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Thematic Section - Production Engineering leading the Digital Transformation

Digital transformation in Brazilian industry: bridging theory and practice

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Abstract

Paper aims: This paper aims to evaluate the digitalization scenario of Brazilian industry, as well as to propose a practical approach to its digital transformation.

Originality: No comparison is available that aims to understand the differences and gaps between theoretical research and the reality of digital transformation in Brazilian industries.

Research method: Based on three steps, namely: review and bibliographic analysis to identify the main aspects of digital transformation; content analysis of national reports to define the state of practice; comparison between the results of theory and practice.

Main findings: The results demonstrate an alignment between the aspects found in the scientific literature and the reports analyzed. The pillars of digital transformation are widely discussed in industrial reality. However, implementation gaps (and related opportunities) difficult the digital transformation of the Brazilian industry.

Implications for theory and practice: This paper introduces a proposition that unites theoretical aspects in a model that may be applied to enable digital transformation in the industry.

Keywords

Digital transformation. Brazilian industry. Industry 4.0. Digitalization.

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1. Introduction

The digitalization of processes has stood out in companies as it promotes a customer-oriented view along with efficiency improvements (Villalonga et al., 2020). In the scenario of global industry competition, production technology, advanced manufacturing, and Industry 4.0 approaches are the primary way to ensure competitiveness, as they provide greater efficiency and resilience in manufacturing systems (Frazzon et al., 2020).

The journey for the use of digital technologies is known as Digital Transformation (DT), through which it is possible to develop highly efficient activities in the corporate value chain (Büyüközkan & Güler, 2020). Digitalization is present in most economic sectors and requires companies to quickly adapt to make it the center of their organizational strategy (Villalonga et al., 2020). Fang et al. (2020) pointed out that the digitalization process is considered a strategic approach to obtaining better operational performance, mainly associated with the ability to analyze a large database that brings new opportunities for traditional companies. Furthermore, according to the World Economic Forum (2018), the digitalization of diverse sectors may benefit society and industry by more than 100 trillion dollars by 2025.

Digital transformation may be defined at the technological, organizational, and social levels, given that the use of digital technologies promotes intelligence and data analysis capacity, digitalization allows the optimization

of processes at the organizational level, and, socially, it influences the experience of consumers (Reis et al., 2018). Regarding the benefits achieved through the digitalization of manufacturing and business processes, Ghobakhloo & Fathi (2020) reported that digital transformation ensures high performance in the short-term and future progress of companies; therefore, it is necessary to develop and plan a business model capable of implementing the emerging technologies and innovations of Industry 4.0. The evolution of information technology and the growth of digitalization makes it possible to connect the physical system and the information flow of the production system. This data-driven approach and the digitalization of production and operations allow possibilities for operational improvements and create value for the organization (Agostino et al., 2020).

Nevertheless, many industries face difficulties migrating to Industry 4.0, especially traditional organizations in emerging countries (Ku et al., 2020). The advancement of digital transformation is considered challenging mainly due to the lack of standardized protocols for its implementation, planning during the application of new integrated technologies, and a realistic vision of the return on investment (Butt, 2020).

According to Fang et al. (2020), the digital transformation process has a greater chance of success in large companies, while small and medium-sized companies need attention and differentiated methods. Still, it is observed that the manufacturing industry moves slowly in the digitalization process, often in a fragmented manner and without a holistic view of the necessary changes, although the importance of digitalization is notorious in the industry as this is the sector that determines the digital economy leadership in many countries (Lola & Bakeev, 2020). Therefore, it is necessary to accelerate digital transformation through efforts not only in applied research but mainly in practical implementation cases to summarize the know-how obtained during the process (Tschandl et al., 2020). From another perspective, the study by Hausberg et al. (2019) revealed that the term digital transformation in manufacturing has been a dominant research subject in recent years. Finally, an important factor regarding the journey of Digital Transformation in the industry is the level of success in its implementation, which is frequently hampered by the difficulty in carrying out the cost-benefit analysis since the investment and infrastructure requirements are considered high (Pflaum & Gölzer, 2018).

In this context, this research aims to compare the practical and theoretical state of digital transformation in Brazilian industries, proposing a model for the digital transformation. The article is divided as follows: the second section shows the method used in the study, Section 3 discusses the content analysis, and the results are exposed in Section 4, followed by the conclusions and references consulted.

2. Research methodology

The research method was structured into three steps, as shown in Figure 1. In the first step, a systematic review was carried out. According to Moher et al. (2010), a systematic review is defined as the review of previously formulated questions using systematic methods of collection, analysis, identification, selection, and critical evaluation of relevant research.

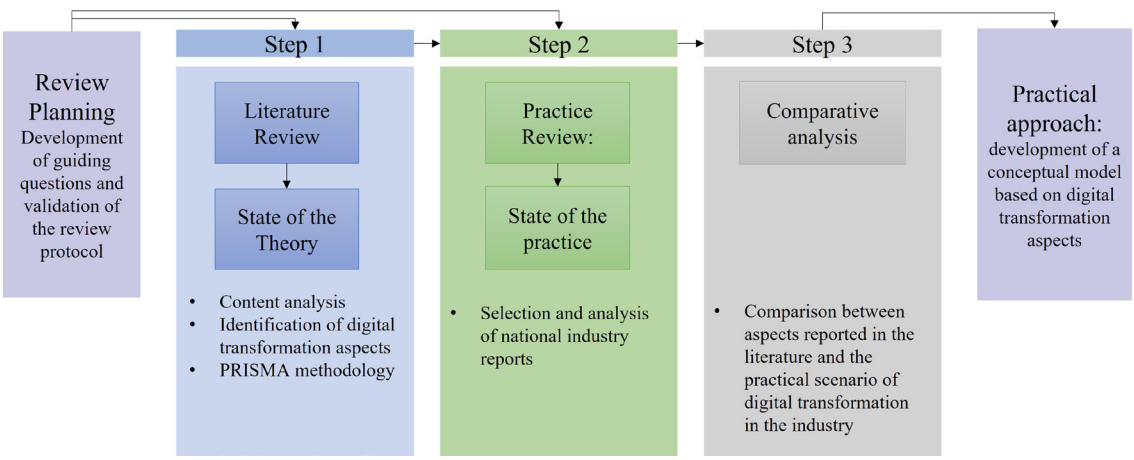

Figure 1. Research steps.

According to Snyder (2019), systematic literature review allows investigating the relationship or effect of specific variables on topics, providing a basis for new conceptual models and theories. Xiao & Watson (2019) highlighted that the review offers a deep understanding of existing work and allows the identification of gaps to be explored.

In this first step, the objective of the literature review was to perform a content analysis of the literature on Digital Transformation and determine the state of the theory. The second step was the selection and review of Brazilian reports on the national industry, bringing the state of practice of the manufacturing industries in the digitalization journey. In the last step, a comparative analysis was performed between the theory and practice of the industries regarding the main aspects of digitalization. From the results, a conceptual model with a practical approach to digitization was developed.

2.1. Review planning

During the review planning, the steps of formulating the questions and validating the review protocol are performed. In the context of Digital Transformation, it is considered relevant to consolidate the state of theory in comparison to the reality of manufacturing industries in Brazil, answering the following guiding questions:

a) What are the relevant aspects of Digital Transformation according to the literature?

This question aims to clarify, based on the literature, what are the guidelines most cited by the various authors relative to the application of the concepts of digital transformation in industries, bringing a theoretical basis to compare to Brazilian practices.

b) How is the advancement of digital transformation in the Brazilian industry from a practical point of view?

The second guiding question aims to comparatively analyze the scenario of the practical application of the aspects previously found, classifying the progress of Brazilian industries in view of the guidelines of digital transformation mentioned in the literature.

c) How to promote digitalization in a practical manner in industries?

The third question aims to propose an applicable model of one of the guidelines found when responding to question one that helps promote digital transformation in the practical and real scenario.

The validation of the review protocol describes the elements of the review, essentially containing the inclusion/exclusion criteria and the strategy used during the research, adapted from Uhlmann & Frazzon (2018) and Liao et al. (2018). The criteria used for inclusion in the article are described in Figure 2, with the selection of studies in the field of engineering focusing on digital transformation in the manufacturing industry published from 2018 to the dates of the searches, aiming to obtain an updated view of the digital transformation scenario of recent years.

Inclusion	Closely Related (CR)	• The research describes studies about DT in manufacturing Industry; • Time Span: from 2018 to July 2021; • Subject Area: Engineering; • Document Type: Conference pair or article; • Source Type: Conference Proceedings or Journals; • Language: English.
Exclusion	Search engine reason (SER)	• The paper has only its title, abstract, and keywords in English but not its full-text
	Without full-text (WF)	• Paper without full-text available
	Non-related (NR)	• NR-1: A paper is not an academic article. For example, editorial materials, conference reviews, contents, or forewords; • NR-2: The definition about “Digital Transformation” is not related to Industry; • NR-3: The definition about "Digital Transformation" is not related to an application of the principles of industry 4.0
	Loosely related (LR)	• The paper does not focus on the discussion, or problem solving of digital transformation. In which: • LR1: Digital transformation is only used as an example fact • LR2: Digital transformations is used to show an application of technology • LR3: Digital transformation is only used as part of its future research direction, future perspective, or future requirement • LR4: Digital transformation is only used as a cited expression • LR5: Digital transformation is only used in keywords and/or references
	Specific area (SA)	• Digital transformation is only used for a specific application area and the results cannot be generalized.

Figure 2. Inclusion and exclusion criteria.

2.2. Literature review

The systematic review carried out in this research uses the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) methodology, described by Moher et al. (2010) and shown in Figure 3.

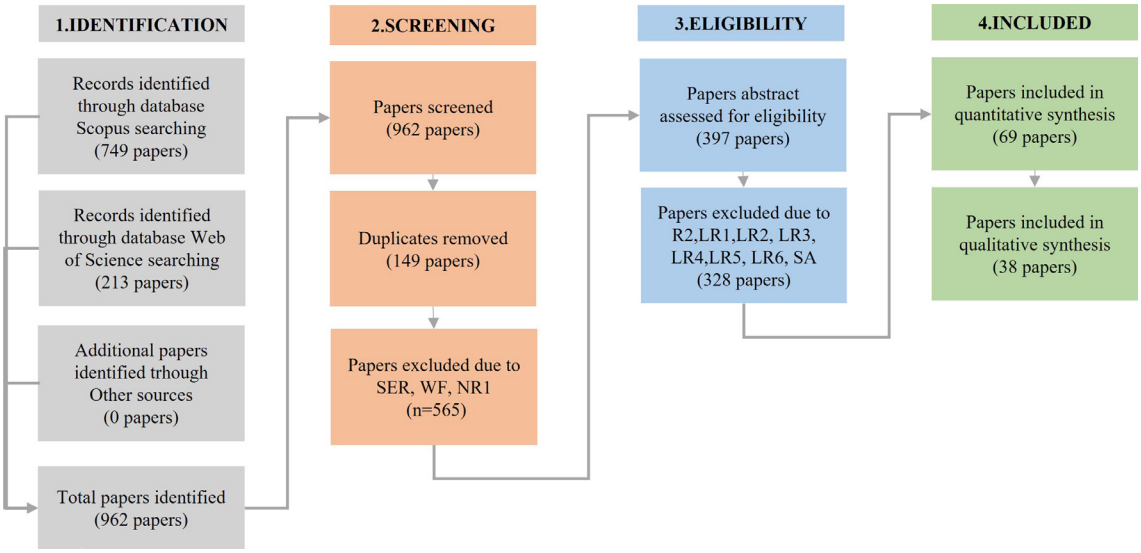

Figure 3. PRISMA steps.

The review was conducted by searching the existing literature using the Scopus (www.scopus.com) and Web of Science (www.webofknowledge.com) databases. The keywords used were "digital transformation", "digitalization", "manufac*", "4.0", "data", and "roadmap". The strings were formed in three ways, obtaining an initial number of identified papers that went through the screening phase, in which duplicates were excluded and the remaining titles were read systematically to exclude articles according to the SER, WF, and NR1 rules. Thus, 397 selected papers were included in the eligibility phase, in which the LR1, LR2, LR3, LR 4, LR5, and SA rules were applied. Finally, the remaining articles were included in the quantitative synthesis and qualitative analysis. The articles included in the quantitative synthesis met all inclusion requirements and were read in full, with 38 being selected that brought qualitative value for analysis.

2.3. Practice review

The review of the practice was carried out through a report content analysis with a qualitative approach described by Krippendorff (2018). Searches were performed in Google Scholar databases to identify the state of practice through scenario analysis reports in Brazil, and the primary sources found and used were the Brazilian Government, McKinsey Brazil, ABIMAQ, and the OECD, as shown in Figure 4.

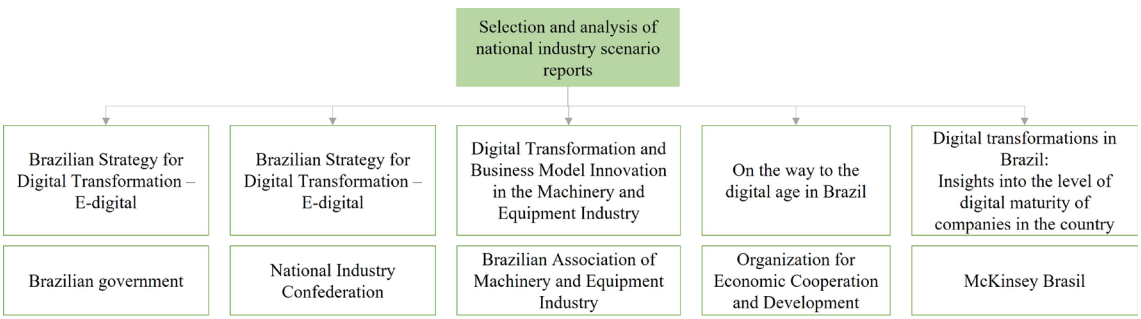

Figure 4. Selected reports.

The data were synthesized through a spreadsheet in a structured manner to generate qualitative information based on the literature. The following section discusses the results and presents the content analysis topics, containing an overview of Digital Transformation based on the literature and reports review.

3. Results

This section is divided into four parts, demonstrating the results obtained in terms of qualitative analysis (theory and practice), comparative analysis, and a practical approach by developing a digital transformation conceptual model.

3.1. Theory analysis

This section aims to describe the relevant aspects of Digital Transformation in the industry according to the authors studied in the qualitative analysis. The Organizational pillar refers to aspects that directly influence a company's business models and the organizational strategy for digital transformation. The Process pillar refers to the adaptations of manufacturing and operational processes in accordance with the strategy considering the aspects of data-driven decision-making. Finally, the Technology pillar is intended for the integration of technology into processes and the organizational structure in a systemic way. Each pillar was subdivided, bringing the 12 main aspects pointed out according to 38 authors, as defined in Figure 5.

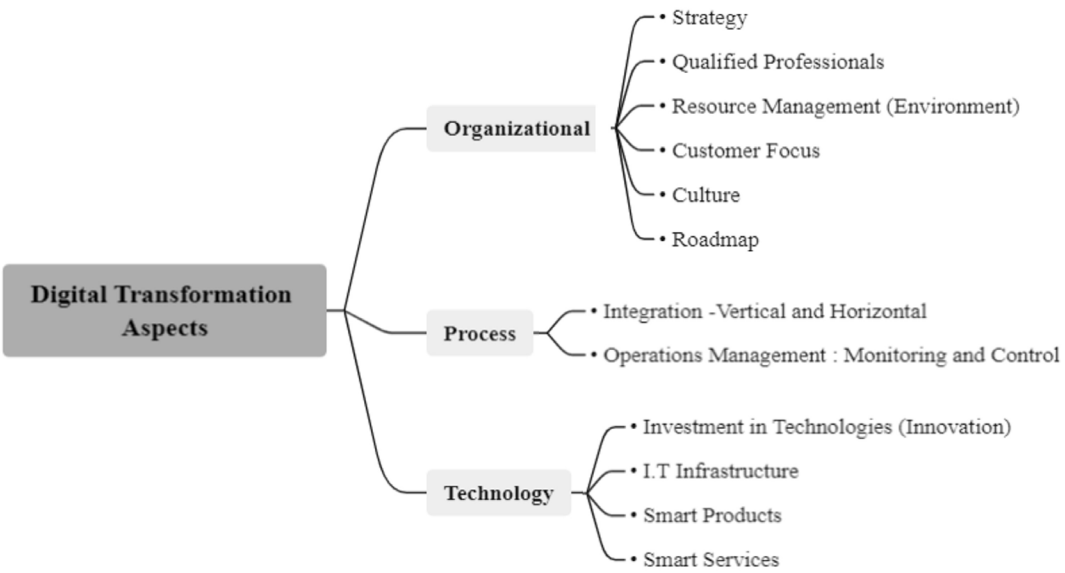

Figure 5. Digital transformation aspects.

Table 1 presents definitions according to some authors, bringing the view of the literature on each of the aspects present in digital transformation.

The radar chart below in Figure 6 shows the distribution of identified aspects, demonstrating the relevance according to the different authors.

The results show that, for most authors, the digital transformation journey is directly associated with organizational strategy since both the business model and the operations must align toward implementing and integrating new technologies. In addition, preparation at the strategic level becomes essential as a guideline for the entire organization during the transformation journey. The organizational strategy was cited as the central aspect of digital transformation with 33 citations, representing 87% of presence among the 38 authors.

To Cachada et al. (2019), digitalization at a strategic level is how an organization will have integrated information across the entire system, allowing understanding from market movements and customer needs to the manufacturing level and disseminating technologies efficiently and in a structured manner in all sectors.

Table 1. Definitions of digital transformation aspects.

Digital Transformation Aspects	Definition	Authors
Strategy	Digital transformation is directly related to creating opportunities through new business models that aim to increase flexibility and improve operational performance. The strategic aspect of the organization must be aligned and planned in a structured manner to achieve the digitalization objectives.	Bader et al. (2019) and Zangiacomi et al. (2018)
Qualified Professionals	It is essential that companies make human competence and employee development one of the main components of the system, strengthening the "digital awareness" of their employees.	Havle & Üçler (2018)
Resource Management (Environment)	Refers to using technology aimed at sustainability to reduce the consumption of resources such as energy and materials during the production process.	Calabrese et al. (2022)
Customer Focus	Digitalization of customer contact and integration of product data. Use of digital technologies to intensify customer contact. Use of digital technologies to constantly adapt to customer needs.	Rachinger et al. (2019) and Schumacher et al. (2019)
Roadmap	The roadmap helps through planning and visualization over time, following each decision on the way to digital transformation. It is a roadmap of the relevant technologies to be implemented to facilitate the digital transformation journey according to the business model and company needs.	Ghobakhloo & Ching (2019) and Zangiacomi et al. (2018)
Culture	Aspect associated with the company's strategy in the sense of a definition of how the existing culture will be adapted and transformed into a digital culture.	Lipsmeier et al. (2020)
Integration – Vertical and Horizontal	Vertical integration aims to connect processes through ERP and MES systems at all organizational levels, from operations to company management. In turn, horizontal integration aims to ensure the interoperability of the supply chain using technology between suppliers and the organization. This aspect represents the complete integration of the value chain from customer to supplier, covering the entire organizational structure from the shop floor to management.	Havle & Üçler (2018) and Lin et al. (2020)
Operations Management: Monitoring and Control	Integration between information systems that allow production management, manufacturing execution, and control of manufacturing processes in a connected way for decision-making. This aspect determines the behavior of operations over time and depends on the commitment of top-level process owners to manage the implementation and performance of processes, the management of systems and process requirements, and the quality of metrics used for measuring the success of the operation.	Calà et al. (2018) and Lin et al. (2020)
Investment in Technologies (Innovation)	The organization must invest in internal and external sources for developing new technologies both externally by observing practical examples from other companies and scientific publications and internally by investing in research and development activities.	Zangiacomi et al. (2020)
Information Technology Infrastructure	The organization must have a clear perception of the value of Information Technology, which includes the development and monitoring of a structure of digital hardware, integration software, data security measures, trained professionals working on technology projects, and, finally, system maintenance.	Ghobakhloo & Ching (2019)
Smart Products	Development of products capable of collecting and transmitting information, either for the organization or its own life cycle.	Török (2020)
Smart Services	Introduction of new services and solutions added to the product, giving a new value proposition to the business through digitalization.	Rachinger et al. (2019)

The second widely highlighted point refers to investment in technology (innovation), mentioned by 24 authors, which may be considered the minimum aspect necessary to support the strategy of digitalization and competitiveness in companies (Ghobakhloo & Ching, 2019). Then, operations management and vertical and horizontal integration are identified as relevant digital transformation aspects by the same proportion of authors, with both highlighted by 24 of the 38 authors.

First, the vertical and horizontal integration aspect of the chains within the organization is pointed out as a great enabler of industry 4.0, promoting the necessary connectivity for the joint growth of all internal company departments, as well as creating a flexible and optimized supply chain at the decision level (Veile et al., 2020). The use of systems such as SCADA, MES, and ERP plays an important role in the centralization and management of data in an integrated manner (Baurina, 2020).

Concerning digitalization at the operational level, operations management or monitoring and control allows the management of plant activities combined with data-based decision-making, enabling improvements in manufacturing performance (Calà et al., 2018).

Figure 6. Digital transformation aspects.

The aspect of professional qualification mentioned by 22 authors exposes the need to develop human capital for digital transformation success. Sjödin et al. (2018) reported that smart factories mature in digitalization have structures that educate people and develop their skills by encouraging the exploration of connected systems and knowledge sharing.

Also, regarding people, according to Sundberg et al. (2019), many companies, especially smaller ones, do not have the digital bias so present in the organizational culture. The study by Türkeş et al. (2019) also revealed that the lack of knowledge about the importance of industry 4.0 is considered a barrier to digital transformation in small and medium companies.

The aspect of organizational culture was pointed out by seven authors, demonstrating that, despite being relevant since it defines how people within an organization will adapt to new technological processes, it is not highlighted in most works. Figure 7 shows the classification of aspects in order from the most relevant to least highlighted by the authors, as well as the percentage of the total citations.

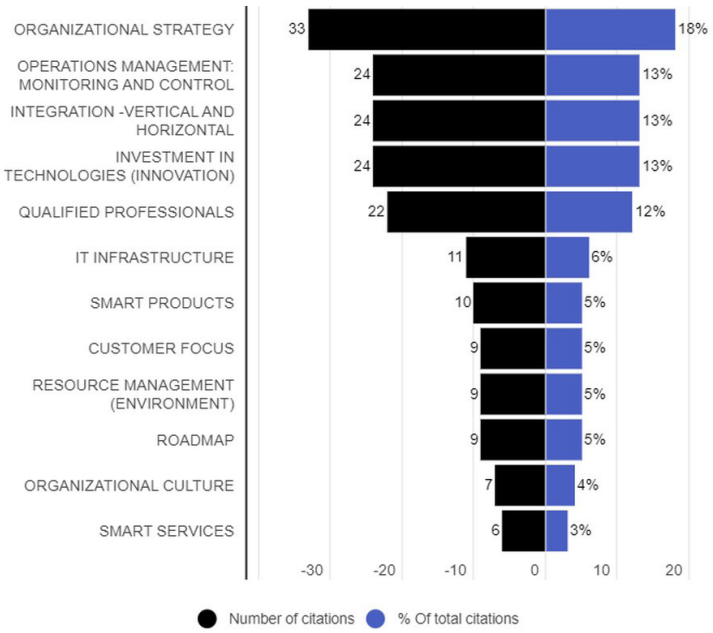

Figure 7. Classification of aspects by number of citations.

3.2. Practice analysis

The following steps were performed to carry out the practical analysis: selection of updated reports with information about the Brazilian industry, full reading for classification, and correlation of each aspect found in the theoretical analysis step with the data provided in the reports. Figure 8 compiles the steps and results obtained in each section up to the current one.

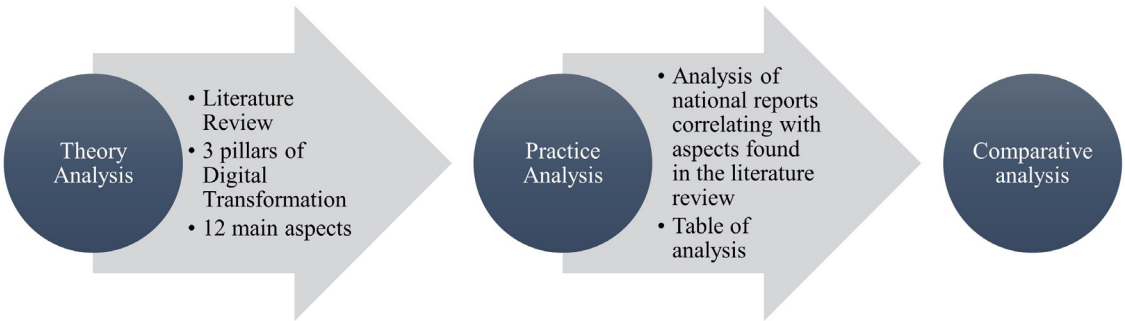

Figure 8. Steps and main results.

Aiming to analyze the Brazilian industry scenario within the described aspects, the evolution of practices adopted by both the government and the manufacturing industry in Brazil was identified. As a result, Appendix A summarizes the state of digitalization practices in the country.

Among the aspects studied, both the government and the companies are clear about the importance of digitalization as the main economic and business strategy to increase the competitiveness of the Brazilian industry (Confederação Nacional da Indústria, 2016). According to the Brazilian Strategy for Digital Transformation report (Brasil, 2018), defining applicable methodologies and technologies is essential to leverage the productivity and competitiveness of manufacturing and to ensure the generation of value at an international level.

As a feasibility factor for the strategy, roadmaps were highlighted by Martins et al. (2019) as present in large companies, while small and medium-sized companies do not have a specific development that encompasses the entire organization, instead focusing on the pillar of technologies and their implementations (Associação Brasileira da Indústria de Máquinas e Equipamentos, 2021).

IT infrastructure is identified as a weak point in the Brazilian case in providing a robust and advanced data network to implement technologies in companies. Also, regarding the adoption of digital technologies in companies, the report by the Organization for Economic Cooperation and Development (2020) highlighted three factors that disadvantage the digital transformation journey in Brazil: insufficient infrastructure, high costs due to the tax system, and financial limitations such as limited access to financing.

In this sense, investments in technology, innovations, and their application still need advances. The CNI highlights that the share of business investment in R&D is 39.9%. In its general report, the Associação Brasileira da Indústria de Máquinas e Equipamentos (2021) indicated that 40% of companies associated with it do not use base technologies such as Cloud Computing, IoT, Big Data, and Analytics. Another study classified the diffusion of these technologies and tools in Brazilian companies, demonstrating that the use of cloud computing has an average above that of countries in the Organization for Economic Cooperation and Development (2020), while technologies such as ERP, GRC, and Big Data have low diffusion among Brazilian companies.

These results are linked to aspects of operations management and integration of data generated in the industry and its use in a connected way that enables the digital transformation of its processes. Relative to this aspect, Associação Brasileira da Indústria de Máquinas e Equipamentos (2021) described that only 30% of the companies surveyed had connected equipment and processes, and less than 20% developed intelligence or analysis with the data collected. The study by Martins et al. (2019) revealed that many companies still used simple statistical data analysis methods, i.e., they had not adopted more sophisticated models such as machine learning to favor and automate decision-making.

Another important factor present in all studies infers the professional qualification and availability of qualified professionals for digital transformation in Brazil. Through *E-digital*, the government indicates that there is a lack of people trained in basic information technology skills, so it highlights several strategic actions, programs, and policies aimed at training professionals and the population. In the industry, the report by Confederação Nacional

da Indústria (2016) pointed out that 38% of workers had not completed at least basic education, making clear the need for initiatives in the area of professional qualification as a basis for sustaining digital transformation.

3.3. Comparative analysis

It is possible to show a comparison between all the aspects described in the literature and the state of the Brazilian industry, as shown in Figure 9, pointing out that there is a similarity between the main factors highlighted by the authors and the points addressed in the reports on the Brazilian scenario, demonstrating a convergence regarding the aspects better known and widespread in both cases.

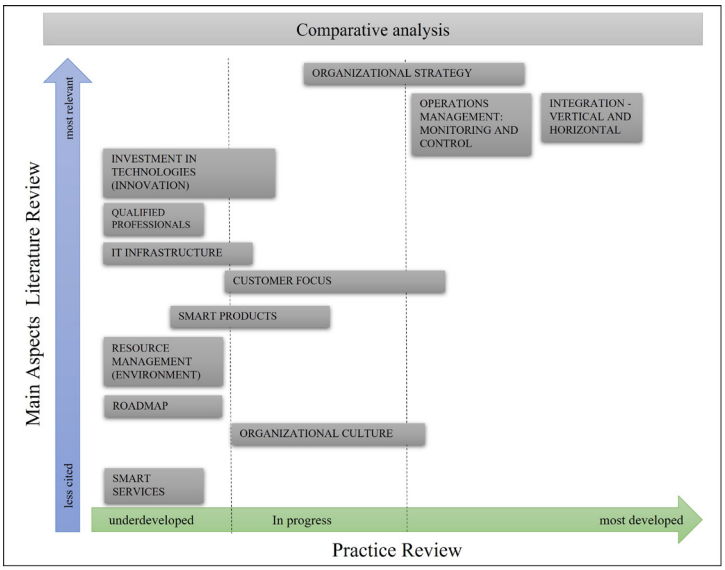

Figure 9. Comparative analysis.

While the literature identifies aspects as drivers of digital transformation, practical reports present the understanding and rate of implementation of companies towards digital transformation. In this sense, it was determined that the aspects with greater adherence in Brazil are digital transformation as an organizational strategy, operational management through monitoring and control, and vertical and horizontal integration, in line with the most mentioned aspects in the literature.

However, even with the equivalence between the results in relation to aspects, the practical scenario of the Brazilian industry presents less significant advancement in the level of perception of the factors, verified through the superficiality and low rate of technological applications and process integration compared to the deep knowledge present in the literature.

On the other hand, investment in technologies, professional qualification, and IT infrastructure are widely discussed and pointed out at the top of the ranking among the main aspects in the literature. However, they are underdeveloped in most industries in Brazil, showing a disparity between the degree of importance for digital transformation and the level of maturity in the country.

Other points such as resource management, customer focus, intelligent services and products, and the definition of a roadmap are still sparse concepts both in terms of application in the Brazilian industry and the number of citations in research in the context of digital transformation.

3.4. Practical approach

Based on the definition of the three pillars identified in the literature, namely organizational, process, and technology, a roadmap was developed aiming to create a practical approach to help companies from the beginning of the implementation till the complete digitalization stage. This guide includes the aspects identified during the theory review and then explores one of them, as shown in Figure 10, to promote the advancement of one aspect of digitalization in a real-world case.

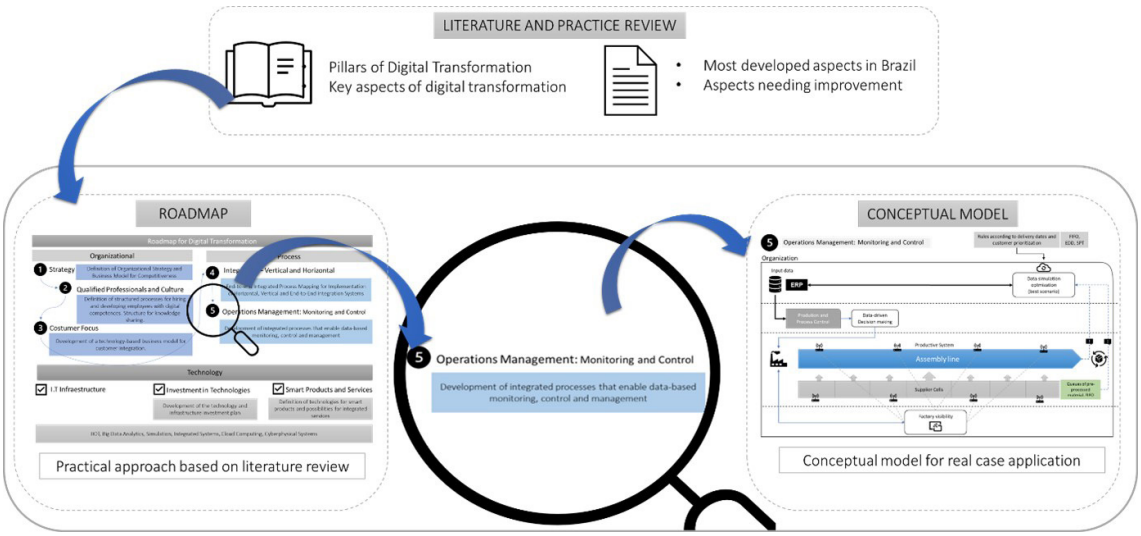

Figure 10. Framework for the practical approach.

This section comprises the proposition of a model for the digital transformation of the industry. A roadmap was elaborated with macro-steps that address the key points of digitalization according to the literature. Figure 11 presents the roadmap, adapted according to the Organizational and Process pillars and based on the technological aspects (Lin et al., 2020). Each pillar includes the dimensions of digital transformation highlighted in Section 3.2. Unlike other roadmaps for digital transformation, such as that in Ghobakhloo (2018), which described a roadmap derived from documented best practices, this roadmap originates from the relevant aspects found in the literature.

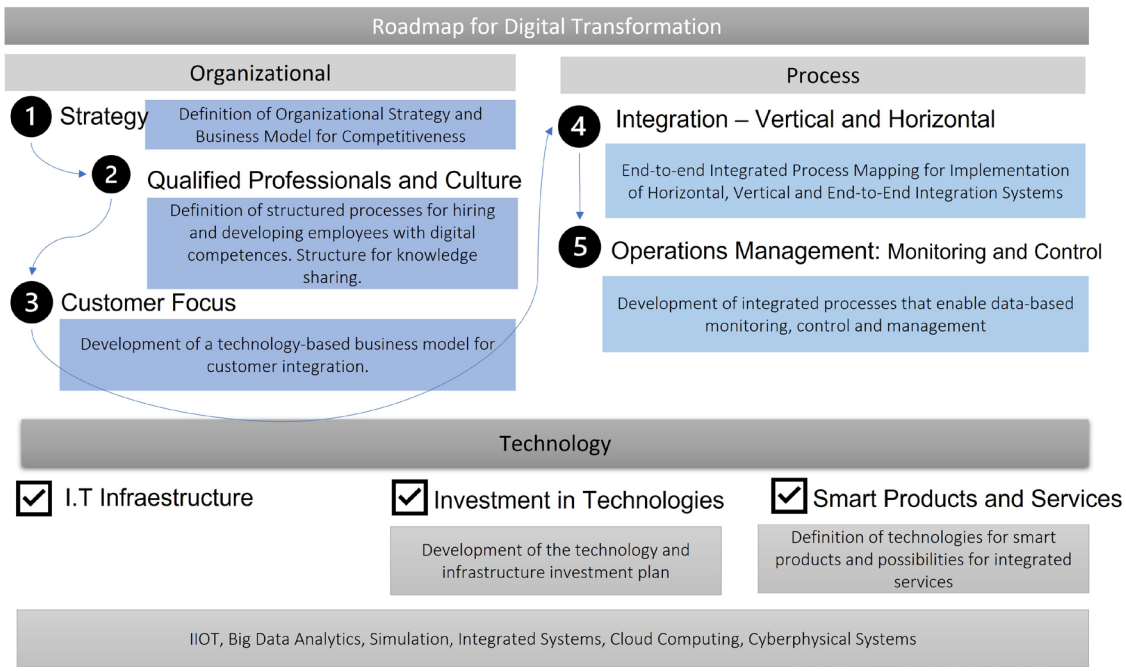

Figure 11. Digital transformation roadmap.

For the implementation, companies must first understand their current level at each feature. According to Carolis et al. (2017), the initial flow must contain the steps of maturity assessment, an analysis of the strengths and weaknesses of each aspect, the opportunities identified in each dimension, and the defined roadmap execution.

Operations management step was chosen because it is one of the most important aspects identified during the qualitative analysis. According to Sjödin et al. (2018), a company must establish systems to monitor, visualize, and analyze the operating system in real-time, implementing simulation models for testing, prototyping, and plant optimization. As stated by Gamache et al. (2019), most of the technologies implemented in the industry are aimed at monitoring and controlling production, mainly seeking to make processes more flexible.

According to Pires et al. (2018), the real-time monitoring capability allows decision-making and quick response to conditional changes and, when combined with data optimization models, generates significant improvements in performance, system, and machine efficiency. As a result, a detailed conceptual model is described in Figure 12 to enable a specific aspect of the roadmap and exemplify a structure for its application.

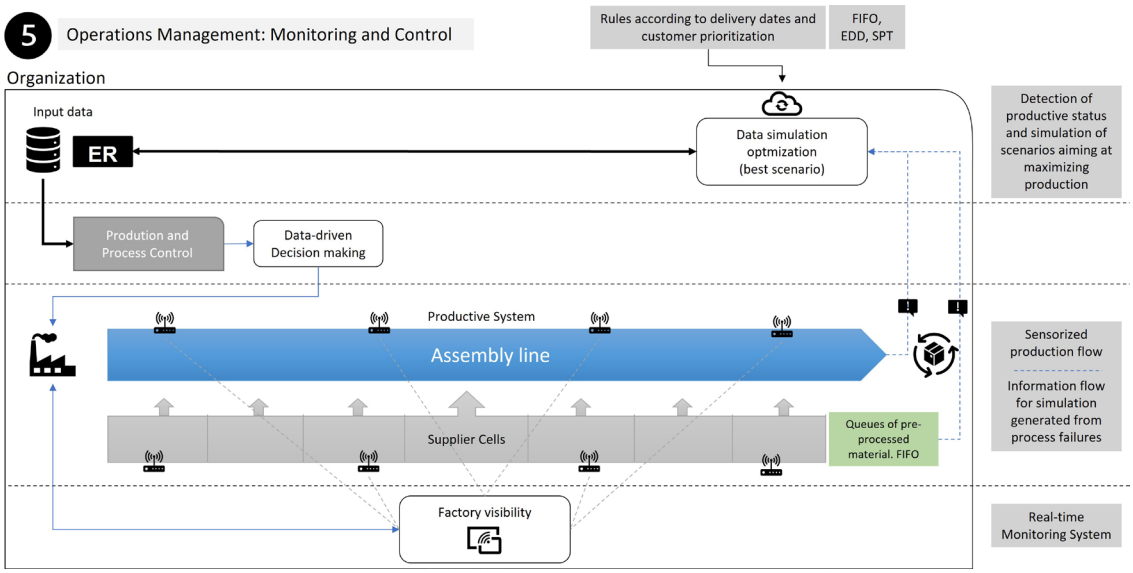

Figure 12. Conceptual model for a real-world case.

This model proposes the digitization of assembly line data. Initially, the data is available in the Enterprise Resource Planning (ERP) for the production planning and control, including order and priority sequence for to the assembly line. The data is read by barcode readers, RFID sensors in the initial supply cells. This information is transmitted in real time, which promotes the visibility and monitoring of the production. The status of the orders is then transmitted to the cloud, including production stage and interruption reports or line failures, which can be generated by material shortages, equipment breakdowns and other disruptions. This data is used to automatically redefine the queue of products to be produced in the supply cells and, consequently, in the assembly line. For this reordering, regular priority rules are used. This flow allows the production to work in an enhanced way, reducing the number of stops and improving the balance between the supply cells and the assembly line. The digitalization of data promotes fast responses in a synchronized way.

The main objective of this model is to represent the practical aspects of data digitalization applied to a real production system, promoting the concepts of monitoring and control for optimal data-driven decision making. According to Frazzon et al. (2020), using analytical optimization models through simulation and analyzing the data generated in the operation improve the performance of manufacturing systems and promote flexibility in the reaction to adverse situations in production systems. These virtual tools and techniques enable support for industrial processes, including system integration and real-time visualization of various scenarios, facilitating user understanding and operator interaction (Espíndola et al., 2012). In addition, the collection of this data, characterized by Big Data, and the subsequent processing with business analytics provide information and value to organization, boosting their gains from the management, effective data analysis, and the visibility of processes in real time, promoting the improvement of operational performance (Isasi et al., 2015).

4. Discussion

Digital transformation and its aspects are widely discussed both in the literature and in practice, with the main topics concerning the present and future of the global industry. However, many of the major concepts

disseminated in depth in the literature still show low adoption in the manufacturing industry in Brazil. On average, the Brazilian industry is in the implementation stage and initial digital development of some technologies compared to other countries in the OECD. The reality of the national industrial scenario demonstrates that, although highlighted as the central aspect, many companies do not have a well-defined digital strategy or do not consistently apply it, corroborating the results that the implementation of technologies such as big data, analytics, and IoT still cannot be considered advanced in the country.

Another correlation factor between the literature and practice concerns the importance of the human element in leading digital transformation. Even though the literature presents several practices and methodologies for digital training, the reality of the Brazilian scenario shows a deficiency in the aspect of professional qualification that may be considered critical in the digitalization journey of Brazilian companies. However, it is evident that there are policies and programs aimed at digital education under development by both the government and the industries, a fact that jointly benefits the aspect of digital culture in organizations.

For companies to be efficient and agile in their digital transformation journeys, a clear integration among the digitalization project, its concepts, and the defined business plan is paramount. An organization's managers must initially develop and communicate questions such as the following: What are the long-term strategic vision and medium-term tactical vision that the company wants to achieve with the project? What is the socio-technical and organizational context of the implementation? What resources are needed, how much, and when? What are the expected returns, how much, and when? What is the implementation schedule, steps, activities, resources, and intermediate and final deliverables? What is the communication plan?

With these definitions, it is possible to understand important aspects for the project to be successful: who are the supporters of the implementation, the decision-makers, if there are needs for employee training, retraining, and/or relocation, which are the teams and profiles needed for implementation, and what is the degree of technological maturity of the company. Intangible returns such as image, mindset, and organizational transformation should also be considered.

Regarding operational management and vertical and horizontal integration, they were indicated in both analyses (theoretical and practical) as key aspects for digitalization, highlighting a bias towards manufacturing and transformation processes as the focus of practice reports and published articles. On the other hand, the actions aimed at using technologies with customer thinking are not so clearly reported by the companies, thus needing further deepening by the industry. Furthermore, sustainable resources management is not mentioned in the industry and government reports as a significant aspect of the digitalization journey.

5. Conclusion

The purpose of this article was to compare the available theory and the current stage of the digital transformation of Brazilian industry. The literature review showed that the main concepts to be implemented in the industry towards digital transformation are related to the organizational, procedural, and technological pillars. Based on these definitions, a roadmap was developed, which proposes macro steps towards digitalization. The comparison showed that the status of the digital transformation presents implementation gaps in relation to the theoretical aspects, indicating the existence of opportunities for improvements in the industrial scenario by the application of proper digitalization concepts, methods and technologies. A roadmap and application model specifically for the operations management aspect were described in order to illustrate potential benefits in terms of improved flexibility and productivity due to data integration and simulation-based optimization deployment.

Further research and applied projects should focus on bridging the theory-practice gap regarding digital transformation of Brazilian industry, so that, first, scientific knowledge creation is supported by empirical evidence and, second, digital transformation application properly selects and deploys suitable concepts, methods, and technologies.

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Appendix A. Practice analysis.

DT Aspects	Brazilian Machinery Builders' Association (ABIMAQ)	McKinsey	Brazilian National Confederation of Industry (CNI)	Organisation for Economic Co-operation and Development (OECD)	GOVERNMENT (e-digital)
Organizational Strategy	61% of companies are undergoing major changes in their business models, aiming to increase competitiveness relative to the foreign market	Companies are aware of the potential of digital transformation within their organizational strategy. Leading companies in the Brazilian scenario show a clear link between digital and business strategy, while other companies tend to view digital as an additional pillar, generating initiatives that are dispersed within the organization.	The strategic focus on using technologies is highly associated with cost reduction and increased productivity. 58% of companies understand the importance of digitalization for competitiveness; however, less than half of the industries studied use digital technologies in their organizations.	The Brazilian strategy for digital transformation includes a set of practices and incentives of the Brazilian government, following the enabling axes and axes of digital transformation, which unfold strategic actions aimed at the reach and progress of the entire country in the following aspects: data-based economy, connected devices, and new business models, supported by citizenship and government.	
IT Infrastructure	Need to improve infrastructure, especially regarding networks, access, and internet speed, considering these critical factors in the implementation of IoT systems and other technological solutions.	-	The lack of infrastructure is considered the fifth most significant internal barrier to the adoption of technologies, mainly impacted by the high costs of technology implementation, which is regarded as the biggest internal barrier.	The Brazilian scenario reveals that investment in the information and communications technologies (ICT) sector is below the OECD level, which reveals Brazil's backwardness in terms of information technology infrastructure.	The government aims to expand the infrastructure of networks (5G) that support digital applications.
Organizational Culture	Most companies (66%) identify and recognize that their employees are open and engaged in adopting digital transformation in the organization.	Most companies recognize the importance of a culture focused on innovation; however, they still face barriers regarding the long-term financial result mentality generated by digital transformation.	Identified as the third biggest internal barrier to the adoption of digital technologies.	-	-
Customer Focus	Digital transformation actions are developed with a customer focus in 66% of organizations.	Most organizations have widespread concepts regarding focusing on the customer journey and improving the experience.	The industry extensively uses digital technologies for product development with a focus on reducing customer availability.	In Brazil, customer relationship management systems are present in 22% of companies.	-

Appendix A. Continued...

DT Aspects	Brazilian Machinery Builders' Association (ABIMAQ)	McKinsey	Brazilian National Confederation of Industry (CNI)	Organisation for Economic Co-operation and Development (OECD)	GOVERNMENT (e-digital)
Integration – Vertical And Horizontal	Integration in the industry is mainly focused on vertical integration, with high levels of Programmable Logic Controller (PLC) implementation (advanced implementation) on the shop floor regarding the digitalization of objects, but ongoing implementation projects and interest in implementing systems such as Manufacturing Execution Systems (MES), Enterprise Resource Planning (ERP), and Supervisory Control and Data Acquisition (SCADA) in an advanced manner. Concerning horizontal integration, they indicate little integration with the supply chain, with a high interest in implementation.	-	Vertical integration is identified as important for competitiveness, but its use is below average among the companies surveyed. There are no results regarding horizontal integration. There are clear initiatives recognized in the National Internet of Things Plan, highlighting "servitized" business models in manufacturing.	The Brazilian average for using vertical integration technologies such as ERP is below the OECD average, representing a gap. However, the significant differential of advancement in integration in small and large companies stands out.	-
Smart Services	Advanced implementation of maintenance, installation, and customer customization services. Growth in the offer of services related to product performance monitoring.	-		-	
Smart Products	High degree of interest in product digitalization within the scope of performance monitoring and fault detection and maintenance, and low level of implementation of digitized products for autonomous or remote operation.	-	The use of data from customers through Big Data is performed by only 9% of industries, of which only 4% incorporate digital services in their products.	Manufacturing companies in the ICT sector are prone to innovate in their products, while other sectors develop innovations with a focus on the process. Therefore, Brazil is below the OECD average in terms of representation in high-technology manufactured goods.	-

Appendix A. Continued...

DT Aspects	Brazilian Machinery Builders' Association (ABIMAQ)	McKinsey	Brazilian National Confederation of Industry (CNI)	Organisation for Economic Co-operation and Development (OECD)	GOVERNMENT (e-digital)
Monitoring and Control	Although most companies have access to data through connected equipment and processes, less than 20% use this data through analytics or digital intelligence. These data are mainly used to develop production indicators and understand patterns.	Companies are still concentrating efforts on structured collection and improving data quality. The data-based mindset is present in specific areas of some industries. However, there is a trend toward increasing the amount of data and the capacity to process it. The opportunities for improvement in the models and analysis techniques used are evident.	Recognized as the most important aspect for industrial competitiveness. Mainly through the implementation of sensors for process control, product identification, and operating conditions. However, its full implementation is still considered low.	The average Brazilian use of cloud computing is above the average of OECD countries, representing 80% of all companies, while big data has a low diffusion in the country, representing 11% among companies.	The government aims to develop actions that promote dynamic and competitive industrial environments through IoT devices, sensors, machines, and equipment.
Operations Management	32% of companies have some type of operation virtualization, which allows them to anticipate problems and make strategic and agile decisions, with this being an aspect that still needs development.	-	-	Still below the average for OECD countries, an increase in the use of M2M (machine-to-machine) cards was identified, indicating an advance in the use of IoT in the industry. In the last three years, only 4.5% of Brazilian manufacturers have been operating with industrial robots. These data reveal a deficit in operations management, monitoring, and control.	The government aims to develop actions that promote dynamic and competitive industrial environments through IoT devices, sensors, machines, and equipment.
Qualified Professionals	Most companies (51%) agree that they have qualified and prepared professionals on their team; however, they recognize that aspects related to digital transformation training need further development.	Many companies report a shortage of skilled talent primarily in analytics, pointing out internal development as an option for professional training.	41% of employers report difficulty in filling vacancies due to the lack of hard skills (digital technical skills)	Companies report the lack of skilled workers as a barrier to adopting and implementing new technologies. In Brazil, the proportion of graduates among the adult population represents 18% compared to 39% in OECD countries.	The Brazilian digital transformation includes actions for professional training aimed at developing skills for use in new technologies, in addition to new educational lines in this area.

Appendix A. Continued...

DT Aspects	Brazilian Machinery Builders´ Association (ABIMAQ)	McKinsey	Brazilian National Confederation of Industry (CNI)	Organisation for Economic Co-operation and Development (OECD)	GOVERNMENT (e-digital)
Resource Management (Environment)	-	-	-	Until 2017, Brazil registered an increase in the intensity of energy use in manufacturing. The adoption of industry 4.0 technologies is expected to favor the country, boosting energy efficiency, and increasing manufacturing productivity.	-
Investment in Technologies (Innovation)	40% of member companies do not use the base technologies: Cloud computing, IoT, Big Data, Analytics, or AI. Of the companies that own and invest in technology, the most used is Cloud Computing, representing 43%, followed by IoT (30%), Big Data (2%), and Analytics (19%)	-	58% of industries are aware of the importance of technology for industrial competitiveness, but the rate of use is still low.	73% of manufacturing companies use at least one digital technology, such as process automation sensors. However, there is a lack of investments in the technology area due to the high costs in the Brazilian scenario.	The Government is intensifying investment in IoT, in addition to promoting the development of strategic technologies such as collaborative robotics, AI, big data, additive manufacturing, and nanotechnology.
Roadmap	Companies have a well-defined model but with a focus on technology implementation.	Leading companies have clear roadmaps that are being implemented. The other organizations do not have a defined transformation plan.	-	-	Ongoing development of a technological roadmap supporting the information and communication technology sector, not directly the industry.