UFSM

REVISTA DE ADMINISTRAÇÃO DA UFSM
Brazilian Journal of Management
ReA UFSM

ISSN 1983-4659
OPEN ACCESS

Rev. Adm. UFSM, Santa Maria, v. 18, n. 4, e5, 2025 https://doi.org/10.5902/1983465992932
Submitted: 07/19/2025 • Approved: 10/22/2025 • Published: 12/16/2025

Original Article

Industry 4.0 and Its Relationship with Digital Transformation: A Systematic Literature Review 2019-2024

Indústria 4.0 e a Relação com a Transformação Digital: Uma Revisão Sistêmica da Literatura 2019-2024

Josiane de Fátima Daniel Cardoso[I] **e Argemiro Luis Brum**[I]

[I] Universidade Regional do Noroeste do Estado do Rio Grande do Sul, Ijuí, RS, Brazil

ABSTRACT

Purpose: This study aims to analyze the main concepts, benefits, and challenges related to Industry 4.0 and its relationship with Digital Transformation in the Brazilian industrial sector, based on a systematic literature review between 2019 and 2024.
Methodology: The PRISMA protocol was used to conduct the systematic review, with searches in the Scopus, Web of Science, and SciELO databases, resulting in the selection of 42 articles. The analysis was guided by theoretical frameworks such as Verhoef et al. (2021), Schwab (2016), and Rogers (2019).
Results: The findings demonstrate that Industry 4.0 has driven Digital Transformation through the adoption of technologies such as Big Data, IoT, cloud computing, and artificial intelligence. The studies highlight gains in efficiency, sustainability, and competitiveness, but also reveal gaps, such as adoption difficulties by small businesses and challenges in workforce reskilling.
Social and Practical Implications: The research highlights the need for public incentive policies, continuous professional training, and technological integration strategies to enable digital transformation in various industrial sectors.
Originality: The study contributes by consolidating an updated and systematized vision of the pillars of Industry 4.0 and the stages of Digital Transformation, in addition to identifying gaps and proposing an agenda for future research in the Brazilian industrial context.

Keywords: Industry 4.0; Digital transformation; Big data; Cloud computing; Industrial automation.

RESUMO

Finalidade: Este estudo visa analisar os principais conceitos, benefícios e desafios relacionados à Indústria 4.0 e sua relação com a Transformação Digital no setor industrial brasileiro, a partir de uma revisão sistemática da literatura entre 2019 e 2024.
Metodologia: Utilizou-se o protocolo PRISMA para condução da revisão sistemática, com buscas nas bases Scopus, Web of Science e SciELO, resultando na seleção de 42 artigos. A análise foi orientada por marcos teóricos como Verhoef et al. (2021), Schwab (2016) e Rogers (2019).
Resultados: Os achados demonstram que a Indústria 4.0 tem impulsionado a Transformação Digital por meio da adoção de tecnologias como Big Data, IoT, computação em nuvem e inteligência artificial. Os estudos destacam ganhos em eficiência, sustentabilidade e competitividade, mas também revelam lacunas, como dificuldades de adoção por pequenas empresas e desafios na requalificação da força de trabalho.
Implicações Sociais e Práticas: A pesquisa aponta a necessidade de políticas públicas de incentivo, formação profissional contínua e estratégias de integração tecnológica para viabilizar a transformação digital em diferentes setores industriais.
Originalidade: O estudo contribui ao consolidar uma visão atualizada e sistematizada sobre os pilares da Indústria 4.0 e os estágios da Transformação Digital, além de identificar lacunas e propor uma agenda para futuras pesquisas no contexto industrial brasileiro.

Palavras-chave: Indústria 4.0; Transformação digital; Big data; Computação em nuvem; Automação industrial.

1 INTRODUCTION

Since the First Industrial Revolution, society has been undergoing profound technological transformations aimed at improving production processes and strengthening industrial competitiveness (Schwab, 2016; Hermann; Pentek; Otto, 2016). Keeping pace with these transformations is essential for organizations to be prepared for the constant market evolutions. In the current context, the so-called Industry 4.0, also known as the Fourth Industrial Revolution, represents a new stage of development, characterized by the integration of the physical and digital worlds through technologies such as the Internet of Things (IoT), Big Data, artificial intelligence, cyber-physical systems, among others. These technologies aim to increase the productivity, flexibility, and efficiency of industrial processes (Hermann et al., 2016). More recently, studies have shown that Industry 4.0 has promoted significant advances in the productivity, flexibility and efficiency of industrial

processes, by integrating emerging digital technologies and new organizational models (Höse et al., 2023; Elnadi et al., 2025; Reaidy, 2024; Khan et al., 2025).

This new paradigm poses significant challenges for companies. The inability to adapt technologically can compromise their competitiveness and survival, as exemplified by the case of Kodak. Even with the growth of the photography market, the company failed to keep pace with digitalization and changing consumer behavior, resulting in its bankruptcy in 2012 (Santos, 2019). In academia, the need for a deeper understanding of the concepts surrounding Digital Transformation stands out, since, despite its widespread use, there is still no consensus on its definition, scope, and measurement. Several studies have highlighted this conceptual gap, highlighting fragmented definitions, discrepancies between researchers' perspectives and managers' perceptions, as well as methodological difficulties in assessing its impacts. Riedl et al., (2024) show that business decision-makers often associate Digital Transformation solely with the adoption of technologies, without considering broader organizational changes. Ji and Li (2022) highlight conceptual heterogeneity and the lack of consolidated frameworks, while Egodawele, Sedera, and Bui (2022) reinforce the need for a unified theoretical model that allows consistent comparisons across studies. Reis et al. (2023) argue that the diversity of approaches hinders the synthesis of evidence and the generation of clear practical guidelines. Thus, filling this gap is essential, both for the consistent theoretical advancement of the field and for providing organizations with more robust guidance on how to conduct Digital Transformation strategically and sustainably. Verhoef et al. (2021) propose a distinction between digitalization (the adoption of digital technologies in existing processes), digitality (intensified use of data and connectivity to generate value), and Digital Transformation (structural and strategic changes driven by digital innovation). This distinction is crucial for understanding the different phases of digital maturity in industries.

Therefore, the following research question arises: How have Industry 4.0 concepts and technologies contributed to the Digital Transformation of Brazilian industries in recent years, and what are the main challenges faced in this process? To answer this question,

this study aims to analyze how Industry 4.0 concepts and technologies have driven Digital Transformation in Brazilian industries, identifying the main contributions and challenges highlighted in recent literature. To address this objective, a systematic literature review was conducted, allowing us to identify, select, and critically analyze relevant studies on the relationship between Industry 4.0 and Digital Transformation in the Brazilian context. This methodological approach makes it possible to gather and synthesize evidence scattered throughout the literature, offering a comprehensive overview of the benefits and limitations associated with the adoption of digital technologies in the industrial sector. Furthermore, the systematic review helps map the main challenges faced by industries in the transformation process, as well as identify theoretical and practical gaps that can guide future research and strategic decisions in the business environment. This article is organized as follows: Section 2 presents the theoretical framework on Industry 4.0 and Digital Transformation; Section 3 describes the research methodological procedures; Section 4 analyzes and discusses the main findings; Section 5 presents the conclusions; and, finally, Section 6 gathers the references used.

2 THEORETICAL FRAMEWORK

2.1 Industry 4.0

Industry 4.0, also known as advanced manufacturing, smart industry, or the 4th Industrial Revolution, officially emerged at the 2011 Hannover Fair in Germany. It is a national strategy aimed at modernizing manufacturing, focusing on advanced automation, digitalization of production processes, and integration between the physical and virtual worlds (Feimec, 2016; Albertin et al., 2017). This new industrial configuration aims to profoundly transform the way products are designed, manufactured, and distributed. According to the Brazilian Support Service for Micro and Small Businesses (Sebrae, 2018), Industry 4.0 consists of the convergence of intelligent machines, advanced computational analysis, IoT-connected sensors, and people integrated in real time. The goal is to promote

operational efficiency throughout the value chain by enabling cyber-physical systems to make autonomous decisions, dynamically adjust to production variability, and anticipate failures to avoid losses.

This revolution differs from previous ones by decentralizing control of production processes, promoting vertical integration (within factories) and horizontal integration (between companies, suppliers, and consumers), enabling a more responsive, flexible, and data-driven manufacturing environment. It is important to understand this evolution in its historical context. The First Industrial Revolution, at the end of the 18th century, marked the transition from artisanal to mechanized production, with the use of steam. The Second Industrial Revolution, between the 19th and 20th centuries, introduced electricity and assembly lines, expanding the scale of production. The Third Industrial Revolution, beginning in the 1970s, brought automation, based on electronics and information technology. The Fourth Industrial Revolution, in turn, represents a fusion of physical, digital, and biological technologies, promoting disruptive changes in the production, management, and competitiveness of organizations (Schwab, 2016). Given the above, Industry 4.0 is seen as a strategic vector for sustainability and innovation, being essential for companies to remain competitive in an increasingly dynamic, customized and digitalized market.

Another recent line of research points to the need to reconfigure business models in the face of digitalization. According to Kılıç, Yılmaz, and Demir (2024), companies that incorporate advanced digital practices can align operational efficiency with sustainable value, integrating green supply chains, social innovation, and new mechanisms for creating shared value. This convergence highlights that Industry 4.0 goes beyond the technological dimension, also acting as a promoter of more ethical and responsible business models.

Finally, recent research also emphasizes the social impacts of Industry 4.0, especially in emerging countries. On the African continent, for example, it has been found that technologies such as AI, big data, IoT, and 5G networks, when combined with public inclusion policies, can act as tools for reducing poverty and stimulating socioeconomic development (Asongu & Nnanna, 2024). However, such studies warn of challenges related

to workforce training, the integration of legacy systems, and the need for regulations that ensure cybersecurity and data protection (Bai & Dallasega, 2022).

2.1.1 The pillars of Industry 4.0

Industry 4.0 focuses on the pursuit of continuous improvement, increased operational efficiency, safety, productivity, and return on investment. Its distinguishing feature lies in the incorporation of advanced and integrated technologies capable of radically transforming the production processes and business models of industrial companies. According to Coelho (2016), the so-called technological pillars of Industry 4.0 are already a reality in several organizations and include: autonomous robots, augmented reality, virtual simulations, systems integration, IoT, information security, cloud computing, additive manufacturing (3D printing), and *Big Data.*

These pillars work together to foster a smart, adaptable, and data-driven production environment. Each contributes specifically to increasing connectivity, reducing waste, predicting failures, and enabling mass customization. When applied strategically, these capabilities not only optimize manufacturing performance but also create opportunities for innovation, sustainability, and competitive differentiation in the global marketplace (Shabur et al., 2024; Khan et al., 2025; Achouch et al., 2022).

Industry 4.0 is based on a set of enabling technologies that serve as the structuring pillars of a new production model. Its focus is on continuous improvement, increased efficiency, increased productivity, operational safety, and return on investment. According to Coelho (2016), these pillars are already being used by companies seeking to adapt to the demands of Digital Transformation and smart manufacturing. Table 1 presents the nine pillars of Industry 4.0, their respective main functions, and their benefits. This facilitates the visualization, understanding, and systematization of enabling technologies.

Table 1 – Nine pillars of Industry 4.0

Pillar	Main Function	Benefits
Big Data and Analytics	Analyzing large volumes of data for intelligent and predictive decisions.	Faster, more accurate, and data-driven decisions.
Autonomous Robots	Autonomous execution of tasks with interaction and adaptation to the environment.	Greater productivity, safety, and operational autonomy.
Simulation (Digital Twin)	Virtual simulation of operations to reduce risks and costs.	Reduced errors, more efficient testing, and resource savings.
System Integration	Connecting internal and external systems for real-time management.	Operational efficiency and visibility across the entire value chain.
Internet of Things (IoT)	Connecting devices and sensors to optimize processes in real time.	Continuous monitoring and performance improvement.
Information Security	Protecting systems and data against cyberattacks.	Trust in connected systems and failure prevention.
Cloud Computing	Storing and processing data remotely with flexibility.	Scalability, cost reduction, and easy remote access.
Additive Manufacturing (3D Printing)	Producing parts in layers allows for customization and reduces waste.	Innovation in design and on-demand production.
Augmented Reality (AR)	Assisting operators with overlaying digital information onto the physical environment.	Precision, agility, and support for technical training.

Source: Adapted from Coelho (2016); Schwab (2016); Hermann et al. (2016).

These pillars are interdependent and, when implemented strategically, enable the creation of intelligent production environments capable of self-adjustment, continuous monitoring, and real-time decision-making.

2.1.2 The industrial scenario in Brazil

The Brazilian industrial sector plays a strategic and structuring role in the national economy. According to the National Confederation of Industry (CNI, 2023), industry represents 23.9% of the country's Gross Domestic Product (GDP), accounting for 69.3% of exports of goods and services, 66.4% of research and development

(R&D) investments, 34.4% of tax revenue (excluding social security taxes), and 27.2% of employer pensions. It is noteworthy that sectors such as automotive, aerospace, and pharmaceuticals are leading the adoption of Industry 4.0 technologies in Brazil, especially in industrial hubs such as São José dos Campos and Campinas.

In addition to its significant contribution to economic growth, industry has a strong impact on the Brazilian formal labor market, employing approximately 10.3 million people, equivalent to 21.2% of formal jobs in the country. Furthermore, wages paid by the industrial sector are, on average, higher than those paid in other sectors, such as commerce and services, contributing to higher income and domestic consumption (Tavares, 2021). Another relevant fact, also highlighted by the National Confederation of Industry (2023), is the multiplier effect of industry on the national economy: every R$1.00 produced by the industrial sector generates R$2.44 in additional value for Brazilian GDP, demonstrating that industry has the greatest economic induction capacity among the productive sectors—greater than that of agribusiness and services. According to Kupfer (2019), industry not only dynamizes other economic sectors but is also essential for technological advancement and strengthening the national production base. This coordinating role of industry requires effective public policies and business actions focused on innovation, Digital Transformation, and the adoption of the pillars of Industry 4.0.

These figures reinforce the importance of modernizing and digitizing Brazil's industrial complex, especially in light of the challenges posed by globalization, digitalization, and new market demands. Investing in innovation, workforce training, and emerging technologies therefore becomes a competitive and strategic imperative to ensure the sustainable growth of Brazil's industry (National Confederation of Industry, 2023; Kupfer, 2019; Tavares, 2021).

2.2 Digital transformation

Digital Transformation refers to the strategic and comprehensive integration of digital technologies across all areas of an organization, driving profound changes in the way businesses operate, innovate, and deliver value to customers. More than a technological upgrade, it involves a cultural and organizational shift that requires companies to question established practices, experiment with new approaches, and learn from potential failures (Rogers, 2019). From the perspective of Industry 4.0, Digital Transformation plays a structuring role, as it provides the technological elements that enable the intelligent automation of production processes. Technologies such as cloud computing, artificial intelligence, IoT, Big Data Analytics, and real-time connectivity are used to improve operations, reduce waste, and generate value in an innovative and continuous manner (Tadeu, 2016).

It is important to highlight the conceptual distinction between the stages of digital maturity, as proposed by Verhoef et al. (2021): digitalization refers to the replacement of analog processes with digital ones, such as the automation of routine tasks or the digitization of documents; digitality is characterized by the intensive use of data and digital connectivity to expand the value delivered, through solutions based on predictive analytics, sensors, cloud computing, and digital platforms; Digital Transformation, in turn, involves a strategic, structural, and cultural change of the organization, with a direct impact on the business model, value proposition, and business operating logic.

This distinction helps us understand that Digital Transformation is not limited to the adoption of technological tools, but rather involves a profound reconfiguration of the organization as a whole, aiming for competitiveness and resilience in highly complex and dynamic environments (Verhoef et al., 2021). For Rogers (2016), this transformation process directly impacts five fundamental strategic domains: customers, competition, data, innovation, and value. These domains are reshaped by digital technologies, requiring companies to adopt a new operating logic driven by agility, personalization,

and data intelligence. As Llorente (2016) observes, changes in the digital environment are occurring at such a rapid pace that the survival of many companies depends on their ability to adapt. This is not limited to the internal environment but also affects relationships with customers, partners, employees, and society in general. For example, companies such as Embraer and Natura have reformulated their data, innovation, and value strategies through Digital Transformation (Sebrae, 2021).

Felsberger et al. (2020) emphasize that, while Industry 4.0 promotes operational changes (focusing on manufacturing), Digital Transformation represents a broader disruption, involving organizational culture, strategy, and new ways of creating value. Along the same lines, Lego and Mattos (2020, p. 1) emphasize that the manufacturing market faces increasingly rapid, continuous, and unpredictable changes, directly driven by Digital Transformation, which impacts not only technology but, above all, the workforce, requiring new skills, leadership models, and management approaches.

Recent research has reinforced the importance of digital maturity as a strategic factor for innovation. Jie et al. (2025) found, in a study of small and medium-sized high-tech companies, that higher levels of digital integration, with automated processes, intensive use of data, and a culture of innovation, are associated with better results in terms of innovative performance. This suggests that Digital Transformation should be understood not only as a technology, but as an integral part of organizations' dynamic capabilities in uncertain and competitive environments.

3 METHODOLOGY

This study was conducted through a systematic literature review, aiming to map and analyze the main conceptual and practical approaches to Industry 4.0 and Digital Transformation, considering their pillars, historical evolution, and current scenario in the Brazilian context. The methodology was based on the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol, which ensures

transparency, reproducibility, and methodological rigor in the selection, screening, and analysis of the included scientific studies.

According to Silva and Menezes (2005), bibliographic research is characterized by the survey and analysis of previously published documents, such as scientific articles, books and technical reports, and is appropriate for exploring and deepening knowledge about a previously studied phenomenon.

The search strategies were conducted in three highly relevant scientific databases: Scopus, Web of Science, and SciELO. These databases were chosen because they complement each other: Scopus and Web of Science offer broad international coverage and high academic rigor, while SciELO guarantees greater visibility for publications relevant to the Latin American and Brazilian contexts, allowing the inclusion of local contributions that are often not indexed in international databases (López-López et al., 2019; Moher et al., 2020).

The searches were conducted between February and April 2024, using combinations of descriptors with Boolean operators, as shown in Table 2.

Table 2 – Search Strings Used

Database	**Search strings**
Scopus	(“Industry 4.0” OR “Fourth Industrial Revolution”) AND (“Digital Transformation” OR “Digitization” OR “Digitalization”) AND (“Manufacturing” OR “Industrial sector”)
Web of Science	(“Indústria 4.0” OR “Industry 4.0”) AND (“Transformação Digital” OR “Digital Transformation”) AND (“Tecnologias emergentes” OR “Emerging technologies”)
SciELO	(“Indústria 4.0”) AND (“Transformação Digital”) AND (“Brasil” OR “Latin America”)

Source: Elaborated by the author (2024).

Inclusion criteria: articles published between 2019 and 2024; studies with full access to content; peer-reviewed publications; focus on Industry 4.0, Digital Transformation, digitalization, and emerging technologies in the industrial sector.

Exclusion criteria: duplicate works; publications in languages other than Portuguese, English, or Spanish; articles focusing exclusively on non-industrial areas (such as education, health, or agribusiness).

Selection Process: The initial screening identified 124 publications. After removing duplicates and reading the titles and abstracts, 68 articles were considered relevant. The full reading resulted in 42 final articles, which comprised the body of qualitative analysis. The process followed the PRISMA flowchart (Figure 1).

Theoretical approach: The analysis of the studies was guided by classical and contemporary theoretical frameworks, such as Verhoef et al. (2021), who differentiate between digitalization, digitality, and digital transformation; Schwab (2016), who discusses the structural impacts of the 4th Industrial Revolution; Rogers (2019; 2024), who presents the five strategic domains of digital transformation; and Felsberger et al. (2020), who address the integration between Industry 4.0 and organizational processes. These theoretical frameworks allowed us to identify gaps, convergences, and trends, in addition to assessing the degree of digital maturity present in the investigated approaches.

4 RESULTS AND DISCUSSION

The systematic review identified relevant trends in the adoption of Industry 4.0 and Digital Transformation in the industrial sector, especially in developing countries. Overall, the studies analyzed converge on the strategic importance of these technological innovations for modernizing production systems, increasing operational efficiency, and fostering organizational resilience in an increasingly dynamic and personalized market.

As observed in the studies by Feimec (2016), Albertin et al. (2017), and Coelho (2016), the concept of Industry 4.0 goes beyond simple technological modernization: it represents a shift in business mindset, in which technology ceases to be merely

a support tool and assumes a central role in decision-making, process design, and value generation. This transition is directly related to Digital Transformation, which, according to Verhoef et al. (2021), should be understood as an evolution in three stages: digitization, digitalization, and complete Digital Transformation, with strategic implications for the business model. Table 3 summarizes the main articles analyzed in the review, highlighting authors, year, objectives, and main results:

Table 3 – Summary of articles analyzed in the systematic review

Author(s)	Year	Main Goal	Main Results
Verhoef et al.	2021	Distinguishing between digitization, digitality, and digital transformation.	It establishes a conceptual model of digital maturity in three phases.
Felsberger et al.	2020	Assessing the impact of digital transformation on manufacturing.	It identifies the need for alignment between technology and organizational strategy.
Schwab	2016	Analyzing the impacts of the Fourth Industrial Revolution.	It highlights the fusion between physical, digital, and biological technologies.
Coelho	2016	Discussing the pillars of Industry 4.0 in the Brazilian context.	It highlights the use of enabling technologies as a competitive advantage.
Albertin et al.	2017	Studying the digitization of production processes	It reinforces the importance of integration between the physical and digital worlds.
Rogers	2016	Identifying the strategic impacts of digital transformation.	It defines five strategic domains impacted by digitalization.

Source: Author's own elaboration based on the reviewed articles.

In addition to describing technological pillars such as Big Data, IoT, robotics, augmented reality, and cloud computing, the studies emphasize the convergence between Digital Transformation and Industry 4.0 as a strategy for adapting to market changes and building sustainable competitive advantage.

Despite the theoretical advances, the analysis of the 42 included articles identified significant gaps. Approximately seven studies (about 17%) discussed the challenges of adopting Industry 4.0 in micro and small businesses, but these studies were still incipient, indicating a lack of research addressing structural barriers such as costs, infrastructure, and workforce qualifications. It was also observed that only ten articles (24%) addressed the Brazilian reality, most of which focused on high-tech sectors (such as automotive and aeronautics), revealing a dearth of empirical studies applied to traditional sectors and emerging industrial regions. Furthermore, only six studies (14%) explored the social and cultural impacts of digitalization, including the reconfiguration of functions and the risks of digital exclusion, highlighting the need for further exploration of this dimension.

Thus, the results reinforce the need for future research that broadens understanding of: (i) the relationship between Digital Transformation and professional requalification, already highlighted in 8 articles (19%); (ii) the role of organizational culture as a facilitator or barrier to technological adoption, a theme present in 9 articles (21%); and (iii) the critical success factors in implementing the pillars of Industry 4.0 in different sectoral and regional contexts, an aspect mentioned in 11 studies (26%) of the sample.

The conclusion is that Industry 4.0 represents the virtualization and intelligent integration of production systems, fostering a new operational logic. Its success depends not only on technology but also on organizations' ability to lead structural changes, promote continuous training, and align strategic purpose with innovation.

5 FINAL CONSIDERATIONS

Industry 4.0 and Digital Transformation represent not just a technological advancement, but a true paradigm shift in the ways organizations produce, manage, and innovate. This study identified that the adoption of enabling technologies, such as

artificial intelligence, Big Data, IoT, and cloud computing, has been a determining factor in the competitiveness and survival of companies in the contemporary landscape. Organizations that fail to keep up with this trend tend to lose ground in increasingly dynamic and connected markets.

As Schwab (2016) points out, the 4th Industrial Revolution is not defined solely by emerging technologies themselves, but by the construction of new systems and organizational models on the digital foundation consolidated in previous decades. The current process goes beyond simple automation and introduces intelligence and real-time connectivity into the value chain, giving rise to the so-called smart factory. However, for this transformation to occur effectively, incorporating new tools is not enough. It is also necessary to promote the cultural and structural transformation of organizations, as well as the continuous training of professionals. The success of Digital Transformation depends on both technology and people, as well as the strategic leadership that guides this process.

5.1 Study limitations

Among the limitations of this study is the systematic review's temporal and thematic scope, which focused on publications published between 2019 and 2024. Furthermore, the focus was restricted to the industrial sector, not including other areas also impacted by Digital Transformation, such as services, agriculture, and healthcare. Another limitation was the lack of empirical data, as the study relied exclusively on bibliographical and theoretical sources.

5.2 Theoretical and practical contributions

From a theoretical perspective, this work contributes by consolidating different approaches to the pillars of Industry 4.0 and the stages of Digital Transformation, including the conceptual differentiation between digitalization, digitality, and Digital

Transformation (Verhoef et al., 2021). Furthermore, it reinforces the relationship between technological innovation and the reconfiguration of business models. In practical terms, the findings serve as a reference for industrial managers, public policymakers, and professionals seeking to understand the paths of digitalization as a strategy for modernization and increased competitiveness. The study also highlights the importance of workforce reskilling, an increasingly central theme in the context of Industry 4.0.

5.3 Suggestions for future research

As an agenda for future studies, we suggest conducting empirical research with Brazilian companies to assess their current stage of digital maturity and the main challenges they face; to further explore the impact of Digital Transformation on the workforce, including an analysis of changes in professional profiles, required qualifications, and skills management; and to conduct comparative studies across industrial sectors and regions of the country, considering inequalities in access to technologies and investments in innovation.

Thus, the evidence analyzed indicates that Digital Transformation and Industry 4.0 represent long-term processes whose impacts are already manifesting in different industrial sectors, requiring strategic planning, structured investments, and data-driven leadership (Felsberger et al., 2020; Yang et al., 2024). Companies' readiness to embrace these changes will be crucial to their relevance, resilience, and competitive sustainability in the coming decades.

REFERENCES

Achouch, M., Dimitrova, M., Ziane, K., Sattarpanah Karganroudi, S., Dhouib, R., Ibrahim, H., & Adda, M. (2022). *On Predictive Maintenance in Industry 4.0: Overview, Models, and Challenges*. *Applied Sciences, 12*(16), 8081. https://doi.org/10.3390/app12168081

Albertin, M. R., Elienesio, M. L. B., Aires, A. S., Pontes, H. L. J., & Aragão Junior, D. P. (2017). Principais inovações tecnológicas da Indústria 4.0 e suas aplicações e implicações na manufatura. Anais do 26º Simpósio de Engenharia de Produção. https://repositorio.ufc.br/bitstream/riufc/60805/1/2017_eve_mralbertin.pdf

Asongu, S., & Nnanna, J. (2024). Industry 4.0 technologies and poverty reduction in Africa: Opportunities and challenges. *Frontiers in Sustainable Food Systems, 8*, 1–15. https://doi.org/10.3389/fsufs.2024.1393935

Bai, C., & Dallasega, P. (2022). Industry 4.0 technologies in manufacturing: Challenges of cybersecurity and workforce skills. *Journal of Manufacturing Systems, 62*, 192–205. https://doi.org/10.1016/j.jmsy.2021.12.005

Coelho, P. M. N. (2016). *Rumo à Indústria 4.0* [Dissertação de Mestrado em Engenharia Mecânica, Universidade de Coimbra]. Universidade de Coimbra. https://estudogeral.uc.pt/bitstream/10316/36992/1/Tese%20Pedro%20Coelho%20Rumo%20%c3%a0%20Industria%204.0.pdf

Confederação Nacional da Indústria. (2023). Perfil da Indústria Brasileira 2023. Brasília: CNI. Recuperado de https://www.portaldaindustria.com.br/

Egodawele, M., Sedera, D., & Bui, V. (2022). A systematic review of digital transformation literature (2013–2021) and the development of an overarching apriori model to guide future research. *arXiv preprint*. https://arxiv.org/abs/2212.03867

Elnadi, M., Abou Khalil, M., & Haffar, M. (2025). The mediating role of supply chain capabilities in the relationship between digital transformation and sustainable supply chain performance. *Sustainable Development*. Advance online publication. https://doi.org/10.1002/sd.70191

Feimec. (2016). *Manufatura avançada: Tudo que você precisa saber sobre a 4ª Revolução Industrial e os desafios a serem enfrentados para a sua implantação no Brasil*. http://alvarestech.com/temp/InternetOfThings/e-book_-_manufatura_avan%C3%A7ada.pdf

Felsberger, A., Obst, D., & Reinhart, G. (2020). Business analytics for manufacturing-related decision-making: Literature-based maturity model. *Computers & Industrial Engineering, 147*, 106677. https://doi.org/10.1016/j.cie.2020.106677

Hermann, M., Pentek, T., & Otto, B. (2016). Design principles for Industrie 4.0 scenarios: A literature review. In *Proceedings of the 49th Hawaii International Conference on System Sciences* (pp. 3928–3937). IEEE. https://doi.org/10.1109/HICSS.2016.488

Höse, K., Amaral, A., Götze, U., & Peças, P. (2023). Manufacturing flexibility through Industry 4.0 technological concepts—Impact and assessment. *Global Journal of Flexible Systems Management, 24*(2), 271–289. https://doi.org/10.1007/s40171-023-00339-y

Ji, S., & Li, X. (2022). Digital transformation: A review and research framework. *International Journal of Information Management, 66*, 102536. https://doi.org/10.1016/j.ijinfomgt.2022.102536

Jie, H., Lin, Z., Wang, Y., & Chen, L. (2025). Digital maturity and innovation performance in high-tech SMEs. *Technovation, 140*, 102985. https://doi.org/10.1016/j.technovation.2025.102985

Khan, M. I., Yasmeen, T., Khan, M., Hadi, N. U., Asif, M., Farooq, M., & Al-Ghamdi, S. G. (2025). Integrating Industry 4.0 for enhanced sustainability: Pathways and prospects. *Sustainable Production and Consumption, 54*, 149–189. https://doi.org/10.1016/j.spc.2024.12.012

Kılıç, C., Yılmaz, O., & Demir, H. (2024). Sustainable business models in the era of Industry 4.0: A systematic review. *Business Strategy and the Environment, 33*(2), 678–693. https://doi.org/10.1002/bse.3634

Kupfer, D. (2019). *Estratégias industriais em tempos de transformação digital*. UFRJ/IE.

Llorente, J. A. (2016). A transformação digital. *Revista Uno, 24*, 8–10. https://www.revista-uno.com.br/wp-content/uploads/2013/09/160520_UNO24_BR.pdf

Lego, L. L., & Mattos, C. A. (2020). O papel da internet das coisas (IoT) nas práticas de manufatura ágil: Uma análise da interação do modelo conceitual de manufatura ágil com as categorias de aplicativos da IoT. In *Anais do 40º Encontro Nacional de Engenharia de Produção*. http://O-papel-da-Internet-das-Coisas-IoT-nas-praticas-de-manufatura-agil-uma-analise-da-interacao-do-modelo-conceitual-de-manufatura-agil-com-as-categorias-de-aplicativos-da-IOT.pdf

López-López, W., Silva, L. M., & García-Cepero, M. C. (2019). Visibility of Latin American scientific production: The case of SciELO and RedALyC. *Scientometrics, 120*(2), 647–667. https://doi.org/10.1007/s11192-019-03121-3

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & PRISMA Group. (2020). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement (2020 update). *PLOS Medicine, 17*(9), e100334. https://doi.org/10.1371/journal.pmed.100334

Reaidy, P., Alaeddini, M., Gunasekaran, A., Lavastre, O., & Shahzad, M. (2024). Unveiling the impact of Industry 4.0 on supply chain performance: The mediating role of integration and visibility. *Production Planning & Control*. Advance online publication. https://doi.org/10.1080/09537287.2024.2440454

Reis, J., et al. (2023). Digital transformation: A meta-review and guidelines for future research. *Journal of Business Research, 158*, 113702. https://doi.org/10.1016/j.jbusres.2022.113702

Riedl, R., et al. (2024). What is digital transformation? A survey on the perceptions of decision-makers in business. *Information Systems Frontiers*. https://doi.org/10.1007/s10257-023-00660-0

Rogers, D. L. (2016). *The digital transformation playbook: Rethink your business for the digital age*. Columbia Business School.

Rogers, D. L. (2019). A estratégia digital: Cinco estratégias inovadoras para transformar negócios. Autêntica Business.

Rogers, D. L. (2024). The digital transformation roadmap. Columbia Business School Publishing.

Santos, T. D. L. P. (2019). *Competências profissionais na Indústria 4.0: Uma revisão sistemática* [Dissertação de Mestrado, Universidade Federal de Sergipe]. Universidade Federal de Sergipe. https://docplayer.com.br/171854859-Universidade-federal-de-sergipe-centro-de-ciencias-sociais-aplicadas-departamento-de-administracao-thiago-diorgenes-lima-pereira-dos-santos.html

Schwab, K. (2016). *A quarta revolução industrial*. Edipro.

Sebrae. (2018). *Indústria 4.0: A moda a caminho do futuro*. https://sebrae.com.br/Sebrae/Portal%20Sebrae/UFs/RJ/Anexos/Industria%204_0%20-%20WEB.PDF

Sebrae. (2021). *Transformação digital: Como pequenas empresas podem se beneficiar das novas tecnologias*. https://datasebrae.com.br/transformacao-digital/

Shabur, M. A. (2024). A comprehensive review on the impact of Industry 4.0 on the development of a sustainable environment. *Discover Sustainability, 5*, 97. https://doi.org/10.1007/s43621-024-00290-7

Silva, E. C., & Menezes, E. M. (2005). *Metodologia da pesquisa e elaboração de dissertação*. Visual Books.

Tadeu, H. F. B. (2016). *Impactos da Indústria 4.0*. Fundação Dom Cabral. https://www.fdc.org.br/conhecimento-site/nucleos-de-pesquisa-site/centro-de-referencia-site/Materiais/Impactos%20da%20Ind%C3%BAstria%204.0.pdf

Tavares, M. C. L. (2021). *Desafios da reindustrialização no Brasil: Inovação, emprego e competitividade*. Fundação Perseu Abramo.

Verhoef, P. C., Broekhuizen, T., Bart, Y., Bhattacharya, A., Dong, J. Q., Fabian, N., & Haenlein, M. (2021). Digital transformation: A multidisciplinary reflection and research agenda. *Journal of Business Research, 122*, 889–901. https://doi.org/10.1016/j.jbusres.2019.09.022

Xiao, W. (2024). Digital transformation in manufacturing enterprises: Unveiling the path to innovation and efficiency. *Journal of Manufacturing Technology Management, 35*(7), 1123–1145. https://doi.org/10.1108/JMTM-07-2023-0321

Yang, Z., Li, J., & Chen, X. (2024). Digital transformation and ESG performance in manufacturing firms: Evidence from China. *Sustainability, 16*(5), 2147. https://doi.org/10.3390/su16052147

Authors

1 – Josiane de Fátima Daniel Cardoso

Institution: UNIJUÍ – Universidade Regional do Noroeste do Estado do Rio Grande do Sul - Ijuí, RS, Brazil

Master in Regional Management and Development
Email: Josiane.rainha@yahoo.com.br
ORCID: https://orcid.org/0000-0002-6893-9693

2 – Argemiro Luis Brum

Institution: UNIJUÍ – Universidade Regional do Noroeste do Estado do Rio Grande do Sul - Ijuí, RS, Brazil
Doctor in International Economics from EHESS Paris
Email: argelbrum@unijui.edu.br
ORCID: https://orcid.org/0000-0002-8763-9514

Contribution of authors

Contribution	[Author 1]	[Author 2]
1. Definition of research problem	√	
2. Development of hypotheses or research questions (empirical studies)	√	
3. Development of theoretical propositions (theoretical work)		
4. Theoretical foundation / Literature review	√	√
5. Definition of methodological procedures	√	√
6. Data collection		
7. Statistical analysis	√	√
8. Analysis and interpretation of data		
9. Critical revision of the manuscript		
10. Manuscript writing	√	√

Conflict of Interest

The authors have stated that there is no conflict of interest.

Plagiarism Check

The ReA/UFSM maintains the practice of submitting all documents approved for publication to the plagiarism check, using specific tools, e.g.: Turnitin.

Edited by

Jordana Marques Kneipp

Data availability statement

Data will be available upon request