RELISE

ANALYSIS OF THE RELATIONSHIP BETWEEN DIGITAL TRANSFORMATION AND SUSTAINABILITY: A BIBLIOMETRIC LITERATURE REVIEW[1]

ANÁLISE DA RELAÇÃO ENTRE TRANSFORMAÇÃO DIGITAL E SUSTENTABILIDADE: UMA REVISÃO BIBLIOMÉTRICA DA LITERATURA

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ABSTRACT

The article explored the relevance of digital transformation as a crucial factor for promoting sustainability in organizations and society. The study aimed to map the emergence, evolution, and boundaries of knowledge regarding the relationship between these two themes. To achieve this goal, a bibliometric analysis was conducted, utilizing co-citation and bibliographic coupling techniques through the VOSviewer software, which allowed for the identification of key authors, collaboration networks, and trends. The results highlighted the growing intersection between sustainability and digital transformation, indicating that digital technologies, such as big data, artificial intelligence, and blockchain, are enablers of sustainable practices, optimizing processes and promoting the economy. However, the study also pointed out environmental challenges, such as the increase in electronic waste and energy consumption, that need to be managed for digitalization to be truly sustainable. In conclusion, digital transformation is essential for companies to achieve not only competitive advantages.

Keywords: digital transformation, Sustainability, bibliometrics, co-citation map, bibliographic coupling map.

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RESUMO

O artigo explorou a relevância da transformação digital como um fator crucial para a promoção da sustentabilidade nas organizações e sociedade. O estudo visou mapear o surgimento, a evolução e as fronteiras do conhecimento sobre a relação entre esses dois temas. Para alcançar esse objetivo, realizou-se uma análise bibliométrica, utilizando técnicas de cocitação e pareamento bibliográfico, por meio do software VOSviewer, que permitiu identificar os principais autores, redes de colaboração e tendências. Os resultados destacaram a crescente interseção entre sustentabilidade e transformação digital, indicando que as tecnologias digitais, como big data, inteligência artificial e blockchain, são facilitadoras de práticas sustentáveis, otimizando processos e promovendo a economia. Entretanto, o estudo também apontou desafios ambientais, como o aumento do lixo eletrônico e do consumo energético, que precisam ser geridos para que a digitalização seja realmente sustentável. Em conclusão, a transformação digital é essencial para que as empresas alcancem não apenas vantagens competitivas.

Palavras-chave: transformação digital, sustentabilidade, bibliometria, mapa de cocitação, mapa de pareamento bibliográfico.

INTRODUCTION

Sustainability, as a central concept in contemporary development, is often defined as the ability to meet the needs of the present without compromising the ability of future generations to meet their own needs. This concept has its roots in environmental concerns but has been expanded to include social and economic aspects, culminating in what is known as the triple bottom line of sustainability: environmental, social, and economic. Sustainable development aims to create a balance among these three dimensions, ensuring that economic progress is achieved without detriment to natural resources or social well-being (NOSRATABADI, ATOBISHI AND HEGEDŰS, 2023).

The advancement of digital technologies has introduced a new dynamic in the pursuit of sustainability. Digital transformation refers to the integration of digital technologies into all areas of a business, resulting in fundamental changes in how companies operate and deliver value to customers. This transformation

goes beyond the simple adoption of new technologies; it involves restructuring organizational processes, business models, and interactions with customers and suppliers (HILALI, MANOUAR AND IDRISS, 2019).

As companies adopt digitalization, they find new opportunities to promote sustainable practices, such as optimizing resource use, reducing carbon emissions, and promoting a circular economy (BOCEAN AND VĂRZARU, 2023).

The relationship between digital transformation and sustainability is complex and multifaceted. On one hand, digital transformation can drive sustainability by providing tools and technologies that enable more efficient resource management and the minimization of environmental impacts (YANG, WU AND YANG, 2023).

Technologies such as big data, artificial intelligence (AI), and the Internet of Things (IoT) allow companies to monitor and optimize their production processes in real time, reducing waste and improving efficiency (YING AND JIN, 2023).

On the other hand, the rapid adoption of digital technologies can also generate new challenges, such as the increase in electronic waste (e-waste) production and excessive energy consumption, which must be carefully managed to avoid adverse environmental effects (TRUONG, 2022).

Digital transformation also influences social sustainability. Digitalization has the potential to democratize access to resources and opportunities, especially in remote or developing regions, where digital connectivity can open new possibilities for education, healthcare, and financial services (BOCEAN AND VĂRZARU, 2023).

Moreover, by facilitating communication and collaboration on a global scale, digital technologies can promote social inclusion and equity, allowing more people to actively participate in the digital economy (SINGHDONG, SUTHIWARTNARUEPUT AND PORNCHAIWISESKUL, 2021).

However, digital transformation is not inherently sustainable. For digitalization to effectively contribute to sustainability, it is essential that organizations integrate sustainable principles into their digital strategies from the outset. This includes considering the environmental impacts of new technologies, promoting ethical and fair practices in the digital supply chain, and adopting business models that prioritize longevity and social well-being as much as efficiency and innovation (ZHANG AND JIN, 2023).

The concept of digital sustainability also involves adapting business practices to address the specific challenges of the digital age. Companies that adopt digital transformation as part of their sustainability strategy can achieve significant competitive advantages, including greater operational efficiency, improved resource management, and increased capacity for innovation (YANG, WU AND YANG, 2023). In addition, digitalization can facilitate the creation of new sustainable business models, such as sharing economy platforms, which promote more efficient resource use and reduce the need for excessive production (YING AND JIN, 2023).

Digital technologies offer advanced tools for managing sustainable supply chains. The use of blockchain, for example, enables full traceability of products throughout the supply chain, ensuring that each stage of the process complies with environmental and social standards (TRUONG, 2022).

This not only increases transparency but also enhances consumer trust, as they can verify the origin and impact of their purchases. Such traceability is essential for preventing environmentally harmful practices and promoting corporate social responsibility (YANG, WU AND YANG, 2023).

Digital transformation can therefore be seen as a key enabler of sustainability, allowing companies to turn challenges into opportunities (YING AND JIN, 2023). However, for this to occur, a clear commitment to sustainability is required at all stages of the digital transformation process. This includes

everything from the strategic planning phase to continuous implementation and monitoring, ensuring that new technologies are used in ways that promote long-term sustainable development (ZHANG AND JIN, 2023).

In summary, the relationship between digital transformation and sustainability is one of the most promising and challenging areas in contemporary management. By adopting an integrated approach that considers the economic, social, and environmental impacts of digitalization, companies can not only improve their performance but also contribute to a more sustainable and equitable future. The key to success lies in the ability to align sustainability goals with the opportunities offered by digital transformation, creating value in a responsible and innovative manner.

When analyzing the literature on sustainability and digital transformation, specifically publications in the Web of Science (WoS) database, it becomes evident, despite the importance of these topics, that there is a scarcity of review studies, including bibliometric studies. These studies are important for systematizing, organizing, and comprehensively mapping the formation and evolution of a knowledge domain, as well as guiding future research. Therefore, this study seeks to answer how the discussion on sustainability has emerged and evolved within the field of digital transformation and what the frontiers of knowledge are regarding the relationship between these two themes.

THEORETICAL FRAMEWORK

The concept of sustainability has evolved significantly over recent years, expanding its initial focus on environmental preservation to incorporate economic and social dimensions, forming what is widely known as the triple bottom line of sustainability. Sustainability seeks to balance economic growth, social justice, and environmental protection, ensuring that current development does not compromise the needs of future generations (SINGHDONG,

SUTHIWARTNARUEPUT AND PORNCHAIWISESKUL, 2021). This multidimensional approach is essential for understanding how companies can create long-term value without depleting natural resources or exacerbating social inequalities (BOCEAN AND VĂRZARU, 2023).

Digital transformation, which involves the integration of digital technologies into all aspects of a business, has the potential to significantly transform corporate sustainability practices. This digitalization process not only optimizes business operations but also creates new opportunities to reduce negative environmental and social impacts (HILALI, MANOUAR AND IDRISS, 2019). Furthermore, digital transformation can promote energy efficiency, improve waste management, and enable real-time monitoring of carbon emissions, contributing to climate change mitigation (ZHANG AND JIN, 2023).

The circular economy is a model that aims to minimize waste and maximize the reuse of resources, promoting sustainability throughout the product lifecycle. Digitalization plays a fundamental role in this model by enabling the traceability of materials and products and optimizing recycling and reuse processes (SINGHDONG, SUTHIWARTNARUEPUT AND PORNCHAIWISESKUL, 2021). Technologies such as blockchain are especially useful in this context, as they provide a transparent and traceable supply chain, ensuring that resources are used efficiently and sustainably. In addition, digitalization supports the circular economy by enabling the creation of new business models, such as sharing economy platforms, which reduce the need for the production of new goods (TRUONG, 2022).

Despite the benefits of digital transformation, such as greater operational efficiency and cost reduction, it also presents significant environmental challenges. The increase in electronic waste (e-waste) production, due to the rapid obsolescence of electronic devices, is one of the main environmental problems associated with digitalization. Moreover, energy consumption in data

centers and other digital infrastructures has grown exponentially, contributing to increased greenhouse gas emissions. Therefore, it is crucial that digital transformation strategies include sustainable practices to mitigate these environmental impacts, such as the use of renewable energy and the implementation of effective recycling policies (TRUONG, 2022).

Digital transformation also has profound implications in the social sphere. On one hand, it can democratize access to information and services, especially in remote or developing areas, where digital connectivity can open new opportunities for education, healthcare, and financial inclusion. On the other hand, if not managed inclusively, digitalization can exacerbate social inequalities, leaving behind those who do not have access to digital technologies. Additionally, automation and artificial intelligence, central components of digital transformation, may lead to job losses in sectors that rely on manual labor, creating challenges for social equity (NOSRATABADI, ATOBISHI AND HEGEDŰS, 2023).

For digital transformation to be truly sustainable, it is essential that companies integrate sustainability principles into their digital strategies from the outset. This includes considering the environmental and social impacts of new technologies and promoting ethical practices throughout the supply chain. Digital sustainability should be viewed as a strategic element, not only as a corporate responsibility but also as an opportunity for innovation and long-term value creation. Companies that adopt this integrated approach are more likely to achieve sustainable success, contributing to a more equitable and environmentally responsible future (ZHANG AND JIN, 2023).

METHODS

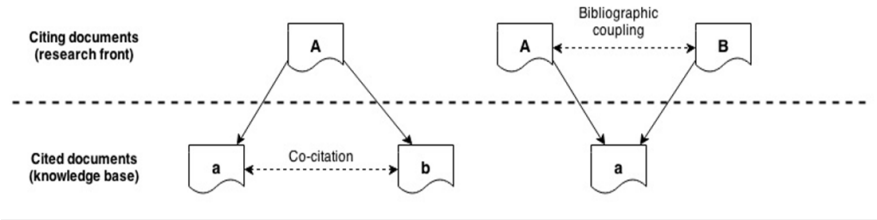
This research is a bibliometric review, a statistical method that provides a quantitative overview of academic literature in a specific scientific field (BENCKENDORFF AND ZEHRER, 2013; LIMA AND RIBEIRO; 2023). According to Pritchard (1969), this method integrates literary statistical tools, resulting in an activity that connects various indicators. Bibliometric analysis examines a set of publications using quantitative techniques (COBO ET AL., 2011). More specifically, bibliometrics facilitates the identification of the emergence, evolution, and future trends of a specific topic through the analysis and organization of related publications (ZUPIC AND CATER, 2015). The bibliometric research process includes several phases: extraction, processing, network analysis, and visualization (COBO ET AL., 2011).

It is important to note that the bibliometric method applies quantitative tools to bibliographic data (BROADUS, 1987). This type of analysis is widely accepted as a valid approach for scientific review across various fields (PANDEY ET AL., 2021; KUMAR, SUREKA, ET AL., 2021), including the field of management (DONTHU ET AL., 2021). Due to its quantitative nature, bibliometric analysis is efficient in handling large volumes of bibliographic data, reducing potential biases (BURTON ET AL., 2020).

To achieve the objectives of this research, two techniques were selected from the five main ones described by Zupic and Cater (2015): co-citation analysis and bibliographic coupling analysis. The co-citation technique is based on the idea that articles that are cited together have similar content (DONTHU ET AL., 2021; LIMA AND RIBEIRO, 2023). This analysis is useful for identifying the main themes within a body of work (LIU, YIN ET AL., 2015) and, therefore, for mapping the intellectual structure of a field (ROSSETTO ET AL., 2018; LIMA AND RIBEIRO, 2023). Our analysis uses co-citation to identify the central themes in the evolution of knowledge on Blockchain in supply chains.

Bibliographic coupling analysis, also known as bibliographic correlation, is based on the principle that the similarity between two documents is related to the references they share (KESSLER, 1963; KUMAR ET AL., 2020; MUKHERJEE ET AL., 2021; LIMA AND RIBEIRO, 2023). The development of any scientific field is based on pre-existing knowledge (SAMIEE ET AL., 2015), and the contributions of each study are grounded in the reviewed literature (HOFFMAN AND HOLBROOK, 1993). Prior knowledge in the field is often reflected in bibliographic references. Bibliographic coupling analysis focuses on the articles themselves and is therefore more suitable for linking and summarizing a relatively small number of works. Figure 1 illustrates the two bibliometric analysis techniques employed.

Figure 1 – Bibliometric Techniques for Co-citation and Bibliographic Matching



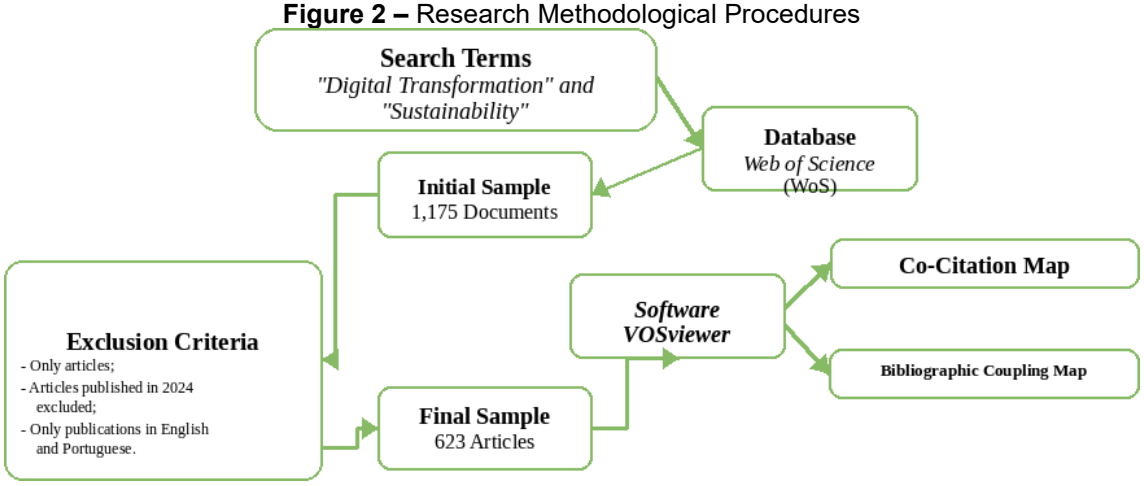
Source: Zupic e Carter (2015)

The studies analyzed in this research were selected based on the keywords "Digital Transformation" and "Sustainability" in the topic field (title, abstract, and keywords) of the Web of Science database in July 2024.

Initially, 1,175 documents were found. To ensure the replicability of the research, we excluded documents published in 2024, since the year was still ongoing, limiting the dataset to documents up to 2023 and reducing the number to 909. Within this group, we focused our analysis exclusively on articles, due to the robustness of the peer-review process, which strengthens both theoretical and methodological credibility, resulting in 670 articles. Finally, considering operational constraints, we chose to include only articles in Portuguese and English, resulting in a final sample of 623 articles.

To conduct the co-citation and bibliographic coupling analyses, the VOSviewer software was selected. Although several programs offer these functionalities, VOSviewer was chosen due to its ability to create high-quality graphical visualizations and its wide availability, which makes it more accessible to researchers (Van Eck and Waltman, 2018). The methodological procedures of this research are presented in Figure 2.

Figure 2 – Research Methodological Procedures

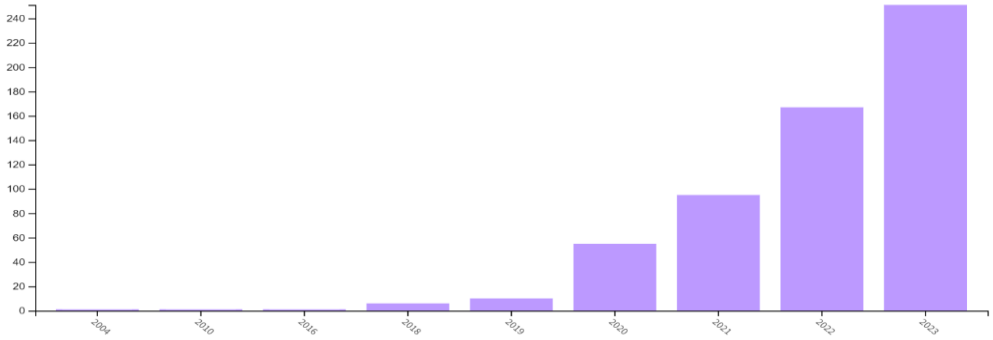


Source: Elaborated by Authors (2024)

With regard to the advancement of studies on digital transformation and sustainability, it is important to note that the first works emerged in 2004. However, between 2004 and 2018, there was a very limited number of studies, with only 1 to 3 articles being published annually during these 14 years. Evidence indicates that the exponential growth in the number of studies on the topic occurred during the pandemic period. Traditional consumer goods companies faced pressure due to restrictions on the movement of goods and limitations imposed by governments to contain the spread of the virus, which clearly drove the search for the digitalization of organizational processes in industrial activities. Figure 3 illustrates this growth, showing that the number of publications on sustainability and digital transformation increased from 18 in 2019 to 60 in 2020 and 100 in 2021.

Even after the pandemic, the volume of publications continued to grow. In 2023, approximately 160 articles on the topic were published. Part of this growth can be attributed to significant changes in business operations driven by new generative artificial intelligence tools, such as ChatGPT and Gemini, which allowed many processes previously carried out by humans to now be performed by algorithms, and this influenced companies' interest in adopting processes, including those related to environmental actions operated by information systems.

Figure 3 – Evolution of Publications by Year on Digital Transformation and Sustainability



Source: Web of Science (2024)

RESULTS AND DISCUSSION

This section will present and discuss the three clusters mapped in the co-citation map and the eight clusters identified in the bibliographic pairing map, primarily defining the theme analyzed within one of these clusters.

Co-citation map analysis

The most important group of studies in this map, according to the VOSviewer manual, is the red cluster, composed of 34 articles. The central theme analyzed in this group refers to the relationships between digital transformation, Industry 4.0, servitization, and sustainability.

The most important study developed within this cluster was published by Ghobakhloo (2020), with a link strength of 180, cited 19 times by other articles in the sample and connected to 63 other studies. In this research, the author is based on the interpretive structural modeling technique to model the contextual relationships between the sustainability functions of Industry 4.0. The results indicate that there are sophisticated precedence relationships among several sustainability functions of Industry 4.0. The “Matrice d'Impacts Croisés Multiplication Appliquée à un Classement” (MICMAC) analysis reveals that economic sustainability functions, such as production efficiency and business model innovation, tend to be the most immediate outcomes of Industry 4.0, paving the way for the development of more distant socio-environmental sustainability functions, such as energy sustainability, reduction of harmful emissions, and improvement of social well-being.

The second main article in this cluster was developed by Frank et al. (2019), with a link strength of 173, cited 21 times in other studies and connected to 69 other studies in the co-citation map. The authors aimed to develop a conceptual framework that connects the concepts of servitization and Industry 4.0 from a business model innovation (BMI) perspective. This framework is based on three levels of servitization (i.e., smoothing, adaptation, and substitution) and three levels of digitalization (i.e., low, moderate, and high levels). They showed that the correspondence between these levels results in nine possible configurations classified into manual, digital, and Industry 4.0-related services, which may focus on smoothing, adapting, or substituting services.

The second most relevant cluster in the co-citation map is the green cluster, composed of 31 studies. The predominant theme of analysis in the research published by authors in this group is the analysis of the importance of digital transformation in promoting environmental sustainability.

The most influential study in this cluster was developed by Vial (2019), with a link strength of 334 and cited 67 times in other studies in the sample. Through the analysis of 282 studies, the author developed an inductive framework for digital transformation, composed of eight fundamental blocks. This framework highlights digital transformation as a process in which digital technologies cause disruptions that lead organizations to adopt strategies to modify their ways of creating value. At the same time, organizations must manage structural changes and internal barriers that influence the positive and negative outcomes of this process. Based on this framework, the author proposes a research agenda suggesting (1) investigating the role of dynamic capabilities and (2) considering ethical issues as important areas for future strategic research in Information Systems on digital transformation.

The second most important publication in the green cluster was written by Feroz, Zo, and Chiravuri (2021), with a link strength of 188 and 35 citations by other studies. This article examines how digital transformation is impacting environmental sustainability, based on a systematic literature review. The results reveal a framework that details changes in four main areas: pollution control, waste management, sustainable production, and urban sustainability. Each of these areas is subdivided into more specific categories. The study also suggests an agenda for future research, addressing aspects such as organizational capabilities, performance, and digital transformation strategies in the context of environmental sustainability.

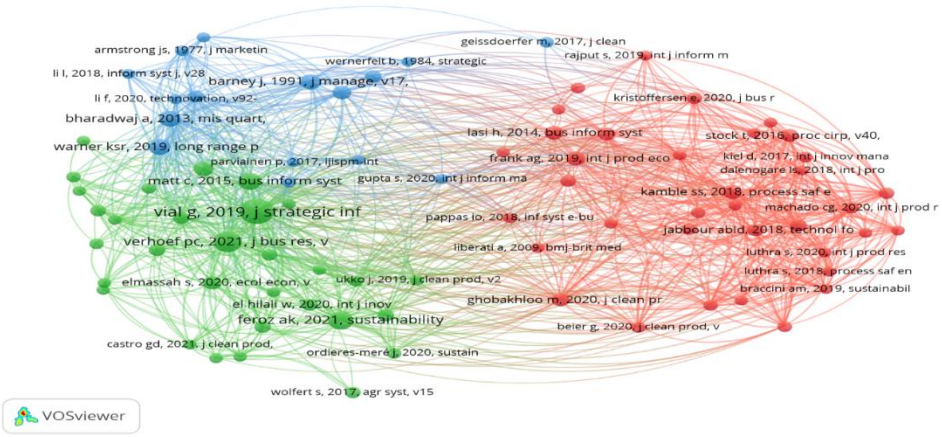
The last cluster in terms of relevance in the co-citation map is the blue cluster, composed of 17 articles. The research theme of the studies in this group focuses on analyzing the role of dynamic capabilities in digital transformation and sustainability, and their effects on improving company competitiveness.

The main study in this cluster was developed by Bharadwaj et al. (2013), with a link strength of 154 and cited 27 times by other studies in the co-citation

map. The research argues that it is time to rethink the role of IT strategy, shifting from a functional-level strategy - which, although aligned, is essentially always subordinate to business strategy - to one that reflects a fusion between IT strategy and business strategy. This fusion is termed digital business strategy. Four main themes are identified to guide thinking about digital business strategy and provide a framework for defining the next generation of insights. The four themes are: (1) the scope of digital business strategy, (2) the scale of digital business strategy, (3) the speed of digital business strategy, and (4) the sources of business value creation and capture in digital business strategy.

The second study considered the most influential in this group of research was developed by Warner and Wager (2019), with a link strength of 155 and 28 citations by other studies in the co-citation map. Based on the experiences of senior executives involved in digitalization projects in established companies, a process model composed of nine microfoundations was developed to identify the general contingent factors that trigger, enable, and hinder the development of dynamic capabilities for digital transformation. The findings indicate that digital transformation constitutes a continuous process that integrates new digital technologies into organizational routines, highlighting agility as the central element for the strategic renewal of (1) the business model, (2) the collaborative approach, and eventually (3) the organizational culture.

Figure 4 – Co-citation Map – Digital Transformation and Sustainability



Source: VOSviewer (2024)

Analysis of the bibliographic pairing map

The most important cluster in the bibliographic coupling map is the red cluster, composed of 25 articles. The theme of analysis of these studies focused on examining the impacts of digital transformation on environmental performance and the promotion of sustainable business innovation.

The most prominent study in this group was developed by Chen and Hao (2022); the article has a link strength of 36 and 106 citations in other studies in the bibliographic coupling map. In this research, the authors explored the relationship between digital transformation and environmental performance from the perspective of board characteristics. Chinese listed companies from 2010 to 2019 were used as original data, and the moderating effect of board characteristics was tested using the moderating effect model. They found that digital transformation can significantly improve corporate environmental performance.

The second most prominent study in this cluster was developed by Wang et al. (2023), with a link strength of 77 and cited 67 times in other studies. The authors explored the effects of digital transformation and associated micromechanisms on green productivity, using a sample of Chinese A-share

listed companies from 2004 to 2020. In addition, a heterogeneity analysis was conducted on research themes from business, industrial, and provincial perspectives.

The second main cluster in order of importance in the bibliographic coupling map is the green cluster, composed of 23 articles. The studies in this group focused on investigating the relationship between Industry 4.0 and sustainability, and the importance of firms' dynamic capabilities in promoting the digitalization of industrial processes.

The main research in this cluster was published by Birkel et al. (2019), with a link strength of 105 and 210 citations in other studies. The article proposes a risk framework in the context of Industry 4.0 that is related to the Triple Bottom Line of sustainability. The framework is developed based on a literature review, as well as 14 in-depth interviews with experts. Regarding economic risks, risks associated with high or false investments are described, as well as threatened business models and increased competition from new market entrants. From an ecological perspective, increased waste and energy consumption, as well as possible ecological risks related to the concept of "lot size one," are described.

The second most important research in this group was developed by Felsberg et al. (2019), with a link strength of 123 and cited 99 times in other studies. This article investigates the impact of implementing Industry 4.0, with a specific emphasis on digital transformation, on the sustainability dimensions of European manufacturing industries. In doing so, it proposes a framework to identify the implications of Industry 4.0 in reconciling firms' existing and new dynamic capabilities, competencies, and market requirements to achieve sustainable competitive advantage.

The third cluster in terms of relevance mapped is the blue cluster, composed of 19 articles. The central theme analyzed was the effects of digital transformation on the circular economy. The most relevant study was developed

by Bag et al. (2020), with a link strength of 98 and 179 citations in other studies in the sample. The objective of this study was to identify how Procurement 4.0 and digital transformations are related and how digital transformation impacts the intention to optimize the purchasing process in the circular economy. The moderating effect of information processing capability is also investigated.

The second most relevant research developed in the blue cluster is the study by Giudice et al. (2021), with a link strength of 93 and cited 161 times in other studies. The authors analyzed the effect of circular economy practices on firm performance in a circular supply chain and explored the moderating role that a big data-based supply chain plays in these relationships. The results indicate that the three categories of circular economy practices investigated—namely, circular supply chain management design, circular supply chain relationship management, and circular human resource management—play a crucial role in improving firm performance from a circular economy perspective.

The fourth group of studies mapped is the yellow cluster, composed of 16 articles. The studies in this group emphasized the analysis of the relationships between digital business strategy and sustainability, and their effects on firms' financial performance. In terms of importance, the main research identified was developed by Ukko et al. (2019), with a link strength of 58 and cited as a reference in 95 studies in the bibliographic coupling map. In this research, the authors empirically examined the role of a sustainability strategy in the relationship between digital business strategy and financial performance.

The second main research in terms of importance in this group was developed by Nayal et al. (2021), with a link strength of 97 and 84 citations by other studies in the sample. This study aimed to investigate the effect of supply chain collaboration and coordination (SCC), sustainable development strategy (SDS), digital transformation (DIT), and collaborative advantages (COA) on the sustainable supply chain firm performance (SSCFP). The conceptual model is

based on relational view (RV), transaction cost economics (TCE), technology, organization, and environment (TOE), and resource-based view (RBV) theories. The findings show that SCC positively affects SDS and DIT; SDS positively affects DIT and COA; and DIT positively affects SSCFP. DIT fully mediates the relationship between SCC and COA. The study suggests that managers can apply SCC, SDS, and DIT in sequence to achieve sustainable performance; however, COA can only be enhanced in a digitized supply chain.

The fifth identified cluster is the purple cluster, composed of 12 articles, whose focus was on the challenges, opportunities, and benefits of sustainable Industry 4.0 in supply chains. The most prominent research in this group was written by Caiado et al. (2021), cited 39 times in other studies and with a link strength of 194. The research states that the challenges for integrating Industry 4.0 and sustainability in supply chains, as well as the possible benefits of this integration, in line with the SDGs, remain unclear.

The second most impactful article in this group was developed by Verma et al. (2022), with a link strength of 207 and cited 52 times in other studies. The objective of the study is to analyze the intricate barriers of Industry 4.0 to the advancement of digital manufacturing in the long term. The adoption of Industry 4.0 is challenging in the current environment, but considering Industry 4.0 within sustainability is even more difficult. The empirical investigation followed a mixed-method approach, including a systematic literature review (SLR) and the Analytic Hierarchy Process (AHP). Thirty sustainability barriers related to technological, organizational, economic, environmental, social, and institutional factors were identified using the SLR approach, and the AHP method (a multicriteria decision-making method) was used to rank or prioritize these barriers.

The sixth mapped cluster is the light blue cluster, composed of 12 articles. The studies in this group predominantly emphasized research on firm internationalization, digitalization, and sustainability. The main research in this

group was developed by Denicolai et al. (2021), with a link strength of 29 and cited 198 times by other studies. The findings confirm, as expected, that Artificial Intelligence readiness positively influences firms' international performance. In addition, it was found that digitalization and sustainability are positively related, but become competing growth paths when firms internationalize.

The second most relevant research in the light blue cluster was developed by Barata (2021), with a link strength of 112 and cited 32 times in other studies. This article unfolds the ongoing fourth revolution of supply chains (4SC) and proposes guidelines for future research. The review of 65 literature reviews follows three stages: bibliometric analysis of Industry 4.0, its synergies with supply chain transformation, and state-of-the-art evaluation. 4SC is a context-limited technological change, driven by organizational and cultural priorities, aimed at creating more sustainable networks to serve customers and support responsible decision-making in the supply lifecycle.

The seventh cluster identified in the bibliographic coupling map is the orange cluster, composed of 11 articles. The theme analyzed in this group was the role of information and communication technologies (ICTs) in digital transformation and firms' environmental performance. The main research developed in this group is the study by Wen et al. (2021), whose results indicate that the environmental performance of manufacturing firms was significantly improved during the process of industrial digital transformation. Structural and technological effects are the transmission channels; moreover, the structural effect is the main contributor to the positive environmental effects of ICT penetration.

The second main research in this cluster was developed by Kunkel and Matthess (2020), with a link strength of 39 and cited 101 times by other studies in the sample. The authors analyzed the digital and industrial policies of four Sub-Saharan African countries (South Africa, Rwanda, Kenya, Nigeria) and three East

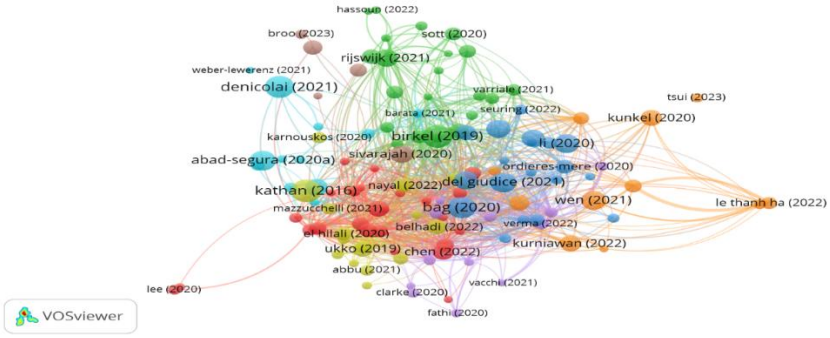
Asia and Pacific countries (China, Thailand, Philippines) in relation to their expectations regarding the impacts of ICTs on industry for environmental sustainability. They built upon existing frameworks for ICT assessment that distinguish between direct environmental effects occurring during the ICT lifecycle and indirect environmental effects resulting from the application of ICTs in various production processes and economic activities.

The last cluster identified in the coupling map is the brown cluster, composed of only 5 articles, which generally focused on analyzing the role of Data Science, Big Earth Data, and Digital Twins in sustainable Industry 4.0.

The main research in this group was developed by Guo et al. (2020), cited 72 times by other studies. In this study, the authors argue that to understand the impacts and interrelations between humans as a society and the processes of the Earth's natural system, a new engineering discipline is proposed: Big Earth Data science. This science is intended to provide methodologies and tools to generate knowledge from diverse, numerous, and complex data sources, necessary to ensure a sustainable human society, essential for the preservation of planet Earth. Big Earth Data science aims to use Earth observation and social sensing data and develop theories to understand how such a socio-physical system operates and evolves.

The second research considered most relevant in this group was developed by Broo (2022), cited 35 times by other studies in the sample. This study aimed to understand how digital twins can help the infrastructure sector deliver and operate sustainable and intelligent infrastructure assets. The article presents an overview of definitions of digital twins, current practices, benefits, and challenges through a series of semi-structured interviews with experts and executives from the UK infrastructure sector. In addition, it suggests a set of strategies to support digital transformation and the adoption of digital twins in the sector.

Figure 5 – Bibliographic Pairing Map – Digital Transformation and Sustainability



Source: Vosviewer (2024)

FINAL CONSIDERATIONS

The present study shows the growing relevance of the intersection between digital transformation and sustainability in organizations. The bibliometric analysis carried out revealed that, although digital transformation has the potential to promote more sustainable practices, such as reducing resource waste and optimizing processes, it also presents considerable challenges, such as the increase in electronic waste production and high energy consumption. For digitalization to effectively contribute to a more sustainable future, it is essential that companies integrate sustainability principles into all stages of their digital strategies.

Emerging technologies, such as Big Data, Artificial Intelligence, and Blockchain, play a crucial role in facilitating more efficient and responsible business practices, aligned with the principles of a circular economy. However, to ensure that these technological innovations do not increase environmental damage, it is necessary for companies to adopt a strategic approach from the planning phase, incorporating both social and environmental impacts into their policies.

This study presented some limitations that need to be considered when interpreting the results. First, the analysis was based exclusively on publications extracted from the Web of Science database, which may have limited the scope

of the sample of analyzed articles. Thus, the inclusion of other databases, such as Scopus or Google Scholar, could expand the bibliographic coverage and provide a more holistic view of the topic. However, it is understood that the most influential articles were selected in the sample of this research, since there is a high overlap of articles published across databases.

Another important limitation was the decision to restrict the analysis to articles published up to 2023. Although this is a criterion that allows the replicability of bibliometric studies, it prevents the analysis of more recent studies that may have emerged after this period, considering the rapid advancement of digital technologies. In addition, the focus on publications in English and Portuguese may have excluded relevant contributions in other languages, such as Spanish and Mandarin, which also present important advances in the fields of sustainability and digital transformation.

Based on the identified limitations, several directions for future studies are suggested. First, it would be interesting to expand the bibliometric analysis to include other databases and extend the temporal scope to encompass more recent publications, especially considering the impact of new technologies, such as the use of digital twins and the rise of Generative Artificial Intelligence (AI). Comparative studies between different regions of the world are also recommended, since the local context may influence how companies approach digital transformation and sustainability.

Another suggestion would be to explore in greater depth the social impact of digital transformation, especially in terms of digital inclusion and equity. Although digitalization has the potential to democratize access to resources and opportunities, it may also widen inequalities, especially in regions with less access to technology. Therefore, research that investigates strategies to mitigate these social impacts would be of great importance.

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