to solve problems. The goal is to add value to products and services, resulting in flexibility and productivity gains (Dal Forno et al. 2023; Akhtar et al. 2022).

In this context, according to Fromhold-Eisebith et al. (2021), traditional industries are resistant to the acceptance of the implementation of new technologies and computerized systems within the industry's production routine, which is encompassed in the list of risks and challenges.

Thus, Falani et al. (2021) highlight the three most recurrent and relevant challenges for implementing I4.0 concepts in the clothing sector: investment in technologies, lack of qualified labor, and a change to a new business layout. The implementation of I4.0 technologies in emerging countries presents more resistance than developed countries (Wijewardhana et al. 2021). Furthermore, it can be highlighted that this deficit in acquiring I4.0 enabling technologies is caused by the need for clarifications related to the cost–benefit of the applications, which denotes a lack of information. Another facet is the lack of qualified professionals to handle new technologies (Confederação Nacional da Indústria 2016).

Historically, it has been observed that the clothing industry seeks modernization to provide agility in preparing clothing items and production flow. It depends on a complex and well-branched production chain (from fiber production to the final customer), responsible for formal and informal employment, which it employs directly or indirectly. According to the Brazilian Association of the Textile and Clothing Industry (ABIT) (Associação Brasileira da Indústria Têxtil e de Confecção 2022), clothing is the sustenance source for many families located around the local production arrangement.

Thus, the discussion outlined here innovates by carrying out the theoretical—empirical exercise of industry 4.0 and the clothing sector and by revealing how the two constructs are approached jointly in the intellectual production related to the theme. Given this perspective, the research presents the following question: What are the main trends and practices of Industry 4.0 in the clothing sector? Therefore, the aim is to identify global trends and practices in I4.0 applications in the clothing sector based on a systematic literature review. Thus, the hypothesis raised by this paper is that the application of Industry 4.0 technologies in the apparel sector is driving significant innovations in production processes, mass customization and sustainability, resulting in efficiency improvements, cost reduction and greater responsiveness to consumer demands. This hypothesis focuses on the main global trends, practices and expected benefits of adopting Industry 4.0 technologies in the apparel sector.

Among the original points of this paper, the specific sectoral focus, emerging applications of Industry 4.0 and the holistic approach to the value chain stand out. It is worth mentioning that although the literature presents several studies on Industry 4.0, studies dedicated exclusively to the apparel sector are still incipient. This sector has particularities in terms of supply chain, production and demand for innovation, which make the findings of this study valuable. In addition to the academic contribution, regarding the mapping of the main global trends, the identification of challenges and opportunities and the basis for future research, the results can provide practical recommendations for companies in the apparel sector that are seeking to start or accelerate their digital transformation journey.

This paper is structured into five sections, including this introduction. Section 2 highlights the Theoretical Background, addressing the historical context and tools, characteristics, challenges, and impacts of Industry 4.0. Section 3 presents the Materials and Methods used to carry out the research. Then, the research results will be described and analyzed in Section 4. Finally, in Section 5, we provide our conclusions and final remarks.

2. Theoretical Background

This section presents the historical context and tools, characteristics, challenges and impacts of Industry 4.0 that will guide this Systematic Literature Review.

2.1. Industry 4.0

The historical process of the production system of the clothing sector has passed through four stages. The first was a leap from the mechanical loom to steam, an event in steam-powered machinery whose responsible engineer was Cartwright in 1785 (Cartwright 1785). Then, there was the emergence of the standardization of the mass production system after the insertion of electrical energy, and later, there was an increase in the automation of machines, which were connected by systems and computers, making it possible to add intelligent systems and machines to the industries (Dal Forno et al. 2023).

The phases of industrial revolutions are responsible for changes in the production process through technological advances, which directly impact the efficiency and optimization of the use of inputs and a qualitative increase in productivity. The arrival of the steam engine marked the First Industrial Revolution (1712–1913), a technological advancement created by James Watts. In this way, steam engines replaced human labor in several segments, resulting in, in addition to the increase in different types of pollution, unequal distribution of income, favoring the impoverishment of families and concentration of wealth among large industries (Tessarini and Saltorato 2018).

With the Second Industrial Revolution (1913–1969), assembly lines and the division and standardization of labor inspired by the Taylorism movements emerged (Tessarini and Saltorato 2018). The Third Industrial Revolution, also known as the Digital Revolution, emerged in the 1970s (1970–2010) due to the emergence of new robust technologies through the exploration of electronics and information technology, incorporated in different areas of advancement, such as automation, information technology, genetic engineering, electronics and chemistry.

The processes were computerized, resulting in a considerable reduction in jobs previously occupied by human labor (Tessarini and Saltorato 2018). According to Schwab and Davis (2019), the emergence of the Fourth Industrial Revolution (2011—the present day) is not restricted only to the use of enabling tools that are integrated by systems with intelligent machines but are structured around the pillars of discoveries, covering several areas, including nanotechnologies and renewable energies, encouraging sustainability on the planet.

The expressions Industry 4.0 (I4.0), the Fourth Industrial Revolution, advanced manufacturing, industry and intelligent manufacturing allude to innovative technologies that enable increased productivity and correlation between production stages in the clothing sector, which allow for the development of transformative products and services (Falani et al. 2021).

In this context, Industry 4.0 refers to disruptive and technological transformations that modify the traditional arrangements and relationships between economic factors and bring new business opportunities. According to Lima and Gomes (2021), Industry 4.0 is characterized by presenting solutions that optimize equipment, activities with high added value and software that allows the use of materials in effective and efficient methodologies in manufacturing customized goods.

Furthermore, Industry 4.0 originated in Germany, with the use of new technologies in the industrial process as its foundation. Therefore, countries such as the USA, Japan, United Kingdom, China, and South Korea began to use the expression Industry 4.0 in different terms aimed at their needs, making it a global industry (Kagermann 2013).

In this context, I4.0 can be understood as a viable solution applied in several countries around the world and has a fertile field of action, as it was previously restricted to specific sectors and segments, for example, the automobile industry, with its powerful productive centers.

Thus, although I4.0 was made official in 2011, according to Madsen (2019), I4.0 was already marked during the global financial crisis from 2008 to 2009. Similarly, Dastbaz and Cochrane (2019) argue that the definition of I4.0 originated after the financial crisis due to industries needing to boost profitability and competitiveness so that economic growth and recovery from the recession could be encouraged.

In this way, it is observed that the use of information technology in manufacturing environments contributes to the insertion of disruptive technologies in industrial processes, referring to the enabling tools of I4.0, such as the Internet of Things, big data and data analysis, increased reality, cybersecurity, among others, which are responsible for improving production processes throughout the value chain (Gausemeier 2016).

2.2. Indutry 4.0-Enabling Tools

New technological trends, currently considered tools that enable Industry 4.0, have a digital aspect, with applications in various manufacturing stages, adding value to the production process. The integration of these tools, such as cyber–physical systems, IoT and Internet of Services, big data analytics and cloud computing, artificial intelligence, robotics, virtual modeling or digitization of industrial processes, among others, generate varied benefits, such as reducing production line automation, reducing process variability, standardizing processes, and accelerating inspections, providing better quality control and promoting more effective and practical operational safety (Luu et al. 2019). Thus, considering the aspects mentioned above, Table 1 shows the representation of the tools that enable Industry 4.0, their main characteristics, and their application in the production process.

From Table 1, it is possible to verify the broad application of the tools and how they become essential for transforming the manufacturing environment and promoting cultural and productive disruption. Verifying the significant applications of enabling tools in the clothing sector is possible. One example is big data analytics, a trending tool, as it has a proposal for storing, filtering, and consolidating results. It adds value to assertive decision making and makes production more competitive. Augmented reality, a trend in the fashion industry, allows the creation of scenarios in a virtual format, reducing waste. Cloud computing deals with server storage with encrypted keys, optimizing rental costs and security of physical spaces (rooms). Additive manufacturing is widely used in fashion shows and accessories (necklaces, earrings, bracelets, watches), reducing acquisition costs (Falani et al. 2021).

Table 1. Industry 4.0-enabling technologies.

Enabling Tool	Characteristics	Definition
Big Data and Analytics	Pre-processing and processing information from a huge volume of data, with high speed and diversity.	It consists of collecting a huge volume of data generated by several systematized sources, with diverse traffic at high speed of information processing (Wasim 2019).
Internet of Things	Automatic communication between devices via the internet.	The integration of objects from different areas with sensors connected to the internet transmitting information in real time (Fachini et al. 2017).
Machine to Machine—M2M	Automatic communication between devices allowing machines to exchange data and perform actions without human intervention.	It consists of the type of technology that allows direct communication between devices, sensors or machines without the need for human intervention (Fachini et al. 2017).
Robotics	The union of three essential elements, such as mechanics, electronics, and programming, which allows the development of a range of skills.	They are safe, flexible and economical, managed directly by a smart factory and responsible for significantly changing the production chain (Amaral and Gasparotto 2021).
Cloud Computing	Computational resources file storage, virtual servers, database, software.	It is responsible for managing and processing the database, enabling access to information from any geographic point in the world that has internet (Xu et al. 2014).
Augmented Reality	It combines real-world elements with virtual 3D elements, allowing interactivity between objects (real and virtual) in real time.	Its purpose is to make processes intelligent, responsible for the communication link between elements of the real and virtual world (Falani et al. 2021).
Additive Manufacturing (3D)	Prints objects through the progressive overlapping of a material.	A technique for manufacturing a wide variety of structures through the addition of materials in overlapping layers to form an object. It strongly relates to the short production time and eliminates waste in production (Falani et al. 2021).
Artificial Intelligence	Intelligent perception capacity, such as visual perception, speech perception, auditory perception and processing and learning of perceptual information.	It is a process used to manage experiences on machines that depended directly on human interference. Algorithms evaluate situations on their own and optimize machine settings (Falani et al. 2021).
Cybersecurity	Storage of a large volume of information that can be accessed from anywhere in the world.	It uses policy-action mechanisms to protect information from potential threats (Dal Forno et al. 2023).
Integration systems	Software that promotes interaction between all industry components.	It can also be called hardware systems integration, and aims to create and integrate vertically and horizontally, data, processes and management systems (Dal Forno et al. 2023).

Clothing is a human necessity. Initially adopted by nomads in the prehistoric period, who made them by hand, skirt-type garments were created from the leather acquired from animals captured during hunting (Pereira 2015). These garments had the sole purpose of protecting and sheltering the nomads from the cold. As man evolved, his way of dressing adapted according to his customs and climatic conditions, increasing the demand for clothing production due to population growth. As a result, it was necessary to increase new technologies to assist in the processing of fabric and speed up the delivery of finished garments (Mendes et al. 2015; Bataglini et al. 2021). Table 2 presents a comparison between the production stage of clothing production without the use of 4.0 technology and with the implementation of these technologies in different processes.

Table 2. Overview of the production stages of a garment factory with and without I4.0 technology.

Clothing Sectors	Textile Manufacturing Process	Without I4.0 Technology	With I4.0 Technology
Manufacturing Inventory	Separation of the fabric roll and supplies for cutting and sewing	Removing supplies for manufacturing	Blockchain
Manufacturing Office	Idealization of a new clothing model	Drawing on paper and cutting fabrics with pins	3D Design
Designer's Office	Visualization of prototypes	Assembling pieces on a mannequin	Augmented reality (AR)
	Request for adjustments or approval of the model	Presenting them physically or by photo	Remote collaboration via AR
	Sewing and assembly of clothing items	Sewing the prototype and testing on machines	Model created in 3D and fitting via augmented reality
	Discarding of incorrect items	Throwing raw materials in the trash	Delete unapproved files to the computer's trash
Production Line	Training of seamstresses for the new garment	Just delivering a photo or a mannequin wearing the new model	Training of the sewing team in advanced techniques via AR
	Quality control (Anti-defect)	Manual checking to identify possible defects in the piece	Advanced inspection via artificial intelligence
Marketing	Fitting rooms	Physical fitting rooms with curtains	Virtual fitting rooms
Inventory	Visualization of production status	Physical form monitoring	Automatic storage and entry into the system via barcode and QR code
Information Technology	Data center	Poor data systems	Security with firewall to prevent invasions

Through the information above, it is possible to understand that the arrival of 4.0 technology in the industry has brought many gains through the implementation of technology. One point to be highlighted, about the manufacturing inventory, is that the adoption of technologies, such as blockchain, allows for more efficient management, enabling traceability from the separation of the roll of fabric and trimmings to the removal of inputs for manufacturing. This reduces the risk of errors and optimizes logistics (Magalhães and Vendramini 2018). Machado and Delis (2021) state that in the manufacturing and designer's office, the transition to 3D design and augmented reality have revolutionized the creative process, allowing the idealization of new clothing models in a more agile and interactive way. Visualizing prototypes through augmented reality facilitates remote collaboration, speeding up adjustments and approvals. On the production line, the introduction of training in advanced techniques through AR for seamstresses increases teams' skills, contributing to the production of high-quality pieces. Quality control also benefits from artificial intelligence, which performs advanced inspections, identifying possible defects more quickly and accurately.

According to Girard (2017), in the marketing field, the adoption of virtual fitting rooms transforms the customer experience, replacing physical fitting rooms with digital solutions, which are more practical and accessible. Finally, in the warehouse, the visualization of production status, combined with automatic storage via barcode and QR code, provides more effective monitoring, ensuring the integrity and accuracy of information, while in IT, data security is improved, avoiding threats with the use of companies standard firewall, ensuring the protection of the data center.

These innovations converge toward more efficient, productive and technologically advanced management in the clothing industry, enhancing the benefits in several aspects of the process. Thus, the implementation of I4.0 technology in the clothing industry represents a significant transformation in the entire production process. From design conception to delivery to the customer, I4.0 technology offers efficiency, precision and innovation. The use of tools such as artificial intelligence, augmented reality, IoT and automation redefines the way the clothing industry operates, improving quality, reducing waste and optimizing the entire production and logistics chain (Yamada and Martins 2019).

According to data from the 2023 annual report of the Associação Brasileira da Indústria Têxtil e de Associação Brasileira da Indústria Têxtil e de Confecção (2022), the textile and clothing sector in Brazil ranks 5th in the textile industry dimension and 4th in the clothing segment, worldwide. This sector has relevant growth indicators in terms of production, employment and revenue.

In 2021, the sector managed to close with a clothing production of a little over 8 billion pieces launched on the market, as it employs a large contingent of people. In the same year, there were around 1.34 million formal employees, who were responsible for revenue of around BRL 1.9 billion, representing a growth of BRL 29 billion compared to 2020, the result of an investment of around BRL 4.9 billion (Cavalcanti and Santos 2022).

3. Materials and Methods

We developed a systematic literature review to identify global trends impacted by the digital transformation of Industry 4.0 applications. The methodological path of this systematic literature review is presented in Figure 1 and involves three steps: (1) Planning, (2) Conducting and (3) Execution (Gomes et al. 2022).

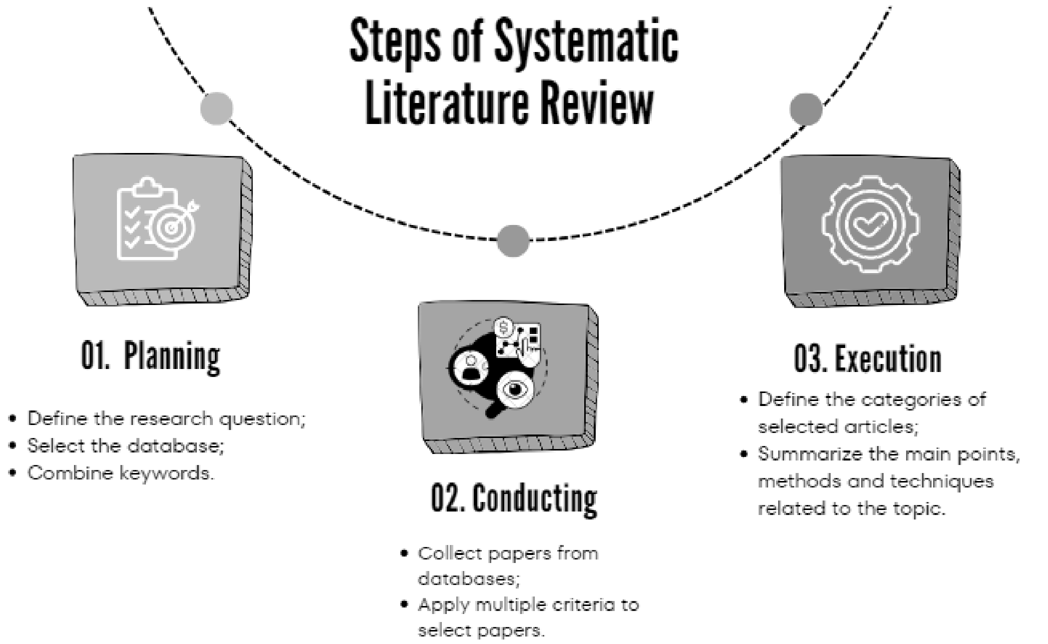

Figure 1. Steps of systematic literature review. Source(s): Adapted from Gomes et al. (2022).

In the first methodological stage, we prioritize defining the research questions, choosing the databases to be consulted, selecting the materials found, and structuring the subsequent steps. The following were used as the guiding questions: What has been discussed about digital transformation in the clothing sector? What perspectives are projected by the digital transformation of I4.0 in the clothing sector? Moreover, what benefits in the scope of work organization could entrepreneurs achieve in the clothing sector? These questions allowed us to verify the need for the study to be carried out to expand and modernize the vision of the directly involved researchers. From the questions presented, combinations of keywords, categories, and connectives were listed, which resulted in the presentation of Table 3.

Table 3. Combination of keywords.

Description of Titles	Connectors and/or	Description of Topics
Industry 4.0	and	Apparel
Industry 4.0	and	Garment
Industry 4.0	and	Fashion
Industry 4.0	and	Textile

In the second stage, relevant works from the scientific literature were captured through a search conditioned to inclusion and exclusion criteria (Table 4). Among the academic databases, the two largest in international representation and concept were selected: "Scopus" and "Web of Science" (WOS), as they are two platforms that cover articles from several journals with a high impact factor.

Table 4. Inclusion and exclusion criteria.

ID	Inclusion	ID	Exclusion
CI1	Articles published between the years 2018 and 2023	CE1	Any work outside this time frame
CI2	Only works in English	CE2	Articles written in any language other than English
CI3	Articles related to business	CE3	Articles that are not related to the business area
CI4	Works that are related to the topic studied (title and Abstract).	CE4	Articles that are not related to the subject of this study in the title or abstract
CI5	Full article reading		

In these databases, the phases of the theoretical survey were designed based on criteria that, in addition to keywords, were based on the period of publication (from 2018 to June 2022), language (English), sub-area of knowledge ("Business"), textual content (whether the available text is complete or not—exclusion of incomplete text), duplication of articles on the platforms as mentioned earlier (exclusion of duplicate articles), words contained in the titles of publications.

Therefore, we converged on a selection of works, following the inclusion and exclusion criteria for a subsequent document analysis, which, in turn, was recorded in organizational spreadsheets using Excel. Thus, the string search scheme is presented in Table 5.

Table 5. Combination of keywords of the deployed query.

Basis	String
WOS—Web of Science	INDUSTRY4.0 (Topic) and APPAREL (Topic) or INDUSTRY 4.0 (Topic) and GARMENT (Topic) or INDUSTRY 4.0 (Topic) and FASHION (Topic) or INDUSTRY4.0 (Topic) and Textile (Topic) and 2023 or 2022 or 2021 or 2020 or 2019 or 2018 (Publication years) and English (Idioms) and Business (Categories of Web of Science) and Articles (Kinds of document).
Scopus	(TITLE-ABS-KEY (industry 4.0) AND TITLE-ABS-KEY (apparel) OR TITLE-ABS-KEY (industry 4.0) AND TITLE-ABS-KEY (garment) OR TITLE-ABS-KEY (industry 4.0) AND TITLE-ABS-KEY (fashion) OR TITLE-ABS-KEY (industry 4.0) AND TITLE-ABS-KEY (textile)) AND (LIMIT-TO (PUBYEAR, 2022) OR LIMIT-TO (PUBYEAR, 2021) OR LIMIT-TO (PUBYEAR, 2020) OR LIMIT-TO (PUBYEAR, 2019) OR LIMIT-TO (PUBYEAR, 2018)) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (SUBJAREA, "BUSINESS").

Then, we analyzed the obtained papers, and those that involved many of the subjects highlighted above and presented institutional, methodological and results solidity were considered for the next phase of execution. According to Figure 1, it is observed that from the initial amount of work identified, 11 articles were obtained at the end of the process to review and consolidate the study. After searching and thoroughly exploring the content, the materials that addressed the research question were selected. Figure 2 summarizes the trajectory of the systematic review, flanked by the respective results achieved in each phase.

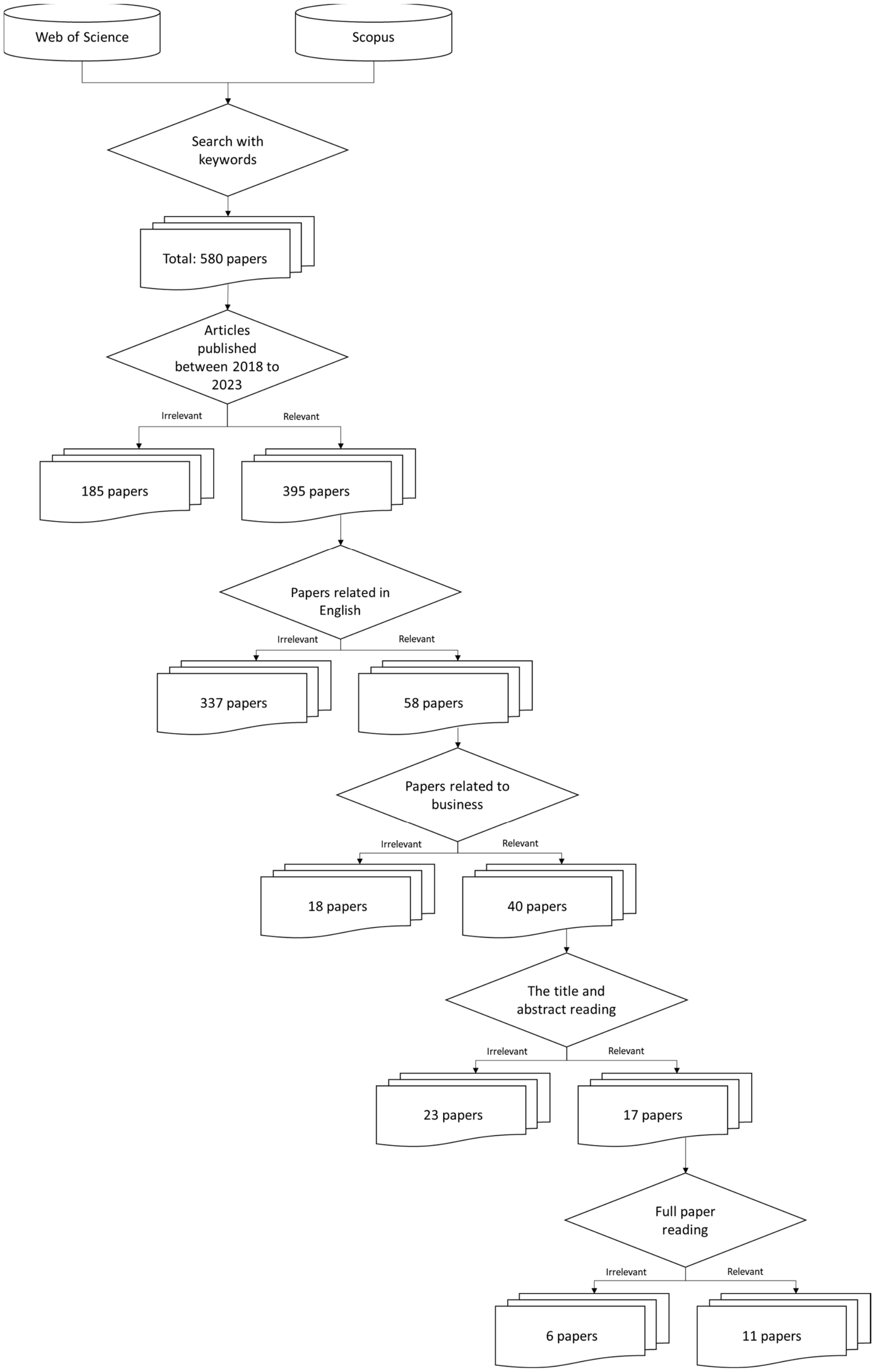

Figure 2. Trajectory of the systematic literature review.

4. Results and Discussion

From the remaining 11 papers, we present the number of articles published per year as shown in Figure 3.

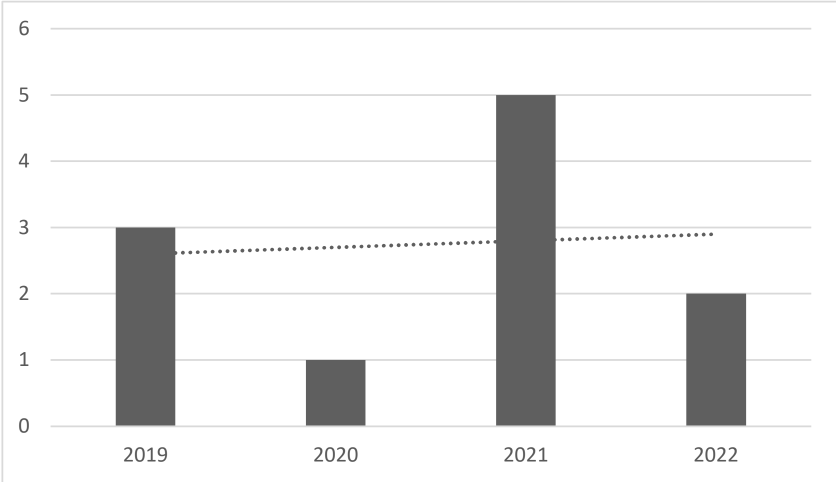

Figure 3. Papers published per year.

The literature on this specific topic is scarce, making essential the existence of a field of study still under construction. Based on the systematic literature review carried out through the 11 selected papers, it was possible to verify that no articles from the years 2018 and 2023 were selected for analysis. The year 2021 presented the most relevant papers on this topic. Table 6 details the 11 articles selected based on titles, authors, publication period and objectives.

Figure 4 presents the cloud with the most used words in the titles of the papers selected for this study. One can observe that the most frequent words are industry, textile, production and technology. These words refer to the theme explored here, indicating that the selected articles correspond to the study's objective.

Figure 4. Word cloud formed using the titles of articles selected for LSR.

Table 6. Summary of the selected papers.

Title	Authors	Year	Main
Use of Industry 4.0 and Organizational Innovation Concepts in the Serbian Textile and Apparel Industry	Lalic, Rakic and Marjanovic	2019	Present the applicability of Industry 4.0 through scientific evidence.
Digitization and Industry 4.0 in the Portuguese T&C sector	Luu, Marques and Ferreira	2019	Discuss new directions in the textile and clothing industry, the use of new tools that can influence new strategies.
The Emergence and Rise of Industry 4.0 Seen Through the Lens of Managerial Fashion Theory	Madsen	2019	Carry out a critical analysis of the internal and external environments that were influenced by I4.0.
Awareness and Readiness of Industry 4.0: The Case of Turkish Manufacturing Industry	Sari, Güleş and Viğitol	2020	Investigate the application of Industry 4.0 concepts in manufacturing factories.
Torn Between the Digitized Future and the Context-Dependent Past—How the I of 'Industry 4.0' Production Technologies Can Transform the German Textile Industry	Fromhold-Eisebith, Marshall, Peterrsb and Thomasb	2021	Present the advances and challenges of a textile industry in the process of modernizing production, using the digital tools of industry 4.0.
New Product Development Process in the Apparel Industry Using Industry 4.0 Technologies	Wijewardhana, Weerabahu and Nanayakkara	2021	Measure the technological development processes of new products in the textile area.
Initial Overview of Industry 4.0 in Textile Companies in Santa Catarina	Falani, Aguiar and Forno	2021	Analyze the use of I4.0 tools in a region of Brazil.
3D Printing Technology: An Overview of the Textile Industry	Bataglini, Forno, Steffens and Souza	2021	Present the history, concept and applicability of additive manufacturing (3D Printing) in the textile industry.
Industry 4.0 in Textile and Apparel Sector: A Systematic Literature Review	Dal Forno, Bataglini, Steffens and Ulson	2021	Present concepts and tools that enable I4.0, and their application in the textile and clothing sector.
Coordination Mechanisms for Digital and Sustainable Textile Supply Chain.	Kumar, Sharma and Pandey	2023	Analyze the textile supply chain, sharing virtual information to reduce environmental impacts in unnecessary production.
Intellectual Capital, Blockchain-Driven Supply Chain and Sustainable Production: Role of Supply Chain Mapping	Kusi-Sarpong, Mubarik, Khan, Brown and Mubarak	2022	Present the relationship between man and machine, allowing sustainable production, through supply chain mapping, through blockchain integration.

Upon the analysis of the selected papers, we could observe that they can be categorized into two groups: (1) Sustainable supply chain development in the textile and apparel sector through I4.0; (2) Application of I4.0 tools in the textile and apparel sector. The number of papers per category is shown in Figure 5.

In the first category (Sustainable supply chain development in the textile and apparel sector through I4.0), two (2) articles are listed, and in the second (Application of I4.0 tools in the textile and apparel sector), nine (9) articles are listed. We highlight that only two papers discuss strategies to overcome challenges related to sustainability, addressing personalization as a trend for the sustainable fashion production process, causing an ecological impact on textile production and using blockchain technology. It is essential since polluting residues are emitted into the water, air and soil during the production of textile products. Then, it is crucial to create mechanisms for production traceability, allowing the visualization of each stage of the production process through visual management (being an ideal tactic for identifying bottlenecks) and carrying out interventions to the point of generating a transformation towards a sustainable industry through the context of I4.0 (Kusi-Sarpong et al. 2022).

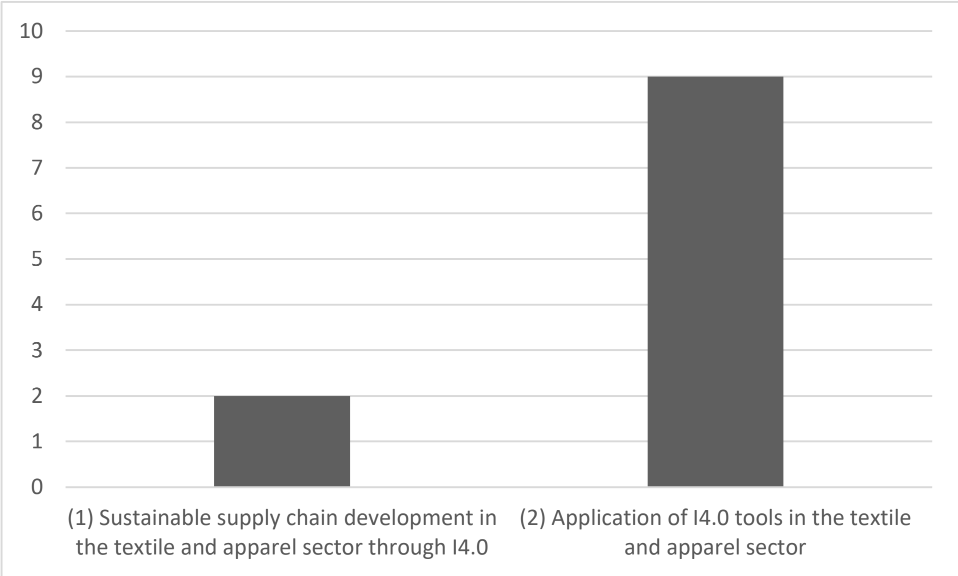

Figure 5. Number of papers per category.

Regarding the second category, the widespread trends were related to the applicability of enabling tools in the clothing industry, including IoT, autonomous robots, and augmented reality. Specifically, the main advantage of IoT is the short response time and interaction between industry, customer and product through sensors responsible for monitoring and collecting information. Corroborating with Sarı et al. (2020), in the context of clothing, through IoT technology, it is possible to share data in real time between machines, suppliers, products and customers applied in the clothing area, capable of optimizing production processes, through the collection and mining of information during the useful life of the products.

IoT and industrial robotics need more specialized labor, only available in some parts of the world, raising the need for handy and easy-to-use robotic platforms in the organization and execution of activities (Dal Forno et al. 2023). Thus, the use of these technologies makes possible favorable conditions for the logistical flow of production in the clothing industry, which occurs through unmanned and autonomous vehicles, such as drones or cars, which in turn denote safety, agility and efficiency in conveying inputs and products to their programmed, coded and tracked destinations.

In this sense, this technological device would be a possible alternative to unpredictability scenarios, such as were noticeable during the lockdown period caused by COVID-19. Autonomous technologies were sought as a possible solution for daily relationships. One example is sending clothes and accessories via delivery to customers, ensuring the growth of commerce during the pandemic and developing alternatives for the growth of the clothing sector 4.0. This scenario was also observed in quality control, which used mechanisms through islands of robots with sensors to inspect products, ensure quality excellence and eliminate defective products (Dal Forno et al. 2023).

Similarly, another technology from Era 4.0 that revolutionized and strengthened the relationship between man and machine was virtual reality, a tool that made it possible to configure the means of simulating natural objects in virtual scenarios without financial costs, being able to generate a trend of fashion through computational devices. With this, the customer can scan their body and dynamize various combinations of clothes and accessories before finalizing the purchase (Dal Forno et al. 2023). It can create applications in products (clothing) to expand the general usefulness of fabrics in the medical, defense, entertainment and aerospace areas (Juanga-Labayen et al. 2022) and generate possibilities for electronic applications (Ornaghi et al. 2022).

Kusi-Sarpong et al. (2022) argue that future generations will be directly dependent and interconnected with the present actions of production and consumption of textile products, which are mainly responsible for environmental changes in the world. Kumar et al. (2023) state that the textile industry is the second-largest pollutant in the world, behind only the oil industry. Based on this statement, it is necessary to enable and encourage policies that minimize environmental impacts and modernize the industry through intelligent technologies, which guarantee high-performance and ecologically correct production, impacting a conscious consumption of textile products from sustainable production.

The relationship between sustainability and Industry 4.0 should concern the search for sustainable solutions through intelligent technologies. In this context, Kusi-Sarpong et al. (2022) highlight that the first way to create strategies to reduce the environmental impact and make the industry more sustainable is through monitoring suppliers and batches of products via remote access. It implies that the insertion of these technologies in the production process must focus on quick access to data in real time.

Machado and Delis (2021) report that the textile industry is one of the largest generators of pollutants in the world, representing only 21% of industries that collaborate with the triple helix of sustainability through environmental and social actions and economics. Regarding these alarming concerns, creating policies and restrictive measures to slow down environmental degradation is relevant. Recent data reveal that around 23 kg of green-house gases are produced by producing just 1 kg of fabric fiber.

Thus, Figure 6 presents the geographic distribution of the selected works, with application or contextualization of the I4.0 tools used in this systematic literature review. It can be identified that the continental region that presents a greater use of the tools is Europe, since it has a denser textile manufacturing network. Despite presenting barriers and challenges for the implementation of enabling tools, it has shown interest in the positive impacts and more efficient processes. Among the countries highlighted in the evaluated papers are Switzerland, the United Kingdom, Poland, Romania, Slovenia, the Netherlands, Brazil and the United States.

It is known that Japan had a very developed textile machinery industry with the Toyoda factory, which was later renamed Toyota and began to produce cars. Japan is significant in that it had a developed textile machinery and textile industry only 40–50 years after Great Britain, which was the world leader at the time. On the other hand, China has been a world leader in the production of textiles and clothing for several decades, and even today, with a very high level of competitiveness. Despite the importance of the Japanese and Chinese textile industry to the world, based on the keywords used in this article, no article was selected.

We observed some trends toward using the I4.0 scenario in the clothing sector. In this context, Kusi-Sarpong et al. (2022) defend in their study the concern for the sustainability of the value chain based on I4.0, reporting that society is concerned with sustainable practices developed within factories, promoting a difference in the decision of the customer's choice of product; this paradigm influences the behavior and mode of production of the industry. Furthermore, Kusi-Sarpong et al. (2022) and Tabassum et al. (2022), concerning trends in the textile and clothing sector, reveal that the use of intellectual capital can contribute to the construction of supply chain mapping and product tracking via blockchain, a methodology capable of eliminating pollutants during the production process, as a way of guaranteeing sustainable production. According to Juanga-Labayen et al. (2022), new technologies used for re-use and recycling can be essential for managing textile waste.

Figure 6. Map with the locations of articles selected for the LSR that use and/or contextualize Industry 4.0 tools.

Kumar et al. (2023) state in their study that visual management is essential in the digital transformation process to identify possible bottlenecks. Furthermore, Falani et al. (2021) states that the digital transformation process contributes to reducing waste and greater efficiency in processes, agreeing with the authors. In this context, Dal Forno et al. (2023) identify I4.0 as synonymous with cost reduction, efficiency and productivity.

Regarding trends related to the application of I4.0 tools in the clothing sector, Kumar et al. (2023) agree with Dal Forno et al. (2023) when mentioning that the use of virtual systems in the textile and clothing industry can impact reduced inventory costs, through monitoring supply and demand through I4.0 technologies. In this area, Falani et al. (2021) ensure that investment in cybersecurity allows the industry to remain competitive with assured information. Corroborating the authors, Sarı et al. (2020) report that the use of the I4.0 cybersecurity tool strengthens the competitive strategies of the manufacturing industry.

Tabassum et al. (2022) observe that it is relatively simple to adapt machines deployed in manufacturing textile products and accessories, which can also be used in fashion shows. The authors believe that using 3D printing technology encourages sustainability in producing accessories and customized products on a unit scale. Concerning cost reduction, Luu et al. (2019) report that the modernization of production, with an increase in RFID technology inserted in fabrics and accessories, is a reliable way to control inventory. Thus, Wijewardhana et al. (2021) admit that investment in digital transformation, generating competitive advantages through the I4.0 tool, can improve product development processes through augmented reality.

Thus, Akhtar et al. (2022) state that the industry significantly shapes the future implementation of Industry 4.0 technologies and the impacts on companies' production systems. With this, Lalic et al. (2019) assume that a monitoring policy becomes essential to enhance the use of the maximum capacity of the I4.0 tool. Furthermore, Madsen (2019) reports that, theoretically, these processes are seen through the perspectives of managerial fashion, a theory well suited to examining the evolutionary trajectories of managerial concepts and ideas. Furthermore, according to Falani et al. (2021), the culture and implementation of I4.0 tools in the clothing industry are still premature due to the lack of investment in equipment and adapters that interact with I4.0; in this context, there is also resistance to its adhesion due to the lack of trust in the security of the industry's strategic data. Therefore, one of the biggest challenges for incorporating sustainable production is information transparency, security and traceability.

Notably, the works analyzed defend digital transformation in industries, as they obtain good results in economic and sustainable terms, presenting financial and environmental impacts and reducing waste and greater security in protected information available in real-time. Figure 7 presents the I4.0 enabling tools most used in the clothing sector, highlighting the Internet of Things, augmented reality and autonomous robots as the most prominent tools.

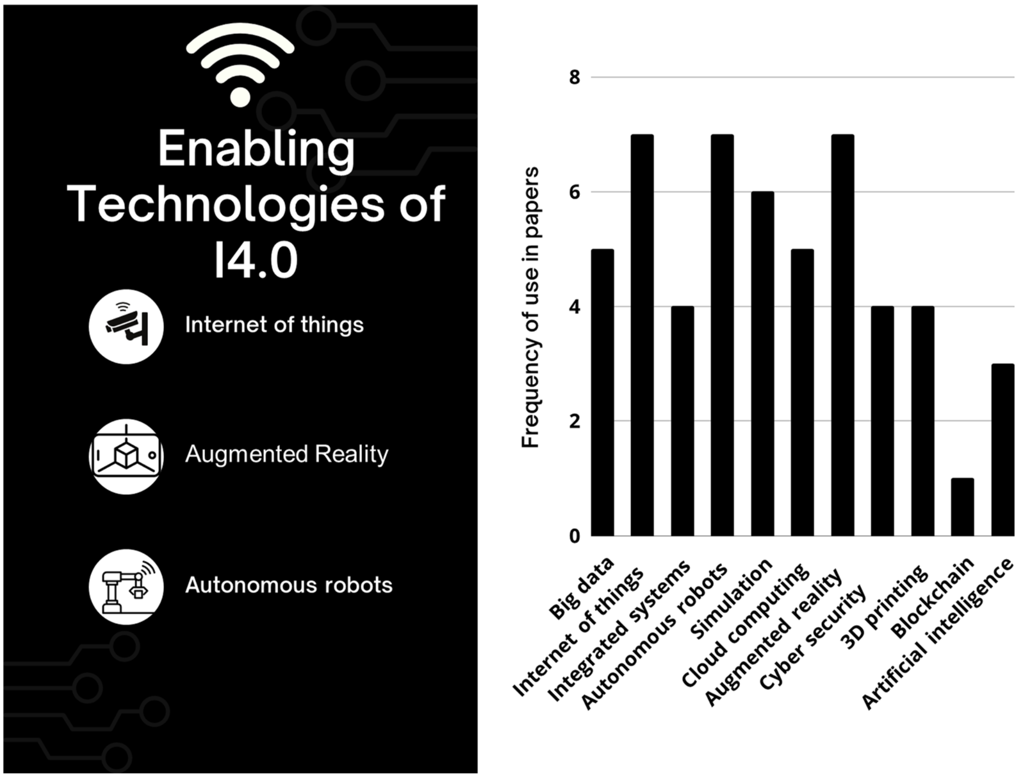

Figure 7. Trends in the types of I4.0-enabling technologies most used in the textile manufacturing sector.

To validate the findings of the systematic literature review, a survey was conducted to assess the perception of eight entrepreneurs regarding technologies applied in the clothing sector in the state of Pernambuco, Northeast Brazil. The survey was conducted in two stages. First, the entrepreneurs self-assessed their priorities versus importance regarding the use and applicability of technological dimensions. Second, these data were validated by visiting the companies. Table 7 presents the dimensions generated from the enabling technologies of systematic literature review.

From an exploratory analysis of the data collected through a questionnaire, it was possible to highlight that eight dimensions were considered critical for the sample studied in the textile sector. Table 8 presents these dimensions.

Table 7. Dimensions generated from the systematic literature review.

Technological Trend	Dimensions
Technologies for smart products	• Data analytics • Connected products
Technologies for smart supply chains	• Supply chain integration • Traceability
Technologies for smart work	• Remote production monitoring • Augmented/virtual reality • Human-machine collaboration
Smart management	• Strategy • Leadership • Customer management
Sustainability	• Energy management • Waste management • Organizational culture and people
Technology base	• IoT • Cloud computing • Big data • Broadband connection • Infrastructure and security

Table 8. GAP 1 (importance x priority relationship).

Dimensions	Textile Sector		GAP
	Importance	Priority	
Vertical integration	85.00%	85.00%	00.00%
Flexibility	77.50%	90.00%	12.50%
Data analysis	92.50%	80.00%	−12.50%
Supply chain integration	95.00%	85.00%	−10.00%
Traceability	87.50%	72.50%	−15.00%
Remote production monitoring	82.50%	67.50%	−15.00%
Strategy	90.00%	82.50%	−7.50%
Organizational culture and people	85.00%	75.00%	−10.00%

In vertical integration, the convergence between importance (85.00%) and priority (85.00%) suggests that entrepreneurs recognize and implement strategies aligned with the essence of the business. The absence of GAP 1 (0.00%) reflects effective management that integrates vertically, standing out in the execution of strategies aligned with the entrepreneurial vision. However, the disparity of 12.5% between importance (77.50%) and priority (90.00%) for flexibility points to the need for entrepreneurs to act more pragmatically.

Operational agility is vital, and the practical application of these strategies can be the key to facing dynamic market challenges. Furthermore, the importance of 92.50% attributed by entrepreneurs to data analysis reflects the practical emphasis on this dimension, closely aligning with expert perceptions. However, the priority of 80.00% suggests an opportunity to integrate more advanced practices, further improving data-driven decision-making, since there was a negative GAP of 12.50%.

In the case of supply chain integration and traceability, there is a moderate convergence between the priority practiced by businesspeople and the importance perceived by experts. In supply chain integration, the proximity between the priority practiced (85.00%) and the defined importance (95.00%) highlights a management with a GAP of 10% of ideal practices, indicating that daily practices are partially aligned in a strategic and optimized manner with expert recommendations.

This result suggests an approach that partially integrates the supply chain, promoting an execution that can be optimized with the needs of the sector. Similarly, with a GAP of 15.00%, when analyzing traceability, the importance attributed by business owners (72.50%) reflects an approach slightly below the necessary one attributed by business owners. However, the 15% difference highlights the potential need for improvements in the implementation of more effective practices, pointing to an opportunity to align these practices to further strengthen transparency in the textile sector.

In the remote production monitoring dimension, the negative GAP of −15.00% represents a discrepancy between the importance attributed by business owners and the perceived validity. This indicates that business owners consider remote production monitoring more critical than the researchers perceived. Possible explanations may include the historical dependence on specific practices in the sector, the urgency perceived by business owners to monitor production in real time, or even the adoption of emerging technologies that researchers have not yet fully recognized.

With a negative GAP of −7.50%, the discrepancy in perception between importance and priority in strategy is less pronounced, but still relevant. One possible explanation for this phenomenon may lie in specific strategies employed by entrepreneurs that, although based on practical experience, may not be fully aligned with the most recent trends or strategic theories recognized by researchers.

In addition, the organizational culture and people dimension presents a negative GAP of −10.00%, which reflects a moderate disparity. It is possible that entrepreneurs, aware of the crucial importance of culture and people management in their specific contexts, attribute greater relevance to these elements than researchers, whose assessments may be based on broader standards. The uniqueness of the business environment may influence entrepreneurs' sharper perception of the fundamental role of organizational culture and interpersonal relationships.

5. Conclusions

Through a Systematic Literature Review, we considered the papers published in the last five years, which involve the digital transformation of the textile manufacturing sector through the enabling tools of Industry 4.0. Eleven studies were selected from the SCOPUS and WOS databases, databases considered relevant to the study of the proposed topic.

Given the analysis of the results, this study demonstrated that this topic still needs to be explored scientifically and technologically, especially concerning the clothing sector (Silva and Melo 2024; Silva et al. 2024). It is observed that the clothing industry is classified as having low technological progression. However, when Industry 4.0 is applied to the clothing sector, it will offer greater employability of science and technology, disseminating tools such as cyber–physical systems, the Internet of Things, and services in its manufacturing, among others. Furthermore, the massive use of new products, processes, communication, and information technologies, together with the trend towards hybridizing products and services, could consequently generate new business profiles, stimulating new business models.

The work carried out highlights the relevance and need to explore the digital transformation in the textile sector scientifically and technologically, through the application of Industry 4.0 enabling tools. When analyzing the potential benefits of implementing I4.0 technology in the apparel industry, this transition offers substantial improvements in efficiency, quality and sustainability. The application of tools such as blockchain for inventory management, augmented reality for design and production, and the integration of cyber–physical systems and the Internet of Things in the production line represent significant advances (Filgueiras et al. 2024a, 2024b; Filgueiras and Melo 2024; Gomes et al. 2023; Santos et al. 2023). These changes not only optimize processes, reduce waste and improve quality, but also signal a new era in the apparel industry, aligned with the demands of a market increasingly sensitive to sustainability and operational efficiency. Despite several advances, the systematic literature review carried out identified the lack of scientific and technological studies adequately addressing the impact of these technologies on the apparel industry. The results indicate a significant opportunity for exploration and development in this segment, especially considering that the clothing industry is traditionally classified as having low technological progression. In addition, the massive adoption of new technologies can generate not only more efficient processes, but also new business profiles and innovative business models.

In view of these findings, future perspectives suggest in-depth research on the economic viability of applying Industry 4.0 concepts in various textile segments, as well as the development of new textile processes and products. In addition, analyzing the perception of entrepreneurs regarding the application of Industry 4.0 in the clothing hub of Pernambuco's Agreste region and monitoring the use of I4.0 enabling tools in the textile sector are promising ways to broaden the understanding of the acceptance and impacts of this transformation in the sector.

As a contribution, this work presents, based on the technologies involved in I4.0, the trends in tools that enable Industry 4.0 to be integrated into the production process, allowing agility in the production line, resulting in more efficient processes and lower operating costs and a market sensitive to sustainability and maximizing profits in the supply chain. Ultimately, the research contributes not only to theoretical understanding, but also to guiding the practical implementation of digital transformation in textile manufacturing companies, promoting cultural and routine changes in the manufacturing environment and in clothing factories.

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References

Akhtar, Waleed Hassan, Chihiro Watanabe, Yuji Tou, and Pekka Neittaanmäki. 2022. A New Perspective on the Textile and Apparel Industry in the Digital Transformation Era. *Textiles* 2: 633–56. [CrossRef]

Amaral, Hudson Nunes, and Angelita Moutin Segoria Gasparotto. 2021. Inteligência artificial: O uso da robótica indústria 4.0. *Revista Interface Tecnológica* 18: 474–86. [CrossRef]

Associação Brasileira da Indústria Têxtil e de Confecção. 2022. ABIT. Available online: https://www.encurtador.com.br/ (accessed on 19 July 2022).

Bataglini, Walakis Vieira, Ana Julia Dal Forno, Fernanda Steffens, Antônio Augusto Ulson Souza, and Liane Mählmann Kipper. 2021. 3D printing technology: An overview of the textile industry. *Proceedings of the International* 5: 5–8.

Bataglini, Walakis Vieira. 2021. Desenvolvimento de um instrumento para diagnóstico da maturidade das tecnologias da indústria 4.0 no setor têxtil e de confecção. Master's dissertation, Universidade Federal de Santa Catarina, Blumenau, Brazil.

Cartwright, John. 1785. *The Postscript to Major Cartwright's Reply to Soame Jenyns, Esq: Humbly Recommended to the Perusal of Lord North's Admirers, Previous to His Lordship's Next Speech Against a Parliamentary Reform*. London: H. Goldney.

Cavalcanti, André Marques, and Gilson Ferreira dos Santos. 2022. The textile industry in Brazil: An analysis of the importance of competitiveness in the global context. *Exacta* 20: 706–26. [CrossRef]

Confederação Nacional da Indústria. 2016. Desafios para a Indústria 4.0 no Brasil. CNI. Brasília. Available online: https://www.portaldaindustria.com.br/publicacoes/2016/8/desafios-para-industria-40-no-brasil/ (accessed on 25 November 2023).

Dal Forno, Ana Julia, Walakis Vieira Bataglini, Fernanda Steffens, and Antonio Augusto Ulson Souza. 2023. Industry 4.0 in textile and apparel sector: A systematic literature review. *Research Journal of Textile and Aprpael* 27: 95–117. [CrossRef]

Dastbaz, Mohammad, and Peter eds Cochrane. 2019. *Industry 4.0 and Engineering for a Sustainable Future*. Berlin and Heidelberg: Springer.

Fachini, Moisés Panegassi, Nathalia Pinheiro Mesquita, Rafael Padovani Oliveira, and Patricia Gallo França. 2017. Internet of Things: A Brief Bibliographic Review. *Conexões Ciência e Tecnologia Brasil* 10: 85–90.

Falani, Leila, Cátia Aguiar, and Ana Julia Dal Forno. 2021. Initial overview of industry 4.0 in textile companies in Santa Catarina. *Proceedings of the International Conference on Industrial Engineering and Operations Management* 2: 5–8.

Filgueiras, Igor Fellype Loureiro Valenca, and Fagner José Coutinho Melo. 2024. Sustainability 4.0 in services: A systematic review of the literature. *Benchmarking: An International Journal* 31: 1771–96. [CrossRef]

Filgueiras, Igor Fellype Loureiro Valenca, Fagner José Coutinho Melo, Djalma Silva Guimaraes Junior, Aline Amaral Leal Barbosa, Eryka Fernanda Miranda Sobral, and Silvio André Vital Junior. 2024a. Evaluation of the Benefits Generated by Sustainability 4.0: A Study of the Perception of Banking Sector Customers. *Sustainability* 16: 2580. [CrossRef]

Filgueiras, Igor Fellype Loureiro Valenca, Fagner José Coutinho Melo, Eryka Fernanda Miranda Sobral, Aline Amaral Leal Barbosa, Denise Dumke Medeiros, Pablo Aurélio Lacerda de Almeida Pinto, and Bartira Pereira Amorim. 2024b. Analyzing the Benefits of Industry 4.0 Technologies That Impact Sustainability 4.0 in Banking Services. *Sustainability* 16: 6179. [CrossRef]

Fromhold-Eisebith, Martina, Philip Marschall, Robert Peters, and Paul Thomes. 2021. Torn between the digitized future and the context-dependent past—How the implementation of 'Industry 4.0' production technologies can transform the German textile industry. *Technological Forecasting and Social Change* 166: 120620. [CrossRef]

Gausemeier, Jürgen. 2016. Industrie 4.0: Internationaler Benchmark, Zukunftsoptionen und Handlungsempfehlungen für die Produktionsforschung. Ph.D. thesis, Universität Paderborn, Paderborn, Germany.

Girard, Manuel Canavarros. 2017. Criação de cenários 3D de história interativa em realidade virtual para mobile: Etapas e processo de criação. Doctoral dissertation, Universidade Federal de Santa Catarina, Florianópolis, Brazil.

Gomes, Poliana Carneiro, Bruna Keila Macieira Santos, Kleber Jose Tenorio Tavares, Fagner José Coutinho Melo, and Pablo Aurélio Lacerda de Almeida Pinto. 2023. Ações de sustentabilidade 4.0 em uma empresa de energia: Uma proposta de modelo de decisão multicritério. *Revista Gestão & Sustentabilidade* 5: e14267.

Gomes, Poliana, Luiz Verçosa, Fagner Melo, Vinícius Silva, Carmelo Bastos Filho, and Byron Bezerra. 2022. Artificial Intelligence-Based Methods for Business Processes: A Systematic Literature Review. *Applied Sciences* 12: 2314. [CrossRef]

Juanga-Labayen, Jeanger, Ildefonso Labayen, and Qiuyan Yuan. 2022. A Review on Textile Recycling Practices and Challenges. *Textiles* 2: 174–88. [CrossRef]

Kagermann, Henning. 2013. Acatech–National academy of science and engineering. *Recommendations for Implementing the Strategic Initiative Industrie* 4: 1–23.

Kumar, Patanjal, Dheeraj Sharma, and Peeyush Pandey. 2023. Coordination mechanisms for digital and sustainable textile supply chain. *International Journal of Productivity and Performance Management* 72: 1533–59. [CrossRef]

Kusi-Sarpong, Simonov, Muhammad Shujaat Mubarik, Sharfuddin Ahmed Khan, Steve Brown, and Muhammad Faraz Mubarak. 2022. Intellectual capital, blockchain-driven supply chain and sustainable production: Role of supply chain mapping. *Technological Forecasting and Social Change* 175: 121331. [CrossRef]

Lalic, Bojan, Slavko Rakic, and Ugljesa Marjanovic. 2019. Use of industry 4.0 and organisational innovation concepts in the Serbian textile and apparel industry. *Fibres e Textiles in Eastern Europe* 12: 10–18. [CrossRef]

Lima, Faíque Ribeiro, and Rogério Gomes. 2021. Conceitos e tecnologias da Indústria 4.0: Uma análise bibliométrica. *Revista Brasileira de Inovação* 19: e0200023. [CrossRef]

Luu, Ha, Fernando Ferreira, and António Dinis Marques. 2019. Digitization and Industry 4.0 in the Portuguese T&C sector. *Textile Industry* 70: 342–45.

Machado, Carolina Pierre Barbosa, and Julia de Souza Delis. 2021. Como explorar o uso de realidade aumentada no Brasil aliado ao cenário da moda. Bachelor's thesis, Pontifícia Universidade Católica de São Paulo, São Paulo, Brazil.

Madsen, Dag Øivind. 2019. The emergence and rise of industry 4.0 seen through the lens of managerial fashion theory. *Administrative Sciences* 8: 1–71.

Magalhães, Regina, and Annelise Vendramini. 2018. Os impactos da quarta revolução industrial. *GV-EXECUTIVO* 17: 40–43. [CrossRef]

Mendes, Layla Brit, Ana Cristina Broega, and Patricia Sant'Anna. 2015. Aplicação de tendências no processo criativo de moda–estudo de caso. Tendere e Luciana Haddad. *III Congresso Científico Têxtil e Moda* 2: 100250.

Ornaghi, Heitor Luiz, Roberta Motta Neves, Francisco Maciel Monticeli, and Lucas Dall Agnol. 2022. Smart Fabric Textiles: Recent Advances and Challenges. *Textiles* 2: 582–605. [CrossRef]

Pereira, Carolina Morgado. 2015. The Clothing and Fashion: And the main theoretical currents. *ModaPalavra e-Periódico* 15: 202–21. [CrossRef]

Santos, Leandra Bezerra, Fagner José Coutinho Melo, Djalma Silva Guimaraes Junior, Eryka Fernanda Miranda Sobral, and Denise Dumke Medeiros. 2023. Application of ISM to Identify the Contextual Relationships between the Sustainable Solutions Based on the Principles and Pillars of Industry 4.0: A Sustainability 4.0 Model for Law Offices. *Sustainability* 15: 14494. [CrossRef]

Sarı, Tuğba, Hasan Kürşat Güleş, and Büşra Yiğitol. 2020. Awareness and readiness of Industry 4.0: The case of Turkish manufacturing industry. *Advances in Production Engineering & Management* 15: 57–68.

Schwab, Klaus, and Nicholas Davis. 2019. *Aplicando a Quarta Revolução Industrial*. Cambuci: EDIPRO.

Silva, Marcella Fernanda Vieira Ottoni Bezerra, Fagner José Coutinho de Melo, Eryka Fernanda Miranda Sobral, Djalma Silva Guimarães, André Philippi Gonzaga de Albuquerque, Silvio André Vital, Pablo Aurélio Lacerda de Almeida Pinto, Tatyane Veras de Queiroz Ferreira da Cruz, Rômulo César Dias de Andrade, and Kliver Lamarthine Alves Confessor. 2024. Contextual Relationships of Factors Affecting Sustainability 4.0 in the Textile Industry. *Sustainability* 16: 5999. [CrossRef]

Silva, Marcella Vieira Ottoni Bezerra, and Fagner José Coutinho Melo. 2024. Sustainability 4.0 in the fashion industry: A systematic literature review. *International Journal of Advanced Operations Management* 15: 293–323.

Tabassum, Madeeha, Qasim Zia, Yongfeng Zhou, Yufei Wang, Michael Reece, and Lei Su. 2022. A Review of Recent Developments in Smart Textiles Based on Perovskite Materials. *Textiles* 2: 447–63. [CrossRef]

Tessarini, Geraldo, and Patrícia Saltorato. 2018. Impactos da Indústria 4.0 na Organização do Trabalho: Uma Revisão Sistemática da Literatura. *Revista Produção Online* 1: 743–69. [CrossRef]

Wasim, Akram. 2019. Big Data Analytics—Current Status, Challenges and Connection of unbounded data Processing platforms. *International Journal Of Innovative Technology And Exploring Engineering* 8: 698–700.

Wijewardhana, Ganguli Eranga Harshamali, Samanthi Kumari Weerabahu, Julian Liyanage Don Nanayakkara, and Premaratne Samaranayake. 2021. New product development process in the apparel industry using Industry 4.0 technologies. *International Journal of Productivity and Performance Management* 70: 2352–73. [CrossRef]

Xu, Yu, Qin Liu, Yun Qing Rau, and Hai Ping Zhu. 2014. Cloud service platform for big data of manufacturing. *Applied Mechanics and Materials* 456: 178–83.

Yamada, Viviane Yukari, and Luís Marcelo Martins. 2019. Indústria 4.0: Um comparativo da indústria brasileira perante o mundo. *Revista Terra & Cultura: Cadernos de Ensino e Pesquisa* 34: 95–109.