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The maturity of Brazilian companies on the adoption of industry 4.0 practices

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Abstract. The fourth industrial revolution, commonly known as Industry 4.0, has brought significant transformations to the global production model by placing information technologies at its core. This technological trend and ecosystem encompass various concepts aimed at optimizing industrial processes, including enhanced resource optimization and flexibility through the integration of human factors and technology. However, the benefits of this model are not uniformly distributed among countries, and peripheral or semi-peripheral countries, within a capitalist framework, face a competitive disadvantage due to limited access to technology when compared to developed nations. In this article, we examine the current state of Industry 4.0 development in Brazil by focusing on the adoption of digital transformation technologies and processes within domestic companies. Our analysis reveals that Brazil is still in the early stages of maturity regarding the implementation of Industry 4.0 practices, and there is a scarcity of research on this topic within the national context.

Keywords: Industry 4.0, Brazil, Digital transformation.

1. Introduction

Industry 4.0 is characterized by the integration of Information and Communication Technologies (ICTs), Internet of Things (IoT), Cloud Computing, Big Data, Artificial Intelligence, among other technologies, into production processes. These technologies integrate perceptions that contribute to increasingly efficient, agile and adaptable production processes,

in addition to offering new business opportunities and service models. It is a paradigm shift in the way we work, how we communicate and how we express ourselves. These behavioral changes promoted by the use of technology favor a new way of producing and consuming (Schwab, 2016).

While Industry 4.0 has the potential to impact all value chains and strengthen sectors dominated by large multinational companies capable of incorporating technologies and driving productivity, small and medium-sized enterprises (SMEs) often remain unaware of the possibilities offered by technology. Economic resource limitations, the adaptability of their workforce, and limited knowledge about technologies hinder the integration of ICTs for these SMEs. The situation has been exacerbated by the COVID-19 pandemic, which caused a significant decline in global industrial production, directly affecting the manufacturing sector (Mon and Del Giorgio, 2022)

The post-pandemic period is expected to accelerate the transformation process of the fourth industrial revolution in large companies with substantial technical resources, as they lead this revolution. However, many micro, small, and medium-sized enterprises that still rely on manual processes and have not embraced technology will be left behind and unable to make the transition.

On one hand, the software industry in emerging countries has experienced remarkable growth in recent decades, absorbing a significant number of skilled professionals. However, this growth has primarily focused on consolidating productivity in the world's most dynamic and concentrated sectors, resulting in a technological gap within other productive sectors.

A survey conducted by the Brazilian Agency for Industrial Development (ABDI) revealed that although 94% of Brazilian companies have their own IT department or outsource IT activities, there is a disparity between the perceived importance of new technologies and their actual adoption by companies. Approximately 73% of companies do not have any projects for IoT adoption, with the majority (44%) stating that they do not see a need for this technology in their business. The main obstacles to implementing IT and connectivity projects are high costs (78% of companies) and a lack of skilled labor (69%). Additionally, 57% of companies report having inadequately trained employees to address connectivity needs in the industry. However, nearly all companies that have adopted an IoT project express satisfaction with the results, with 40% exceeding expectations and 50% meeting

expectations (ABDI, 2021).

In 2018, the Brazilian Ministry of Industry, Foreign Trade, and Services (MDIC) partnered with ABDI to launch a series of measures aimed at assisting small and medium-sized industries in Brazil in transitioning to Industry 4.0. These measures encompass various aspects such as raising awareness, assessing opportunities, developing new technologies, providing financing for production plant modernization, manufacturing machinery and systems, addressing labor market demands, facilitating international trade, and reviewing standards for companies to migrate to Industry 4.0 (Brasil, 2018).

Small and medium-sized companies in Ibero-American economies, including those in Brazil, play a vital role in employment generation and promote the productive development of other industries within value chains. However, most of these companies lack strategies for technological upgrading to enhance competitiveness. Simultaneously, they do not exert significant pressure for the development of ICTs, which implies that the workforce excluded from this transformation will grow alongside technological advancements (Nedelkoska and Quintini, 2018).

The digital transformation of production systems necessitates the horizontal integration of products and processes facilitated by collaborative networks, where workers cover multiple areas within a manufacturing industry. This approach enables simultaneous execution of multiple production processes, encompassing routes, merchandise flows, logistics, delivery, and distribution. This integration drastically reduces production times and operating costs while increasing the complexity of products and processes through the implementation of various technologies (Mon et al., 2023).

In this context, the convergence of integrated digital, physical, and biological technologies, along with the generation and processing of massive data, the deployment of interconnected physical objects through the Internet of Things, the development of learning algorithms, and the utilization of augmented and/or virtual reality, as well as efficient use of energy resources, will drive the acceleration of the fourth industrial revolution. The incorporation of innovative technologies into this scenario requires a deep understanding of existing capacities to identify the real needs for technological evolution in small and medium-sized companies.

This study aimed to investigate the current state of adoption of Industry

4.0 practices by Brazilian companies based on the existing literature. The digital heterogeneity in the Brazilian context raises concerns for strategic planning and the formulation of public and private policies. The research sought to comprehend the scenario and digital maturity of Brazilian companies in order to stimulate reflection on their current and future levels of digitalization.

2. Theoretical Reference

2.1 Industry 4.0 and digital transformation

Industry 4.0, also known as the Fourth Industrial Revolution, is described by Mercier-Laurent and Monsone (2019) as an ecosystem of trends and technologies aimed at enhancing production processes through factors such as increased flexibility and optimization, combining human and technological elements with a focus on cost-effective production. This production model emerged from a hypercompetitive environment where Western manufacturing aimed to match the level of competition from Asian countries.

To be recognized as an Industry 4.0 organization, a company must undergo the process of digital transformation, which entails the application of Industry 4.0 technologies in its daily operations. Consequently, the adoption of these technologies necessitates organizational transformation, which poses challenges for companies, introducing new approaches and techniques in value creation, business models, and digitizing business strategies to align with how they engage, serve, and retain customers.

Considering the significance of human factors in Industry 4.0, where no fully automated system is completely reliable, but better results are achieved through the combination of machines and human capabilities, it is evident that digital transformation is not solely the responsibility of the company. It requires adaptation to the demands of customers, partners, employees, and competitors who utilize and promote the use of new digital technologies (Tadeu et al., 2018). Thus, digital transformation is no longer a standalone goal for companies seeking to be part of Industry 4.0; rather, it becomes an ongoing journey towards achieving digital maturity.

The concept of digital maturity is relatively new in Brazil and has emerged as a response to the challenges posed by the continuous evolution of technologies, tools, and trends in the digital business environment. Brazilian

companies face difficulties in attaining digital maturity due to its dynamic nature, which necessitates constant adaptation to new technologies. Given the absence of a standardized classification for digital transformation in companies, some scholars have developed their own methods based on the level of digital maturity exhibited by these organizations. Various methods exist, but we will focus on one method originating from Brazil.

Martins et al. (2019) have developed a tool for measuring digital transformation that encompasses four dimensions: Strategy, Capacity, Organization, and Culture. This tool assesses the level of digital transformation and assigns a score that reflects the degree of advancement or limitations in each dimension:

- Digital leaders (51 points or more): Companies exhibiting a high level of digital transformation.
- Ascending (between 36 and 50 points, considering the extremities): Companies with a medium-high level of digital transformation..
- Emerging (between 35 and 26, regarding the extremities): Companies with a medium-low level of digital transformation.
- Beginners (under 25 points): Companies at a low level of digital transformation.

The overall score considers all four dimensions, providing a general assessment of the company's performance. However, it is also possible to analyze each dimension separately to gain a more detailed understanding of the company's disparities in each area (Martins et al., 2019).

In addition, Mon and Del Giorgio (2021) present an index for measuring the level of technological development and a company's installed capacity. This index allows for the identification of three levels of technological development: Basic Level (for companies using outdated technology), Medium Level (for companies with moderately updated technology), and Advanced Level (for companies with advanced technology and on the path to Industry 4.0 transformation). The results obtained from this index enable companies to assess the technologies currently employed in different sectors and identify areas where further technological incorporation is needed.

2.2 Industry 4.0 characteristics and their definitions

The concept of Industry 4.0 originated in Germany in 2011, a country

known for its highly competitive manufacturing industry (Rojko, 2017). The term was first introduced at the Hannover Fair in 2011 to explore the potential of new technologies and concepts, including:

- Internet availability and the utilization of connected devices - Internet of Things (IoT).
- Integration of technical processes and business processes within companies.
- Digital mapping and virtualization of the physical world.
- Intelligent factories where production and products embody the concept of intelligence

According to Manavalan and Jayakrishna (2019), the essential and prominent technological trends in Industry 4.0 are multidisciplinary in nature. The revolution is driven by the implementation of cyber-physical systems (CPS), cloud computing, the Internet of Things (IoT), Big Data, automatically guided vehicles (AGV), augmented and virtual reality, virtualization, digital twins, transparency, enhanced security, decentralized decision-making, data processing, new business models, cost reduction, environmentally friendly production, and the central role of the human factor.

The pillars of Industry 4.0, as outlined by Foster et al. (2018), are summarized in Figure 1.

Cyber-Physical Systems (CPS): CPS refers to interconnected systems where the computational and physical components are tightly integrated, forming embedded systems (Vaidya et al., 2018).

Internet of Things (IoT): IoT comprises a network of physical objects connected to the Internet, including devices embedded in vehicles, sensors, computers, and other objects/systems that exchange information and data with each other. It represents the connection between people and things, enabling data collection and sharing to understand usage patterns and the environment. Organizations across various industries increasingly leverage IoT to operate more efficiently, gain deeper customer insights, deliver improved customer service, enhance decision-making, and increase overall business value. In industrial settings, these devices are often referred to as the Industrial Internet of Things (IIoT) (Furtado, 2017).

Cloud Computing: Cloud computing is a broad term that encompasses services delivered over the Internet. It eliminates the need for companies to maintain on-site IT infrastructure, as they can access computing resources

and applications remotely through the cloud (Furtado, 2017).

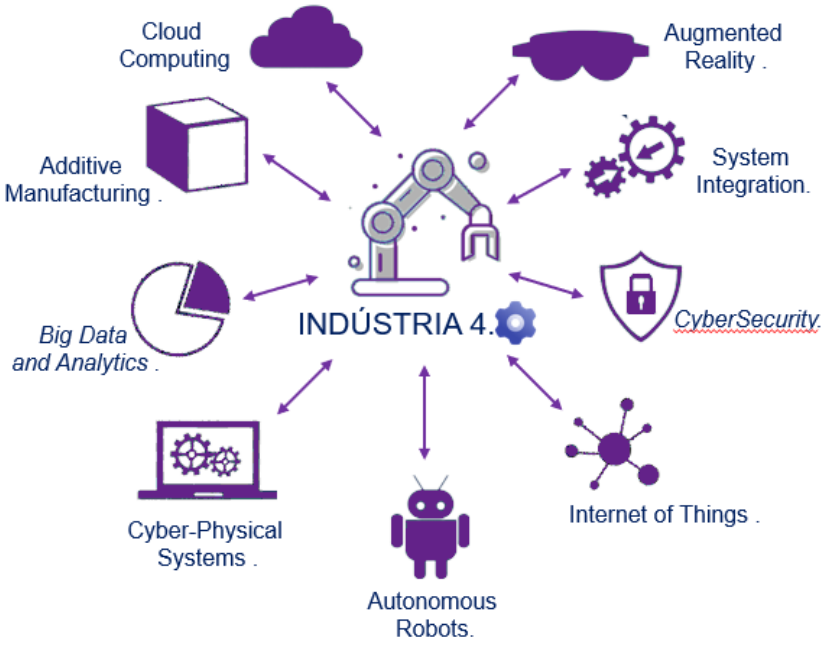

Figure 1. Pillars of Industry 4.0, adapted from Foster et al.'s (2018) drawing

Big Data and Analytics (BDA): BDA refers to technologies such as database tools, data mining, and data analysis techniques that companies utilize to study large-scale and complex datasets. These technologies are employed in various applications to improve a company's performance across multiple dimensions (Kwon et al., 2014).

Augmented Reality (AR): AR involves real-time direct or indirect visualization, where the physical environment is enhanced with virtual information. AR systems aim to improve the user's perception and interaction with the real world (Vaidya et al., 2018).

Additive Manufacturing (AM): AM, previously known as 3D printing, enables the construction of physical objects based on digital files, typically using 3D CAD. This technology involves the consecutive addition of liquid materials, sheets, or powders to create tangible objects (Vaidya et al., 2018).

Cyber Security: With increased connectivity between objects and systems, factories have become more vulnerable to intrusion threats from individuals, organizations, and even governments. Cybersecurity has become crucial to ensure secure and reliable structures that protect systems and minimize vulnerabilities (Vaidya et al., 2018).

Autonomous Robots: Autonomous robots are primarily used in tasks requiring repetitive precision or in restricted and hazardous environments unsuitable for humans. The current challenge is to enable these systems to work collaboratively and safely alongside humans, while also being capable of learning from them (Vaidya et al., 2018).

System Integration: Industry 4.0 emphasizes three dimensions of integration. Firstly, horizontal integration spans the entire value creation network. Secondly, vertical integration involves integrating manufacturing execution systems (MES) vertically within the organization. Lastly, end-to-end engineering encompasses the integration of various engineering processes across the entire product lifecycle (Vaidya et al., 2018).

2.3 Industry 4.0 in Brazil

According to a study by the National Confederation of Industry (CNI), the industrial sector accounted for approximately 23.9% of Brazil's Gross Domestic Product (GDP) in 2022 (CNI, 2022). This percentage is low compared to historical data from Brazil since 1940, which has been slowly growing since 2017. While the industrial sector plays a crucial role in generating jobs and wealth for the Brazilian economy, there is a need for increased investment and innovation.

To foster innovation and technological advancements in the country, the Brazilian Chamber of Industry 4.0 (Câmara Brasileira da Indústria 4.0) was established by the Brazilian government. The aim of this initiative is to enhance the productivity and competitiveness of national companies and integrate Brazil into global value chains (Brasil, 2020). The initiative consists of four working groups:

- Technological development and innovation.
- Human capital.
- Production Chains and Supplier Development.
- Regulation, Technical Standardization and Infrastructure.

Experts agree that the Brazilian industry is still largely transitioning from the second industrial revolution (characterized by assembly lines and electric power) to the third industrial revolution (focused on expanded automation through electronics, robotics, and programming) (FIRJAN, 2016).

While Brazil has the potential for digital transformation, it needs to take more risks to achieve a technological leap of this magnitude. Implementation challenges include formulating innovative strategic policies, government incentives, bringing together industry leaders with vision and courage, and fostering technological development and training of qualified professionals through academic and research institutions (FIRJAN, 2019).

For the CNI (2016), in some countries, Industry 4.0 is already becoming a reality, even with the support of the governments of the leading economic powers, which have placed it at the center of their industrial policy strategies. This creates a double challenge for Brazil because, in addition to seeking the incorporation and development of these technologies, it is necessary to do so with relative agility to prevent the competitiveness gap between Brazil and some of its main competitors from increasing (CNI, 2016).

There are challenges for both the public and private sectors, but there is also a significant opportunity. Through digital technologies, the Brazilian industry has the potential to significantly increase productivity and reduce the gap with developed nations. However, a sense of urgency is required, as major industrialized countries have placed these transformations at the forefront of their industrial policy strategies (CNI, 2016). Key aspects for the industry's advancement include streamlining production processes, requalifying workers and managers, starting the implementation of Industry 4.0 with available technologies and low costs, and investing in research, development, and innovation.

3. Research Methodology

To investigate the situation of Brazilian companies concerning the adoption of industry 4.0 practices and to understand this scenario, scientific databases were consulted both in English and Portuguese. The research sought to broaden the understanding of the digital maturity of these companies. The research questions is: How are Brazilian companies progressing towards Industry 4.0? What is the level of digital maturity of these transforming companies? As inclusion criteria for the study, scientific

publications in national and foreign journals based on pre-established descriptors and publication dates were considered.

Keywords both in Portuguese and translated into English were selected. The use of the English language aimed to expand access and considered that ´many Brazilian researchers have their productions published in this language. The following keywords were used: ("indústria 4.0" OR "industry 4.0" OR "transformação digital" OR "digital transformation") AND ("digital maturity" OR "maturity level" OR "maturidade digital" OR "nível de maturidade") AND (Brasil OR "Companhia Brasileira" OR Brazil OR "Brazilian company") in order to restrict the answer. The period established was from 2017 to 2022. To access scientific publications, the search considered scientific text search engines, namely: Google Scholar and the CAPES Jounals Portal (Coordination for the Improvement of Higher Education Personnel [*Coordenação de Aperfeiçoamento de Pessoal de Nível Superior*]). The choice of the research had as a criterion to be referenced for producing knowledge in digital transformation. The flowchart of the research procedure is shown in Fig 2.

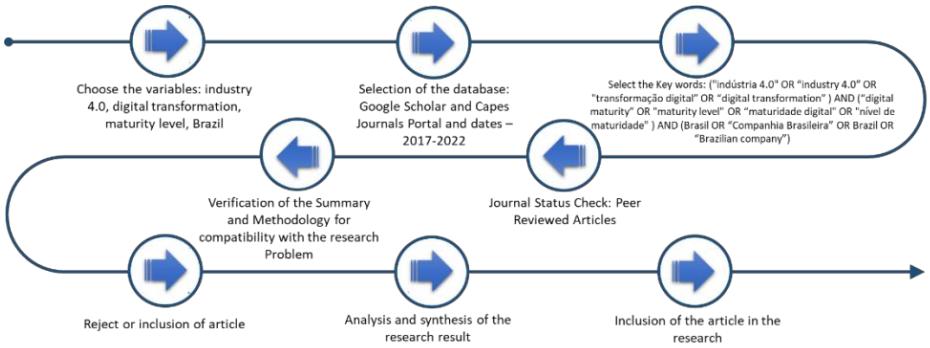

Figure 2. The literature systematic analysis process

The criteria established for searching and selecting scientific publications significantly reduced the number of scientific articles included in this investigation. Although the initial search provided many publications, the requirements included only those studies that analyzed, in some way, the Brazilian panorama towards Industry 4.0 in the national context and with results description. Another relevant exclusion criterion was selecting full articles published in open access journals.

3.1 Research Technique

The research methodology followed a systematic approach with predetermined criteria. A specific research question was formulated, and clear search criteria were established. The selection process involved carefully choosing and explaining each of the studies that were analyzed. The analysis was based on the information provided in the abstracts and the methodology sections of the selected studies. By providing detailed criteria and explanations, the methodology ensures the replicability of the study. The studies included in this research clearly outlined their objectives, methodology, and the results they obtained.

3.2 Search limitations

This study suffers from many limitations that must be pointed out. Firstly, the research criteria adopted were quite restrictive, limiting the studies to be included in this analysis to those that dealt exclusively with Brazilian companies in the digital transformation process. Secondly, a significant amount of work may not have been covered by the academic databases (Google Scholar and CAPES Portal were considered for this study) or excluded by some other criterion. It is essential to mention that relevant papers published in Brazil on Digital Transformation are often limited to master's or doctoral theses, books, book chapters or conferences without peer review, which were excluded from the results.

4. Results

The literature review involved the study of four articles that reflect the digital transformation among Brazilian companies. The search for information on research conducted in the last five years was performed through multi-source analysis of materials in digital format due to the dispersion of available articles. Based on the research results, it was realized that in Brazil, few papers still address the digital transformation of Brazilian companies. In this same sense, it is essential to emphasize that Brazil's literature on digital transformation issues is still embryonic.

In a first search in the selected databases, 894 articles were returned, 887 from Google Scholar and 7 from the Capes Portal. From this total, considering the title, year of publication and peer review, 12 articles were

selected, 7 from Google Scholar and 5 from the Capes Portal. After reading the abstract, most of the articles were excluded because they addressed the management for the digital transformation, others addressed research on the maturity level measurement, and others did not bring the primary source, constituting bibliographic reviews of the literature, outside the scope of this investigation, which resulted in the three articles analyzed (0 from Google Scholar and 4 from Capes Portal).

The research highlights the digital transformation of Brazilian companies and the need to reflect on policies to implement this process. Brazil is still behind in the digital industry, human capital and research compared to other countries, especially in Europe. Below, Table 1 summarizes the systematic analysis results.

Table 1 – Summary of the literature systematic analysis results

Authors (Year of Publication)	Company Branch	Research Tools	Technologies used in the surveyed companies	Results
Brunheroto, Tomanek and Deschamps (2021).	Metal-mechanical and automotive companies in the Metropolitan Region of Curitiba (Brazil)	63 companies answered a questionnaire on the level of implementation of each technology and the improvements 76 responses Qualitative Analysis	Internet of Things Cloud Computing Cyber Security Big Data Analytics Virtually guided self-service 3D printing	The Internet of Things presented significant improvement levels for all performance objectives. The average level of technology adoption increases according to the size of the companies. The results for large companies are significantly higher than other small ones.
Salume, Barbosa, Pinto and Sousa (2021).	Brazilian companies in the retail sector, located in different	The sample consisted of strategic-level managers from Brazilian companies in the retail sector who answered questions related to	None	Communication and high-level engagement contribute to success in the digital transformation

	regions of Brazil	the digital maturity scale 260 valid questionnaires answered Regressive analysis technique		process, in addition to the company's internal analysis and broader market analysis in which it operates to maintain a better positioning.
Almeida, T. S. B. A., Gennaro, D. R., & Ibusuki, U. (2020)	Automotive Engineering	A multi-faceted investigation aimed at pinpointing the optimum juncture for transitioning from Lean Manufacturing practices to adopting Industry 4.0	None	Aimed to identify the optimal transition point from Lean Manufacturing to Industry 4.0, focusing on the manufacturing sector
Lima, A. A. M., Nodari, C. H., C. H., & Froehlich, C. (2022)	Metal-mechanical	Semi-structured interviews, company documents and non-participant observations Qualitative content analysis procedures.	None	The adoption of Industry 4.0 technologies requires a strategic scope oriented toward digital technologies and disseminated throughout all organizational spheres. It should be linked to flexible and manageable governance structures aligned with digital technologies.

5. Discussion

The results of the study on the status of Industry 4.0 in Brazil provide valuable insights into the digital transformation among Brazilian companies. The literature review highlighted a limited number of articles addressing the digital transformation of Brazilian companies, indicating that the literature on

this topic in Brazil is still in its early stages of development.

5.1 Search question results

The study by Brunheroto et al. (2021) refers to a comparison between the main implications of Industry 4.0 technologies for production management in the universe of metal-mechanical and automotive companies in the Metropolitan Region of Curitiba (Brazil) and the Upper Bavaria Region (Germany). For the present investigation, only data referring to Brazilian companies were considered. The study included 63 companies in this mentioned sector above in the Metropolitan Region of Curitiba (Brazil), representing 80% of the regional companies, and 70% were micro and small companies. The results showed that technology adoption increases with the size of the company. Even with the constant adoption of Industry 4.0 technologies, not all technologies seem accessible in Brazil, especially for smaller companies.

Salume et al. (2021) analyzed the elements or dimensions that lead to higher levels of digital maturity. The sample involved 260 valid questionnaires answered by strategic-level managers from Brazilian companies in the retail sector, which involved 2.3% of small companies, 38.9% of medium-sized companies and 58.8% of large ones. The results indicated strong evidence that digital maturity manifests itself positively into a clear, dynamic digital strategy aligned with the business model. The operation dimension, related to collaboration and integration among companies, and the market capacity dimension were also impacted. Moreover, corporate culture must be treated as a fundamental dimension for conducting the digital transformation process, besides implementing digital assets, which characterize the use of technology involving managerial aspects such as leadership, culture, change management and governance.

Almeida et al. (2020) employing a questionnaire based on the Toyota Production System and Lean principles, the study was conducted among companies in the Senai Indústria + Avançada program. The findings revealed that 76% of surveyed companies are highly mature in Lean practices, viewing Lean as a cultural commitment rather than just a set of tools. Despite recognizing the importance of transitioning to Industry 4.0, many companies face barriers, notably in adopting foundational technologies like Big Data and cloud computing. The study underscores that the effective use of advanced technologies in Industry 4.0 is intricately linked with a company's maturity in

Lean practices.

Lima et al. 2022 presents a case study involving a large multinational company located in Rio Grande do Sul in the Metal-Mechanical sector. The research aimed to expand the theoretical contribution of dynamic capabilities in organizations by bridging this theory with strategies for more informed decision-making in the adoption of Industry 4.0-related technologies, thus maximizing opportunities in the digital environment. The results indicate that there is evidence that the adoption of Industry 4.0 technologies requires a strategic scope oriented toward digital technologies and disseminated throughout all organizational spheres. The authors suggest that the adoption of these technologies should be linked to flexible and manageable governance structures, aligned with digital technologies and providing support for the creation of a digital mindset, permeating and aligned with organizational objectives and strategies.

5.2 Findings

Based on the content of the studies and research referenced in this article, some knowledge raises relevant discussion points. Considering that medium and small companies are responsible for a large part of the production in Brazil and that, in an inversely proportional way, they use little or no technology, software, or Internet of things structure, this entire productive sector has its potential committed for both productions and labors generation. In this way, public-private partnership initiatives aimed at promoting industry 4.0 in the country play a fundamental role in Brazil's search for alternative production models through investments in structure and professional training. It is also valid the participation of professionals specialized in HCI studies in the research and performance of such initiatives to facilitate the interaction of professionals from small and middle-sized companies as they integrate information technology into their daily business.

6. Conclusion

The literature review conducted in this study reinforces the notion that the adoption of practices towards Industry 4.0 in Brazil is still in its early stages, indicating an embryonic state within the Brazilian context. Several barriers, such as infrastructure limitations like the slow implementation of 5G internet,

as well as challenges arising from deindustrialization, economic crises, and insufficient training of skilled labor, continue to impede progress in this area.

Furthermore, it is evident that there exists a gap between academia and the needs of the market and society regarding Industry 4.0. This underscores the importance of fostering stronger partnerships between the productive sector, universities, and research centers in Brazil. By establishing collaborative relationships, these entities can work together to address the demands and challenges posed by Industry 4.0. Such collaborations will be crucial in enhancing the international competitiveness of the Brazilian industry and driving research and development efforts in this domain.

In summary, the literature review demonstrates that the adoption of Industry 4.0 practices in Brazil is still in its early stages, hindered by infrastructure barriers, deindustrialization, economic crises, and limited skilled labor training. It is evident that there is a significant gap between academia and the demands of the market and society in terms of Industry 4.0. To overcome these challenges and enhance the competitiveness of the Brazilian industry, it is crucial to foster stronger partnerships between the productive sector, universities, and research centers. These collaborations will facilitate the alignment of research efforts with market needs, driving innovation and contributing to Brazil's international competitiveness

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