Do tecido ao chão de fábrica: contrastando a implementação da indústria 4.0 nas indústrias têxtil e automotiva

From fabric to factory floor: contrasting the implementation of industry 4.0 in the textile and automotive industries

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RESUMO

A indústria 4.0 tem trazido fortes transformações digitais a todos os setores industriais, incluindo a cadeia têxtil, que é considerada um segmento tradicional e que apresenta resistência para aplicar as tecnologias advindas dessa revolução. Em contrapartida, há o setor automotivo, considerado benchmarking para várias áreas. Neste sentido, o objetivo desse estudo é comparar a adoção das tecnologias advindas da indústria 4.0 entre o setor têxtil e o setor automotivo. A metodologia utilizada foi revisão sistemática de literatura que teve as seguintes etapas: definição dos termos e estratégias de busca; eleição das bases referenciais; definição dos critérios de inclusão e exclusão e designação dos *softwares* a serem utilizados para triagem. Foi verificado que as instituições de ensino brasileiras se destacaram no número de publicações científicas associando os termos da Indústria 4.0 com a área têxtil e automotiva na base dados Scopus no período entre 2018-2022, evidenciando que o Brasil se encontra na vanguarda dentro dessa temática. Com base nas análises dos estudos, destaca-se que as áreas de logística e, dentre as linhas de produção, a confecção são os setores têxteis que buscam uma maior aplicação de tecnologias em seus processos. No entanto, a indústria têxtil, em nível mundial, tem se mostrado hesitante na implementação da transformação digital, implicando em menor uso das tecnologias da indústria 4.0. Destaca-se o ineditismo da comparação entre a indústria têxtil e a indústria automotiva. Além disso, a apresentação de um diagnóstico das práticas nos dois setores. As implicações práticas são fornecer subsídios às empresas têxteis para uma tomada de decisão assertiva.

Palavras-chave: transformação digital. Revisão sistemática da literatura. Quarta revolução industrial. Tecnologias emergentes.

ABSTRACT

Industry 4.0 has brought substantial digital transformations to all industrial sectors, including the textile chain, which is considered a traditional segment that tends to resist the adoption of technologies arising from this revolution. In contrast, the automotive sector is often regarded as a benchmark for several areas. In this

context, this study aimed to compare the adoption of Industry 4.0 technologies in the textile and automotive sectors. The methodology employed was a systematic literature review, with the following stages: definition of search terms and strategies, selection of reference databases, definition of inclusion and exclusion criteria, and designation of software to be used for screening. It was found that Brazilian educational institutions stood out in the number of scientific publications linking the terms "Industry 4.0" with the textile and automotive fields in the Scopus database during the period 2018–2022, highlighting that Brazil is at the forefront of this theme. Based on the analysis of the studies, it is highlighted that the logistics area and, among the production lines, the apparel line are the textile sectors that most actively seek to apply technologies in their processes. However, on a global level, the textile industry has been hesitant in implementing digital transformation, resulting in a lower level of adoption Industry 4.0 technologies. This study is original in its comparison between the textile and automotive industries. In addition, it offers a diagnostic overview of practices in both sectors. The practical implication is to provide subsidies for more assertive decision-making by textile companies.

Keywords: Digital transformation. Systematic literature review. Fourth industrial revolution. Emerging technologies.

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1 INTRODUCTION

The textile industry is amid the digital revolution driven by Industry 4.0, which stimulates a significant transformation in the manufacturing sector. This phenomenon, which gave rise to the fourth industrial revolution, is characterized by technological advances such as the Internet of Things (IoT) and cloud-based systems, which integrate manufacturing processes and promote continuous improvements in the production chain (Sharma et al., 2021a) The textile sector stands out as a fertile ground for the introduction of such innovations, although facing significant challenges in the adoption of these technologies, in contrast to sectors such as the automotive, in which the application of Industry 4.0 is already a reality (CNI, 2021). In addition, it is observed that the textile sector has primarily invested in the introduction of technologies aimed at increasing the efficiency of production process, reducing operating costs and improving business management (Dal Forno et al., 2021).

Thus, this study aimed to compare the emerging technologies most commonly used in the automotive sector, which serves as a benchmark for their implementation in the textile sector. The research question addressed was: ***Which Industry 4.0 technologies are most commonly applied in the textile and automotive industries?***

The main motivation lies in the historical importance of the textile sector, which played a vital role in previous industrial revolutions and continues to be a key industry in developing economies (Majumdar et al., 2021).

Therefore, this study conducted a Systematic Literature Review (SLR) to map technological advancements in the textile sector, highlighting specific areas adopting the emerging Industry 4.0 technologies. Moreover, the research aimed to compare the implementation of Industry 4.0 in the textile and automotive sectors, offering insights for textile companies seeking to improve their competitiveness and stand out in an increasingly challenging global economy.

This study not only aimed to identify gaps and trends in the adoption of Industry 4.0 technologies but also to provide clear guidance for the textile industry on its path toward efficient and sustainable digital transformation.

2 METHODOLOGY

For the development of this study, the following steps were undertaken: i) defining the search terms and strategies; ii) selecting the survey sources, iii) establishing the inclusion and exclusion criteria, iv) choosing the screening software, and v) bibliographic management.

To collect information, a search was conducted for articles addressing the topic in question, performing a theoretical survey in the Web of Science (WoS) and Scopus databases, which are recognized for their multidisciplinary scope and the large number of available titles. Regarding the bibliographic survey, specific keywords were identified for the textile and automotive sectors, combined with the term "Industry 4.0". The search was carried out in these databases using the terms defined for the industrial segments in question, as presented in Table 1.

Table 1

Defined search terms

Sector	Initial strings
Textile	("Textile" OR "Clothing" OR "Apparel" OR "Fashion" AND "Industry 4.0")
Automotive	("Automotive Industry" OR "Automobile Manufacture" OR "Automotive Sector" OR "Car Manufacturers" OR "Automotive" AND "Industry 4.0")

As inclusion criteria, academic articles published in English in engineering and related fields between 2018 and 2022 were included. However, the study areas had to be adjusted for each sector since each database has its own categorization. Nevertheless, the other criteria remained consistent and unchanged. Table 2 shows an increase in publications for both analyzed sectors, reinforcing that the theme of the Fourth Industrial Revolution is on the rise.

Table 2

Documents from the Scopus and WoS databases from 2018 to 2022 for the textile and automotive sectors

Ano/Base	Textile			Automotive		
	Scopus	WoS	*Total*	WoS	Scopus	*Total*
2018	147	6	*153*	196	13	*209*
2019	163	10	*173*	216	32	*248*
2020	184	14	*198*	251	34	*285*
2021	265	24	*289*	291	42	*333*
2022	209	26	*235*	260	53	*313*
Total	***968***	***80***	***1048***	***1214***	***174***	***1388***

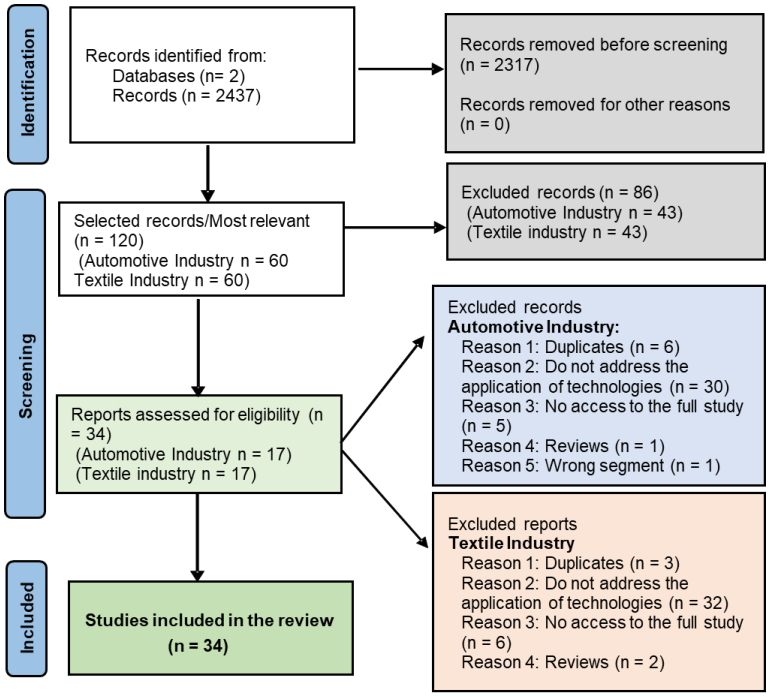
Specialized tools were selected to conduct the systematic review and meta-analysis projects. Rayyan software, developed by the Qatar Computing Research Institute, simplifies the process of screening and selecting articles, offering functionalities such as data export, duplicates removal, and collaborative screening (Ouzzani et al., 2016). In addition, Mendeley software was chosen as the bibliographic manager, as it provides resources for organizing, managing, and citing references. Using its visual flowchart, the PRISMA protocol was adopted to ensure transparency and quality in the systematic review process, providing a clear structure from the initial identification of studies to their final inclusion in the analysis.

After applying the defined limitations, a total of 2.437 documents were identified, with 968 related to the textile sector and 1.214 to the automotive industry found in the WoS database. In the Scopus database, 80 and 174 documents were identified regarding the textile and automotive sectors, respectively.

The results were organized based to the relevance criteria determined by the databases algorithms, which consider keywords frequency, scientific journal quality, and citation count. For this study, the 30 most relevant articles from each of the four searches were selected, totaling 120 studies, whose metadata were

stored for further analysis. The identification and screening process is illustrated in the PRISMA flowchart in Figure 1.

Figure 1 – PRISMA flowchart with the study screening



Next, the 120 documents, 60 from each sector, obtained from the two databases were screened. The Rayyan online tool was used to facilitate this process. The first screening aimed to identifying duplicates among the documents. Then, the document titles were analyzed to assess their relevance relative to the objectives of this study. Subsequently, the abstracts were read to ensure the inclusion of only those documents relevant to the scope of this work. In the end, 34 articles remained, which were stored and imported into the Mendeley bibliographic manager, where critical reading was performed and the necessary information was extracted. Table 3 lists the 17 articles analyzed from the textile industry, and Table 4 shows the 17 articles analyzed from the automotive industry, both organized in descending order of recency.

Table 3

Selected articles on Industry 4.0 in the textile sector

Reference	Title	Country
(Olgun & Turan, 2022)	Digital Transformation in Textile Industry and A Study to Determine the Conceptual Awareness Level of Textile Firms Regarding Industry 4.0	Turkey
(Agrawal et al., 2021)	Blockchain-based framework for supply chain traceability: A case example of textile and clothing industry	Switzerland
(Bonnard et al., 2021)	Big data/analytics platform for Industry 4.0 implementation in advanced manufacturing context	Brazil
(dos Santos et al., 2021)	Decision-making in a fast fashion company in the Industry 4.0 era: a Digital Twin proposal to support operational planning	Brazil

(Lee & Lin, 2021)	A Two-Phase Fashion Apparel Detection Method Based on YOLOv4	Taiwan
(Longo et al., 2021)	Towards a mass customization in the fashion industry: An evolutionary decision aid model for apparel product platform design and optimization	Italy
(Sharma et al., 2021)	Development of an Intelligent Data-Driven System to Recommend Personalized Fashion Design Solutions	France
(Chen, 2020)	Cross-disciplinary innovations by Taiwanese manufacturing SMEs in the context of Industry 4.0	Taiwan
(Santos et al., 2021)	A new concept of full-automated equipment for the manufacture of shirt collars and cuffs	Portugal
(Verleysen, Holvoet, Proesmans, Den Haese, & wyffels, 2020)	Simpler Learning of Robotic Manipulation of Clothing by Utilizing DIY Smart Textile Technology	Belgium
(Ou et al., 2019)	SensorKnit: Architecting Textile Sensors with Machine Knitting	USA
(Ślusarczyk et al., 2019)	Fourth industrial revolution: a way forward to attain better performance in the textile industry	Poland
(Ten Bhömer et al., 2019)	Designing Predictive Tools for Personalized Functionalities in Knitted Performance Wear	China
(Agrawal et al., 2018)	A secured tag for implementation of traceability in textile and clothing supply chain	France
(Bertola & Teunissen, 2018)	Fashion 4.0. Innovating fashion industry through digital transformation	Italy
(Serrat et al., 2018)	Learning to measure for preshipment garment sizing	Spain
(Tsai, 2018)	Green Production Planning and Control for the Textile Industry by Using Mathematical Programming and Industry 4.0 Techniques	Taiwan

Table 4

Selected articles on Industry 4.0 in the automotive sector

Reference	Title	Country
(Aivaliotis et al., 2022)	An augmented reality software suite enabling seamless human robot interaction	Greece
(de Mattos Nascimento et al., 2022)	A sustainable circular 3D printing model for recycling metal scrap in the automotive industry	Spain
(Jiménez-Jiménez et al., 2022)	Advances and challenges in the automotive industry-driving towards sustainable mobility	Spain
(Nagy & Lăzăroiu, 2022)	Computer Vision Algorithms, Remote Sensing Data Fusion Techniques, and Mapping and Navigation Tools in the Industry 4.0-Based Slovak Automotive Sector	Slovakia
(Turner et al., 2022)	Circular production and maintenance of automotive parts: An Internet of Things (IoT) data framework and practice review	United Kingdom
(Bavelos et al., 2021)	Enabling Flexibility in Manufacturing by Integrating Shopfloor and Process Perception for Mobile Robot Workers	Greece

(Brunheroto et al., 2021)	Implications of Industry 4.0 to compan'es' performance: a comparison between Brazil and Germany	Brazil
(Sanz et al., 2021)	BiDrac Industry 4.0 framework: Application to an Automotive Paint Shop Process	Spain
(Bysko et al., 2020)	Automotive Paint Shop 4.0	Poland
(Redondo et al., 2020)	A Decision-Making Tool Based on Exploratory Visualization for the Automotive Industry	Spain
(Fraga-Lamas & Fernández-Caramés, 2019)	A Review on Blockchain Technologies for an Advanced and Cyber-Resilient Automotive Industry	Spain
(Mourtzis et al., 2019)	Augmented reality application to support the assembly of highly customized products and to adapt to production re-scheduling	Greece
(Para et al., 2019)	Analyze, Sense, Preprocess, Predict, Implement, and Deploy (ASPPID): An incremental methodology based on data analytics for cost-efficiently monitoring the industry 4.0	Spain
(Sell et al., 2019)	Integration of autonomous vehicles and Industry 4.0	Estonia
(Krugh & Mears, 2018)	A complementary Cyber-Human Systems framework for Industry 4.0 Cyber-Physical Systems	USA
(Silva et al., 2018)	A Customer Feedback Platform for Vehicle Manufacturing Compliant with Industry 4.0 Vision	Brazil
(Yin et al., 2018)	The evolution of production systems from Industry 2.0 through Industry 4.0	China

3 RESULTS

This section presents the results of the systematic literature review based on the selected articles, as previously presented, for both the textile and automotive sectors.

3.1 Repercussion on the textile industry

3.1.1 Countries and institutions that published on Industry 4.0 in the textile sector

The educational institutions that published on Industry 4.0 in the textile and automotive sectors were analyzed and separated according to the database used (Scopus and WoS). Focusing first the Scopus database and the textile sector, Table 5 shows that the vast majority of institutions had two documents published. Four documents were published by two institutions in Brazil, and four documents were published by two institutions in Italy. However, the vast majority of institutions are located on the Asian continent, which plays a prominent role in the international textile market.

Table 5
Institutions with the most studies indexed in the Scopus database on the textile industry and Industry 4.0 (2018–2022)

Institution / Country	Number
University of São Paulo (USP) / Brazil	2
Donghua University (DHU) / China	2
National Tsing Hua University (NTHU) / Taiwan	2
Polytechnic University of Milan (Polimi) / Italy	2
State University of Campinas (Unicamp) / Brazil	2

Marche Polytechnic University (UNIVPM) / Italy	2
Pakistan National University of Sciences and Technology (NUST) / Pakistan	2
University of Novi Sad (UNS) / Serbia	2
Universitas Pendidikan Indonesia (UPI) / Indonesia	2
FEI University Center (FEI) / Brazil	1

During the collection of documents associating the textile industry and Industry 4.0 in the WoS database, the same protocol used for the Scopus database was employed, while respecting the characteristics of each database. After implementing all restrictive search criteria, the advanced search identified 968 relevant documents by searching only the titles, abstracts, and keywords of the studies. Considering the studied period, the ten most prominent affiliated institutions, i.e., those to which the authors of the scientific articles were associated, are presented in Table 6.

Table 6
Institutions with the most studies indexed in the WoS database on the textile industry and Industry 4.0 (2018–2022)

Institution / Country	**Number**
National Center for Scientific Research (CNRS) / France	29
Donghua University (DHU) / China	28
University of Lille (Univ-Lille) / France	24
National Higher School of Textile Arts and Industries (ENSAIT) / France	20
Hong Kong Polytechnic University (PolyU) / China	17
RWTH Aachen University (RWTH) / Germany	15
Swiss Federal Institute of Technology / Switzerland	15
Indian Institutes of Technology (IITs) / India	14
KU Leuven University (KU Leuven) / Belgium	13
National Institute of Applied Sciences of Lyon (INSA Lyon) / France	12

From Table 6, it can be observed that 70 % of the institutions are European, while the remainder are in Asia. When analyzing the countries with the highest number of publications in the WoS database, France stands out with 45 % of publications, which is consistent with its prominence in the international textile scenario due to fashion. China accounts for 20 % of the institutions, reflecting its leading role in global textile production. Despite Germany being the pioneer in studies related to the Fourth Industrial Revolution, it presented only 8 % of the publications.

3.1.2 Emerging Industry 4.0 technologies in the textile sector

The technologies and areas explored in the textile sector show the multidisciplinarity of these studies. Some topics include the automation of manufacturing, mainly related to the production of shirt cuffs and collars through the development of a new concept of almost fully automatic equipment (Santos et al., 2021). Other studies address the implementation of traceability in the textile and clothing supply chain (Agrawal et al., 2018), studies related to advanced methods of clothing identification (Lee & Lin, 2021), big data/analytics platforms for the implementation of Industry 4.0 (Bonnard et al., 2021), blockchain-based frameworks for traceability in the supply chain (Agrawal et al., 2021), predictive tools for customized functionalities in knitted clothing (Ten Bhömer et al., 2019), and intelligent data-driven systems for customized design solutions for the retail industry (Sharma et al., 2021).

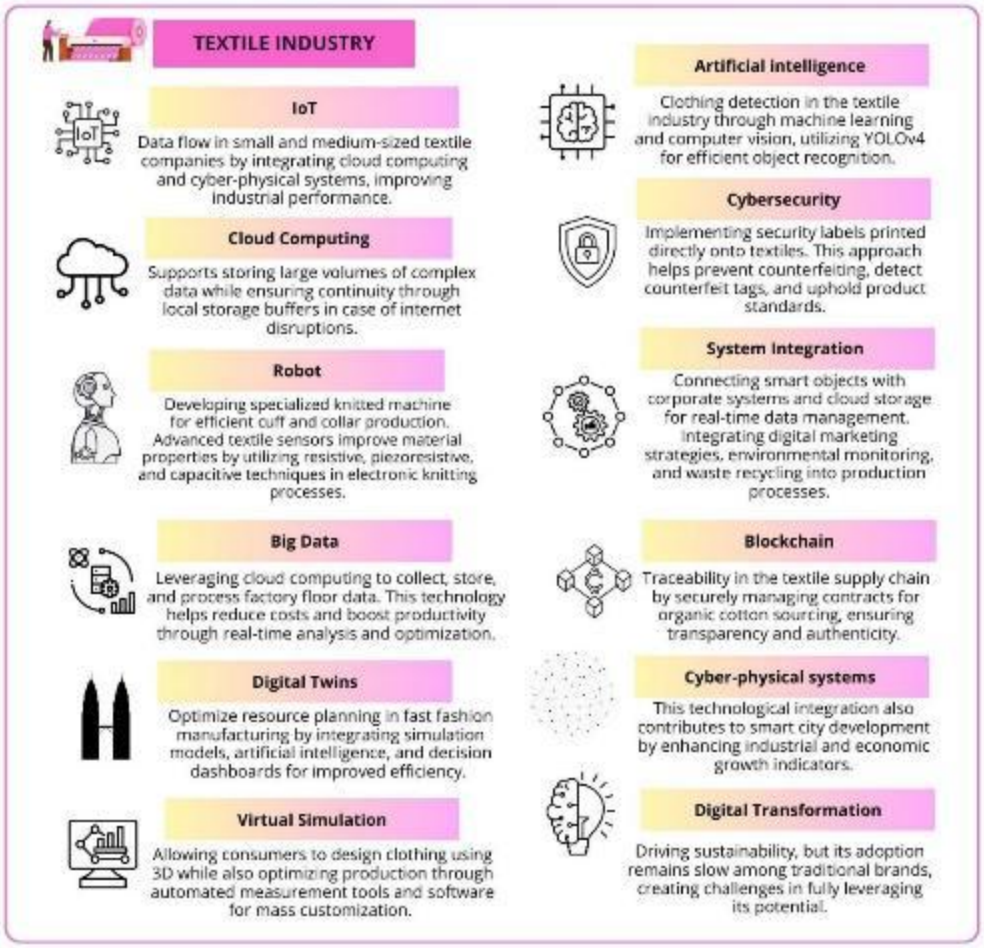
In addition, a focus was observed on incorporating sustainable principles and practices, such as green production, sustainable planning and control, and the pursuit of mass customization in the fashion industry. Some studies highlighted digital transformation as a means of innovation (Bertola & Teunissen, 2018). This concept reflects the need for the sector to adapt in order to remain competitive in the era of Industry 4.0.

It was also observed that production is one of the segments that benefits most from the applying Industry 4.0 technologies. Examples include the use of collaborative robots in activities such as folding clothing (Verleysen, Holvoet, Proesmans, Den Haese, & Wyffels, 2020). Additionally, the use of the Digital Twin strategy to improve production decisions in the fast fashion (dos Santos et al., 2021) and inventory optimization (Tsai, 2018) segments stood out.

The studies revealed an upward trend in the textile industry toward incorporating Industry 4.0 technologies to improve processes, products, and services. Digitization, data analytics, automation, and customization are emerging as crucial elements to address challenges and capitalize on opportunities in the contemporary textile industry.

Of the 17 articles analyzed, the most frequently identified technologies were system integration, virtual simulation, and robots, each mentioned in three articles. Other technologies were mentioned only once, namely cybersecurity, artificial intelligence, blockchain, big data, cloud computing, digital twins, the Internet of Things (IoT), cyber-physical systems, and digital transformation. The relationship of each technology with the textile sector was perceived as follows and summarized in Figure 2.

Figure 2 – Summary of Industry 4.0 technologies applied in the textile sector



3.2 Repercussion on the automotive sector

3.1.2 Countries and institutions that published on Industry 4.0 in the automotive sector

Following the limiting search criteria resulted in 174 documents from the Scopus database. Table 7 presents the ten leading institutions of affiliation representing the authors associations during the study period.

Table 7
Institutions with the most studies indexed in the Scopus database on the automotive sector and Industry 4.0 (2018–2022)

Institution / Country	Number
Pontifical Catholic University of Paraná (PUCPR) / Brazil	5
NOVA University Lisbon / Portugal	5
Silesian University of Technology / Poland	4
University of Warwick / United Kingdom	4
Chalmers University of Technology / Sweden	3
Politehnica University Timisoara / Romania	3
Cranfield University / United Kingdom	3
Tecnológico de Monterrey / Mexico	3
University of Brescia / Italy	3
University of Michigan, Ann Arbor / USA	3

The advanced search identified 1.214 documents. From this result, Table 8 presents the ten institutions of affiliation with which the authors of the scientific articles were associated that gave rise to the studies indexed in the database under analysis.

Table 8
Institutions with the most studies indexed in the WoS database on Industry 4.0 in the automotive sector (2018–2022)

Institution / Country	Number
Technical University of Košice (TUKE) / Slovakia	31
National Center for Scientific Research (CNRS) / France	22
Helmholtz Association / Germany	20
University of Porto / Portugal	20
Chalmers University of Technology / Sweden	19
Technical University of Munich (TUM) /Germany	18
Karlsruhe Institute of Technology (KIT) / Germany	17
Polytechnic University of Turin / Italy	16
Indian Institutes of Technology (IITs) / India	15
BBA (joint venture between BMW and Brilliance Auto Group) / China	14

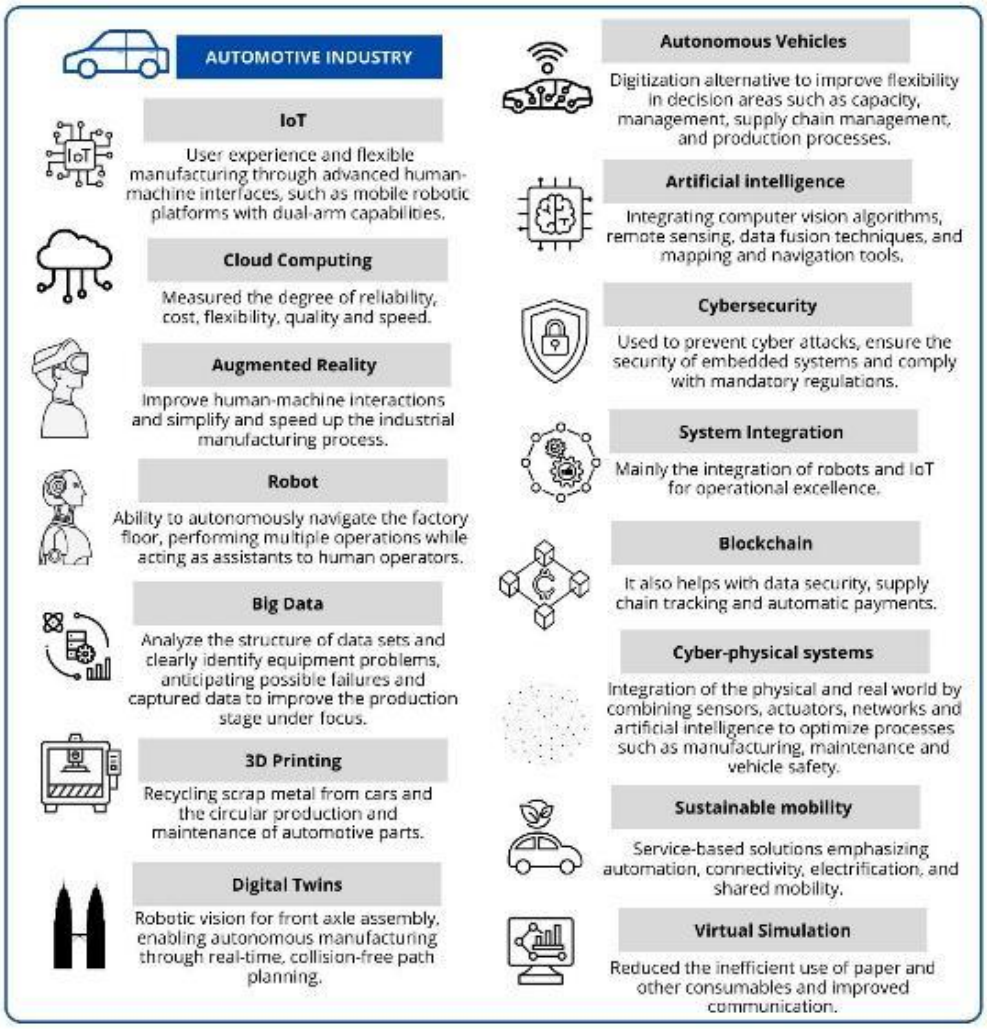
According to Table 8, the Technical University of Košice, a Slovak public university, appears first, standing out with 31 indexed studies. The five most cited studies produced by the institution address several aspects, including the implementation of Digital Twin technology for manufacturing processes, the evaluation of the capacity of the production process, the impact of parameters on gearbox emissions, the application of advanced measurement methods for structural analysis, and the design of large-scale logistics systems using computer simulation.

In the tenth place is a joint venture formed by the German automotive group BMW and the Brilliance Group, called BBA. It is a research and development center in Shenyang, China, which opened in 2013 and expanded in 2020. BMW increased its stake in BBA from 50 % to 7 5% in February 2022, becoming the first foreign automaker to gain majority control of its joint venture in China. In addition, an investment was made in a battery assembly plant with the aim of starting the production of electric vehicles.

Regarding geographic distribution, after compiling the scientific documents from the two databases used, it was found that several countries have implemented strategies focused on Industry 4.0 technologies related to the automotive sector in the development of indexed scientific production. European countries accounted for 82 % of the documents, with only Germany standing out with 55 %. Asia followed, representing 12% of the documents.

3.2.2 Emerging Industry 4.0 technologies in the automotive sector

Figure 3 – Summary of Industry 4.0 technologies applied in the automotive sector

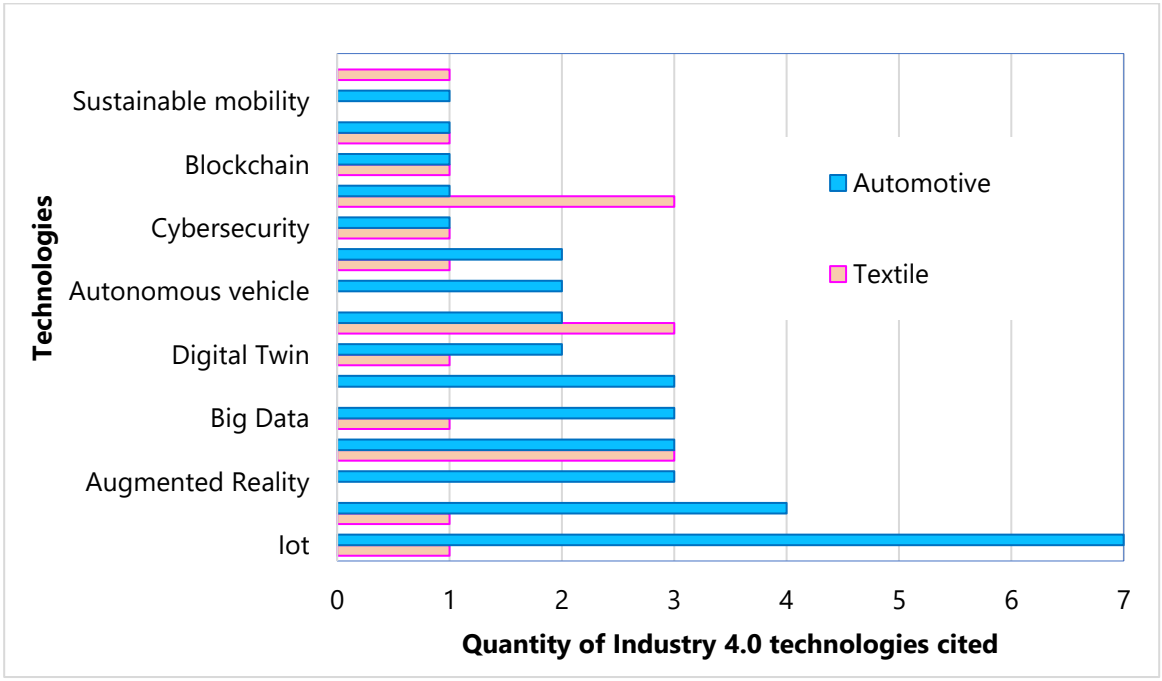


With the analysis of the articles related to the automotive sector, the technology most often present was the IoT (seven documents), followed by cloud computing (four documents). In sequence, with three documents, the technologies of augmented reality, robots, big data, and 3D printing were identified. In turn, digital twins, virtual simulation, virtually guided self-service, and artificial intelligence each appeared in two documents. Finally, sustainable mobility, cybersecurity, system integration, blockchain, and cyber-physical systems each appeared in one article. The relationship of each technology to the automotive sector was perceived as follows: Afterwards, Figure 3 summarizes the application of these technologies applied in the automotiv sector identified in the literature.

3.3 Comparison between the adoption of Industry 4.0 technologies in the textile and automotive sectors

Following the systematic analysis of the literature on the adoption of emerging Industry 4.0 technologies in the textile and automotive sectors, Figure 4 was developed to illustrate the results obtained. The review of 17 articles from each area revealed the identification of technologies in the textile sector. Among these, virtual simulation and system integration were the most frequently cited, each appearing in three studies. The remaining technologies were identified once in each article: cybersecurity, artificial intelligence, blockchain, big data, cloud computing, digital twins, IoT, robots, cyber-physical systems, and digital transformation.

Figure 4 – Emerging Industry 4.0 technologies identified in the literature in the textile and automotive sectors



In the automotive sector, IoT technology was identified in seven articles. Subsequently, four publications highlighted the use of robots, a technology that proved to be particularly prominent in this sector. As noted by Silva et al. (2018), the sector stands out for achieving advanced levels of customization, exemplified by the creation of the Internet of Intelligent Vehicles (IoIV), an evolution of the IoT principles applied to the automotive context. This breakthrough promotes significant improvements in both intelligent

vehicles and industrial automation. Cloud computing technology was also reported in four publications. Additionally, augmented reality, robots, big data, and 3D printing where each identified in three articles.

The use of virtual simulation and system integration predates Industry 4.0 in the automotive sector. This practice was verified in the lean product development process in the study by Dal Forno et al. (2016), who surveyed companies in Brazil and found that at least 80 % had already consolidated these practices. Moreover, virtual simulation is also present in the textile industry, particularly in the development of digital prototypes aimed at reducing the costs associated with physical prototypes. Additionally, there is system integration with suppliers to reduce waste (Dal Forno et al., 2022).

4 CONCLUSION

Based on the analysis of the studies, it is highlighted that the areas of logistics (supply chain) and apparel production are the textile sectors that seek a more significant application of technologies in their processes. While the textile sector is in the early stages of implementing Industry 4.0 technologies, with a focus on software and tools for process and product development, the automotive industry demonstrates an advanced level of application of these concepts, especially within the retail scope, in which there are high levels of customization and enhanced interaction with customers.

It was noted that the textile sector is embarking on a significant journey toward the digital transformation of its processes along its complex chain. The adoption of these technologies may vary between companies, but, in general, it is still relatively incipient, with the introduction of technologies such as robotics (for the clothing folding process) and blockchain (in supply chain traceability) especially standing out.

In contrast, the automotive industry has widely adopted the emerging technologies of the fourth industrial revolution to optimize manufacturing processes, improve product quality, and meet growing consumer demands. Elements such as automation, real-time data analysis, and connectivity along the supply chain have become an integral part of the automotive industry landscape.

Therefore, from this systematic literature review, the studied articles indicated that, although both industries have been incorporating Industry 4.0 technologies, the automotive sector leads in terms of implementation and comprehensiveness. The contribution of Industry 4.0 technologies to render the textile chain more agile, efficient, sustainable, and customer-oriented while remaining competitive in a constantly evolving global market is undeniable.

Research Trends and Future Agenda

Using the same databases and the same search strings from 2023 were checked some current trends overview, gaps and limitations, proposals for future studies e potential impact for the textile industry. The main studies highlighted for the textile industry (Chatchawanchanchanakij et al., 2023; Fani et al., 2024; Ferlito, 2024; Haq et al., 2025; Marshall et al., 2024; Pant and Palanisamy, 2025; Safavi Jahromi and Ghazinoory, 2025; Van Ta et al., 2024):

- **Adoption of emerging Industry 4.0 Technologies**: The textile sector is implementing several Industry 4.0 technologies, such as CPS, IoT, cloud computing, RFID, blockchain, augmented reality and digital twins, to increase automation, traceability and efficiency.
- **Adoption challenges**: despite the potential, adoption is hampered by lack of leadership, educational misalignment, high costs, scalability difficulties, and low utilization of advanced technologies.

- **Transition to Industry 5.0**: there is a movement towards Industry 5.0, which emphasizes collaboration between humans and machines, mass customization, business resilience, economic efficiency and sustainability.
- **Focus on sustainability**: Industry 4.0 plays a crucial role in promoting sustainability in the textile supply chain, through waste reduction, optimization of resource use and better environmental management.
- **Need for integration and development**: for a successful transition to Industry 4.0, it is essential to integrate technologies, develop supporting policies and focus on professional training and practical validation of technologies.

For the automotive industry, which has proven to be more advanced than the textile industry, some trends and challenges are repeated. In summary, the following stand out (El Affaki et al., 2023; Agarwal et al., 2024; Aljuaid et al., 2023; Macpherson, 2024; Patel and Patel, 2025; Piepoli et al., 2024; Schröder et al., 2024):

- **Adoption of emerging Industry 4.0 technologies**: still needs to integrate cyber-physical systems (CPS), Internet of Things (IoT), artificial intelligence (AI) and industrial automation technologies to increase production efficiency, reduce waste and optimize the supply chain.
- **Implementation challenges**: as in the textile and possibly other sectors, the barriers in the automotive sector are financial constraints, a shortage of specialized suppliers, data security concerns and a lack of employee training. In addition, small and medium-sized companies face difficulties due to a lack of digital infrastructure and investment.
- **Focus on sustainability and green manufacturing**: there is a growing emphasis on green smart manufacturing, which combines smart manufacturing with sustainable practices to reduce energy consumption, CO_2 emissions and efficient use of natural resources.
- **Supply chain transformation:** Industry 4.0 optimizes the supply chain through the integration of IoT, cloud computing and big data analytics, improving visibility, traceability and risk management. Automotive mergers also benefit from Industry 4.0, with gains in inventory turnover and reduced delivery times. In addition, there is a trend towards customized and localized manufacturing supported by 3D printing technology.
- **Quality and standardization**: in addition to improving automotive quality, technologies such as Big Data and IIOT (Industrial Internet of Things) need to be aligned with the requirements of IATF 16949:2016. Standardizing processes and integrating technologies are crucial to optimizing flexibility, productivity and operational efficiency.
- **Digitalization and talent management strategies**: companies are adopting different digitalization strategies, focusing on automation, self-regulation and gradual experimentation. Talent retention is essential, requiring customized strategies, continuous training and attention to the Sustainable Development Goals (SDGs).

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