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The influence of industry 4.0 and circular economy on organizational performance: a systematic literature review

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THE INFLUENCE OF INDUSTRY 4.0 AND CIRCULAR ECONOMY ON ORGANIZATIONAL PERFORMANCE: A SYSTEMATIC LITERATURE REVIEW

1. INTRODUCTION

Circular Economy (CE) is a business model that replaces the "end of life" concept with the reduction, reuse, recycling, and recovery of materials in production, distribution, and consumption processes (Ciliberto et al., 2021). It can be considered at different levels, such as micro, meso, and macro to achieve sustainable development and producing environmental quality, economic prosperity, and social equity for the present and future generations (Ciliberto et al., 2021). Industry 4.0 (I4.0) can be considered a production system based on technological, information and communication advancements, making possible the development of virtual and digital integration of manufacturing processes within and across organizations (Jabbour et al., 2022).

CE can be better implemented by adopting I4.0 technologies, since it helps companies through advanced technologies to achieve cleaner production in manufacturing processes (Dantas et al., 2021; Dwivedi et al., 2022; Patyal et al., 2022; Rajput & Singh, 2020). The literature shows some examples, as can be seen in Nascimento *et al.* (2019), that explore how I4.0 technologies can facilitate and be integrated with CE practices. And, Hettiarachchi, Seuring and Brandenburg, (2022) which concluded that big data analytics (BDA) and the Internet of Things (IoT) are the most technologies that have been adopted to facilitate the CE and sustainable supply chains.

However, although there are studies focusing on I4.0-CE, as the literature reviews developed by Dantas et al. (2021) and Patyal et al. (2022) that studied the impact of this integration on the Sustainable Development Goals (SDO), the literature is still limited regarding the influence of these concepts and organizational performance. Therefore, this paper answers the following research question: How does the integration between these two constructs influence environmental, operational, and social performance? To answer this question, we applied a Systematic Literature Review (SLR) to present (i) an overview of the literature over time and (ii) to identify I4.0 technologies and CE practices that are related to organizational performance.

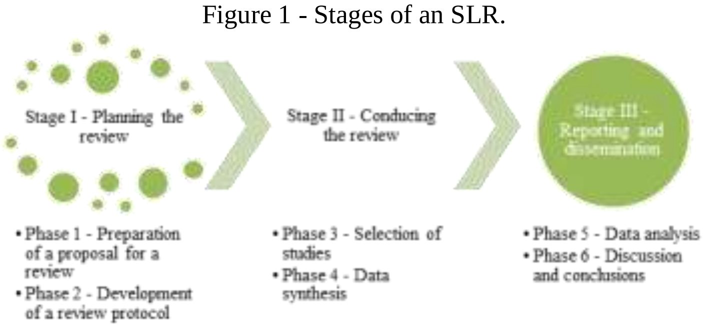
Although other authors have already analyzed the literature about the integration of I4.0 and CE, they focus on specific aspects of that integration, not on organizational performance (considering operational, social, and environmental elements). Therefore, this paper advances the knowledge about I4.0 technologies and CE practices by analyzing the influence of these constructs on organizational performance. The paper also explores the integration of I4.0-CE over time in order to have a deep understanding of how the literature has evolved regarding scientific methods, tools adopted to develop the research, sectors, and countries of application of the empirical research, main theories, levels of CE implementation, CE practices, and I4.0 technologies. Besides, the paper ends by presenting a conceptual framework linking the I4.0 technologies and CE practices with different variables of organizational performance. This information will support understanding aspects less covered by the research over time, also focusing on recent themes that deserve further investigation. Besides, the framework shows for managers and decision-makers in which I4.0 technology or CE practice must invest to improve organizational performance.

This paper is structured as follows. After the introduction (1), the next (2) presents the steps adopted in the SLR. Section 3 provides an overview of the integration between I4.0 and CE over time, followed by the discussion and proposition of the conceptual framework (Section 4). Finally, Section 5 presents conclusions, limitations and future research directions.

2. SYSTEMATIC LITERATURE PROCEDURES

This paper applied an SLR, a scientific methodological approach, because of its replicability. In this method, researchers adopt scientific strategies to reduce errors in the process of selection, critical evaluation, and synthesis of relevant studies on a specific subject (Cook, 1997). The SLR was carried out following the process illustrated in Figure 1, adapted from Tranfield et al. (2003), and Table 1 summarizes the study's methodological path. Therefore, 115 articles were selected to compose the final sample after conducting all the steps.

Figure 1 - Stages of an SLR.



Source: adapted from Tranfield et al. (2003)

Table 1 - Study methodological path.

Stages	Phase	Steps	Details
Stage I - Planning the review	1	Preparation of a proposal	Analysis of previous studies that discuss CE and I.4.0.
	2	Development of a review protocol	The protocol followed the following parameters: (1) <u>Scientific databases:</u> Web of Science (WoS) and Scopus; (2) <u>Search fields:</u> title; (3) <u>Period of analysis:</u> unlimited to 2022, December; (4) <u>Language:</u> English; (5) <u>Publication type:</u> Articles and review articles; (6) <u>Quality filter:</u> Indexed in SCImago Journal Rank (SJR) or Journal Citation Reports (JCR); (7) <u>Search strings:</u> <u>Block 1:</u> Circular Economy ("Circular Econom*" OR "Circulatory Econom*" OR "Circular Ecolog*" OR "Circle Economy" OR "Circularity" OR "Circle" OR "Circular" OR "Closed Loops" OR "green economy" OR "circular practices" OR "circular principles") AND <u>Block 2:</u> Industry 4.0 ("Industry 4.0" OR "4th Industrial Revolution" OR "I 4.0" OR "I4.0" OR "Fourth Industrial Revolution" OR "Smart Manufacturing" OR "Smart Factor*" OR "smartness") (8) <u>Criteria for inclusion:</u> I4.0 and CE, as well as their integration and influence on organizational performance. (9) <u>Criteria for exclusion:</u> articles that do not focus on CE and I4.0.
Stage II - Conducting the review	3	Selection of studies	Removing papers not in English, duplicates, reading the title and abstract, and excluding articles that do not meet the criteria (8 and 9). This process evolved three researchers.
	4	Data synthesis	Data was synthesized in tables and charts. MS Excel was used to extract data (authors, title, year, journal, objective, methodology, tools applied in the methodological approach, I4.0 technology, CE practices, implementation level of CE, theories, variables of organizational performance. The Infogram® was used to create the charts in section 3.
Stage III - Reporting and dissemination	5	Data analysis	Previous studies on CE and I4.0 integration were mapped, and variables related to organizational performance links between I4.0-CE and organizational performance, considering the selected variables.
	6	Discussion and conclusions	Ruminate on findings, discussions, and the proposition of the conceptual framework.

Source: authors.

2.1 Planning the review

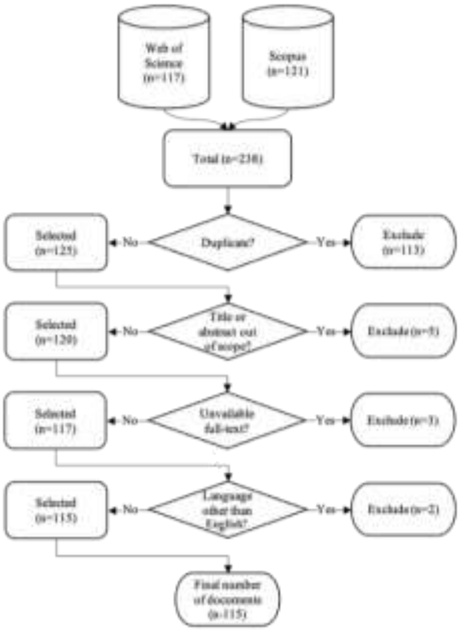
In this stage, the authors developed exploratory research to identify papers regarding the main subjects, which are I4.0 and CE. Some relevant studies were consulted, such as the CE report by the Ellen MacArthur Fundations (2013); the report for implementing I4.0 by Kagermann et al. (2013), and some papers on the subject. Therefore, we delimited the research and clarified the main, as Sauer & Seuring (2023) recommended.

Thus, in order to answer the research question "How does the integration between I4.0-CE influence environmental, operational, and social performance?", we selected the strings presented in Table 1, considering (1) Circular Economy and (2) Industry 4.0, and its variations. Next, a test was done on the selected Databases (Table 1): Web of Science (WoS) and Scopus.. The search in the databases included articles until December 2022.

2.2 Conducting the review

After the adherence test, we conducted the review in Web of Science and Scopus databases, considering the information presented in stage II (Table 1). At this stage, EndNote software was employed to remove duplicates and read titles and abstracts of articles. After completing all the steps presented at this stage, the final sample comprised 115 papers, as shown in Figure 2.

Figure 2 - Process of selecting papers.



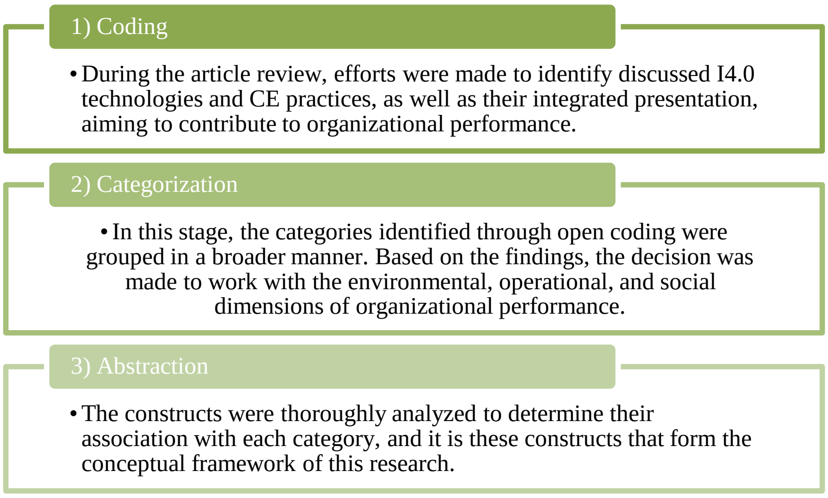
Source: authors.

In the data synthesis, MS Excel was used to extract data (Table 1), making it possible to develop the analysis. We adopted content analysis, a technique that aims to systematically extract and examine the meaning present in a data set, and is often applied in qualitative and quantitative studies (Neuendorf, 2002). Thus, as advocated by Tranfield et al. (2003), the SLR should facilitate the understanding of the research by the professional, summarizing the extensive research upon which it is based. Therefore, the next stage was the analysis of the 115 articles.

2.3 Reporting and dissemination

We employed content analysis to analyze data on sensitive and multifaceted phenomena (Elo & Kyngäs, 2008). Elo & Kyngäs (2008) further recommend the steps represented in Figure 3 for this process.

Figure 3 – Steps of content analysis



Source: authors.

After content analysis of the 115 articles, it was found that 77 of them discussed both I4.0 technologies and CE practices, which will be further detailed in the next section. Out of these 77 articles, 21 integrated these constructs to demonstrate their influence on organizational performance, as presented in Figure 4.

Figure 4 - Data reduction for a literature-based framework.

Source: authors.

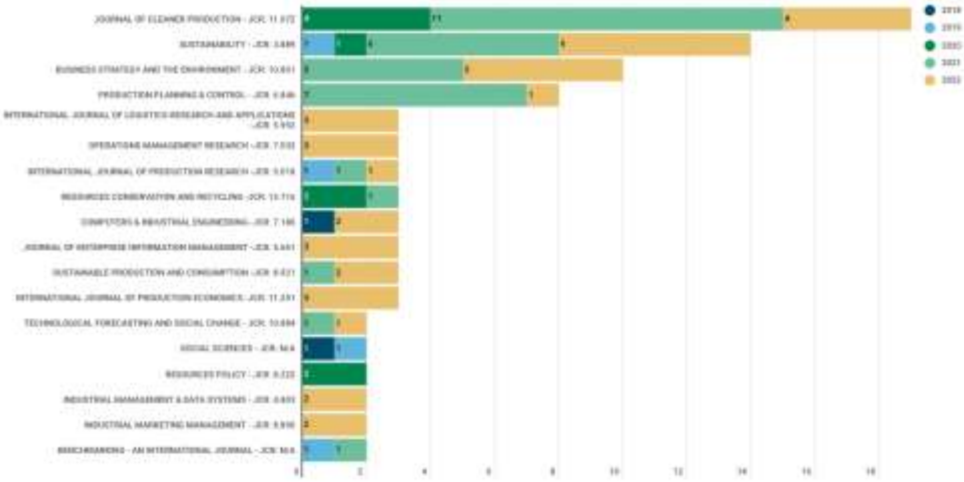
Finally, from these analyses, we proppsed a conceptual framework showing how I4.0 technologies and CE practices are related to organizational performance.

3. OVERVIEW OF THE LITERATURE

Figure 5 displays the journals that have featured at least two articles. There has been a notable increase in articles on this topic, with 52 papers (45%) published in 2022 alone. Regarding journal preference, authors commonly opted for the Journal of Cleaner Production (JCP), which accounted for 19 articles (25%). The JCP primarily focuses on research and practice related to cleaner, environmentally sustainable production. It boasts an impressive impact factor of 11.072 in the Journal Citation Reports (JCR), which measures the qualification of the scientific journal based on the citation it receives.

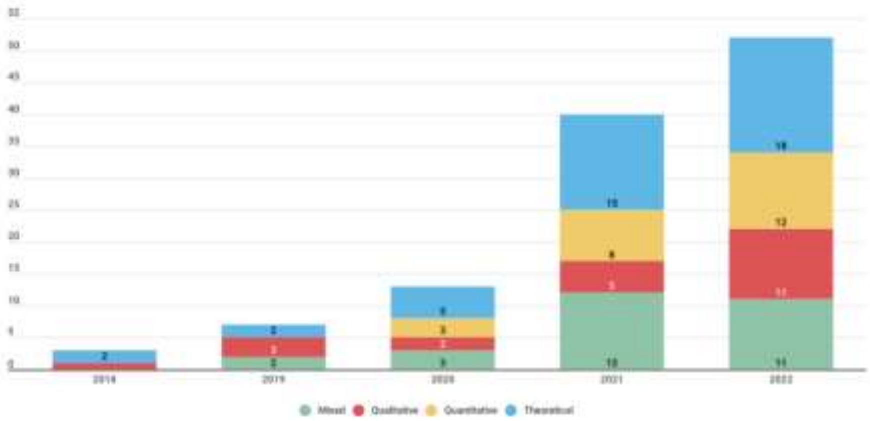
Figure 6 illustrates that the recent sample was initiated in 2018 and highlights a substantial increase in publications. While theoretical and qualitative approaches are prevalent, including literature reviews and case studies, they are essential in building scientific knowledge. Nevertheless, there is a growing utilization of quantitative and mixed methods and the adoption of different tools in various methodological approaches, even qualitative or quantitative, such as the Multicriteria Decision Method (MCDM), fuzzy, among others. Figure 7 provides a more detailed breakdown of the methods employed.

Figure 5 - Distribution of articles in journals over the years.



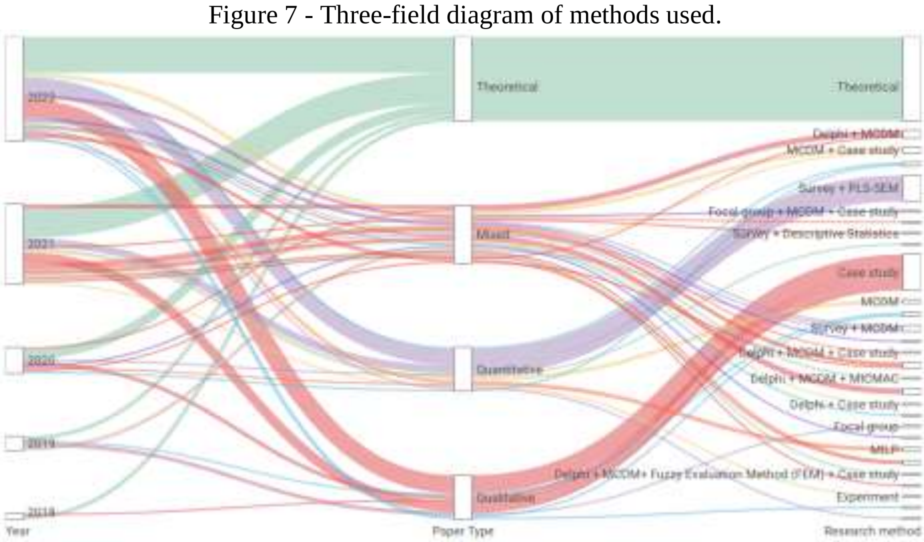
Source: authors.

Figure 6 - Methods over the years.



Source: authors.

Figure 7 - Three-field diagram of methods used.



Source: authors.

Theoretical papers, such as systematic and structured literature reviews and theory development, dominate, totaling 42 articles. Case studies stand out in qualitative research, with 18 articles, while surveys are the more representative of quantitative methods. Most mixed-method papers use Delphi, Survey, Focus Group, etc., with MCDM (Multicriteria Decision Making) or Fuzzy, etc.

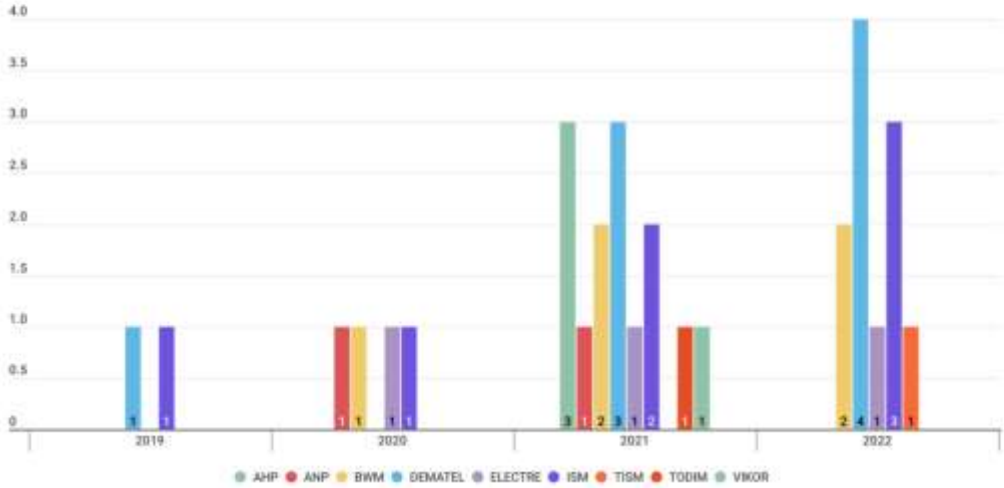
MCDM solves complex problems with multiple criteria and conflicting objectives in this context. It helps decision-makers evaluate alternatives by considering different criteria and their relative importance. MCDM and other techniques are adopted in 26 papers (Figure 8). Notably, two techniques stand out the most: DEMATEL, which appeared in eight articles, and ISM, which was used in seven. Table 2 provides a summary of the techniques adopted in the sample.

Table 2 - Summary of the techniques adopted by the authors.

MCDM technique		**Objective**	**Reference**
AHP	Analytic Hierarchy Process	AHP stands out as one of the frequently employed MCDM techniques, recognized for its ability to handle qualitative and quantitative criteria.	(Kazancoglu et al., 2021; Kumar et al., 2021; Shayganmehr et al., 2021)
ANP	Analytic Network Process	ANP is an extension of AHP that deals with the criteria of internal and external dependence. It evaluates relationships and interdependencies in decision-making by replacing hierarchies with networks, considering potential interactions and feedback.	(Kumar et al., 2021; Ozkan-Ozen et al., 2020)
BWM	Best Worst Method	BWM is a vector-based technique that prioritizes criteria based on pairwise comparisons between the most favorable and least favorable criteria. It requires fewer comparisons than AHP, provides more robust results, and overcomes inconsistency issues in pairwise comparisons.	(Gupta et al., 2021; Jamwal et al., 2022; Krstić et al., 2022; Kusi-Sarpong et al., 2021;Yadav et al., 2020)
DEMATEL	Decision-Making Trial and Evaluation Laboratory	DEMATEL establishes and assesses relationships among factors, categorizing them into cause-and-effect groups and indicating the significance of these relationships between elements.	(Abdul-Hamid et al., 2021; Bai et al., 2022; A. Chauhan et al., 2021; Chhabra & Kr Singh, 2022; Kumar et al., 2021; Rajput & Singh, 2019; Zhang et al., 2021)
ELECTRE	ELimination Et Choix Traduisant la REalité	ELECTRE is used to conduct pairwise comparisons between challenges and potential solutions, with the ability to identify relationship percentages. It provides more optimized results and allows ranking solution measures based on prioritization.	(Jamwal et al., 2022; Yadav et al., 2020)
ISM	Interpretive Structural Modeling	ISM transforms obscure mental models into visible, well-defined models useful for various purposes.	(Abdul-Hamid et al., 2020; Godinho Filho et al., 2022; Khan et al., 2022; Kumar et al., 2021; Pham et al., 2019; Rajput & Singh, 2021; Viles et al., 2022)
TISM	Total Interpretive Structural Modeling	TISM is an improvement of ISM, transforming imprecise models into unequivocal and simple models. It establishes critical relationships between elements and interprets the underlying reasoning to understand the model better.	(Vimal et al., 2022)
TODIM	Interactive and multi-criteria Decision Making	TODIM is a method for evaluating risks and revealing rankings in responses. It uses global measures of values and Prospect Theory for ranking decisions.	(Kazancoglu et al., 2021)
VIKOR	VlseKriterijumska Optimizacija I Kompromisno Resenje	VIKOR provides optimized solutions in complex and conflicting situations with different units of measurement. It is useful for providing compromise solutions closer to the ideal solution.	(Kusi-Sarpong et al., 2023)

Source: authors.

Figure 8 - Different techniques adopted over the years.

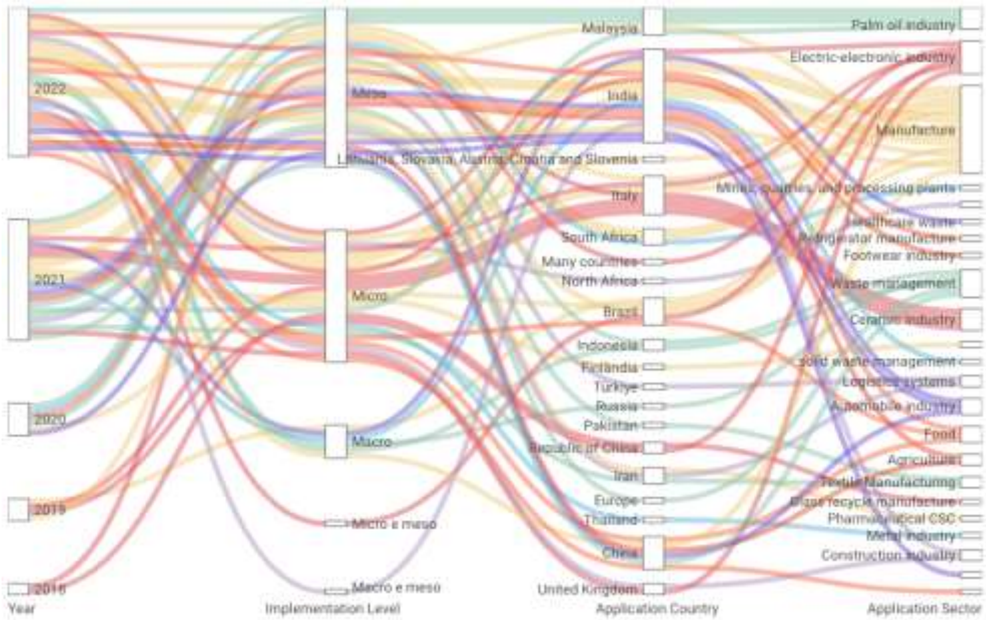


Source: authors.

In addition to those presented in Table 2, other tools were used, such as SECA Fuzzy Pythagorean (Mahdiraji et al., 2022), Cross-Impact Matrix Multiplication Applied to Classification – MICMAC (Godinho Filho et al., 2022; Rajput & Singh, 2021; Vimal et al., 2022); GTA (Bhattacharya, 2023); Mixed Integer Linear Programming – MILP (Rajput & Singh, 2020, 2022); in addition to PLS-SEM or SEM, which were adopted in the survey articles.

Figure 9 shows the distribution of studies by the level of CE implementation, country, and sectors where the studies were developed over the years. There is a higher number of studies at the meso (29 articles) and micro (24 articles) levels of CE, i.e., at the level of industrial parks, symbiosis networks, cooperative supply chains, and the level of the company, respectively. India has the highest number of empirical studies. The macro level of CE needs to be more approached and deserves further investigation.

Figure 9 - Four-field diagram representing the CE dimensions, country, and application sector.



Source: authors.

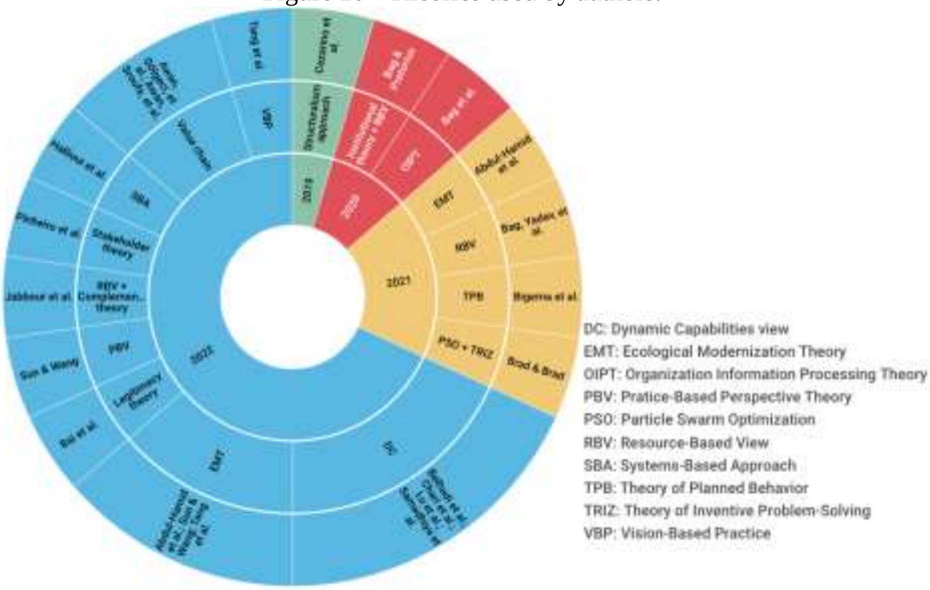
Figure 10 shows the main theories used as theoretical support in the research, and among these, Dynamic Capabilities (DC), Resource-Based View (RBV), and Ecological

Modernization Theory (EMT) were the most adopted. Those theories are well distributed over the years. The DC view emerged from the RBV. Both focus on companies' internal aspects, contributing to the analyses of the micro level of the CE. More recently, the authors have also applied both theories to understand elements in the CE supply chain, contributing to the meso level of analyses of the CE.

A comprehensive analysis was conducted to identify and examine the technologies related to I4.0. Out of the 115 articles, 27 distinct I4.0 technologies were identified. Figure 11 illustrates the ten most frequently throughout the years. Additionally, concerning CE, 24 distinct practices were identified (Figure 12). This Figure presents the top 10 most frequently over the years. In the early years, there were fewer papers related to the topic, and I4.0 was addressed more broadly, with some referring to the Internet of Things as Industry 4.0.

As technology has evolved, the range of I4.0 technologies has expanded. Figure 12 shows that CE is frequently associated with the 3Rs (Reduce, Reuse, and Recycle) and has expanded its scope to include more Rs, such as 4R, 6R, 9R, and even authors who refer to 10R. Among these practices, Recycling, Reuse, and Remanufacturing have stood out. The ReSOLVE framework, a set of guidelines developed by the Ellen MacArthur Foundation (2013) to help businesses adopt the CE, appears in 11 papers.

Figure 10 - Theories used by authors.



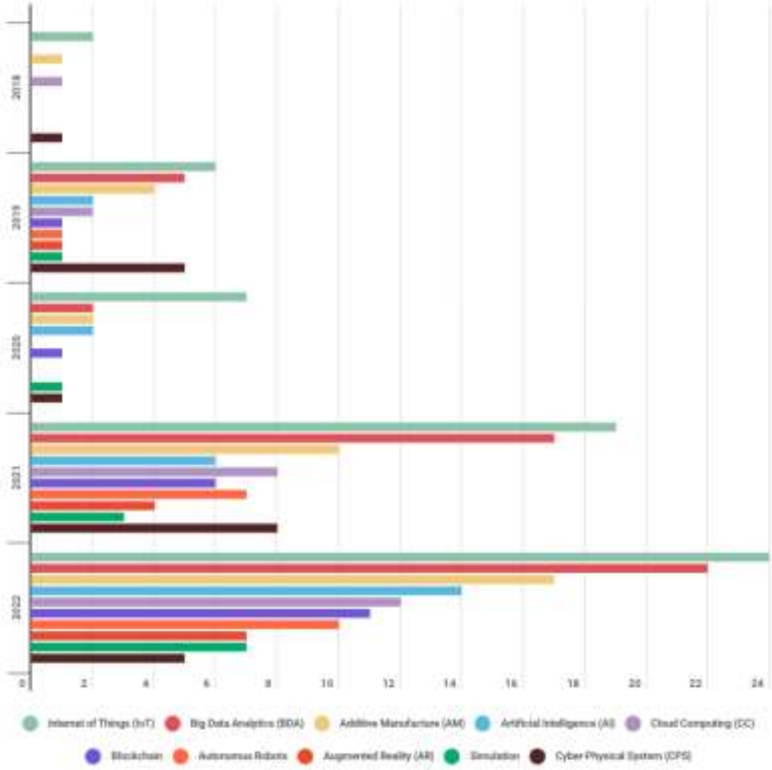
Source: authors.

4. DISCUSSION AND PROPOSING A THEORETICAL FRAMEWORK

To identify evidence of the influence of I4.0-CE integration on organizational performance, we initially conducted a content analysis of the articles to extract the integration relationships between I4.0 technologies and CE practices. Subsequently, these relationships were divided into three dimensions: environmental, operational, and social. It is important to note that there may be overlaps between these dimensions, such as environmental factors also affecting the operational dimension. However, our analysis categorized them based on the best fit.

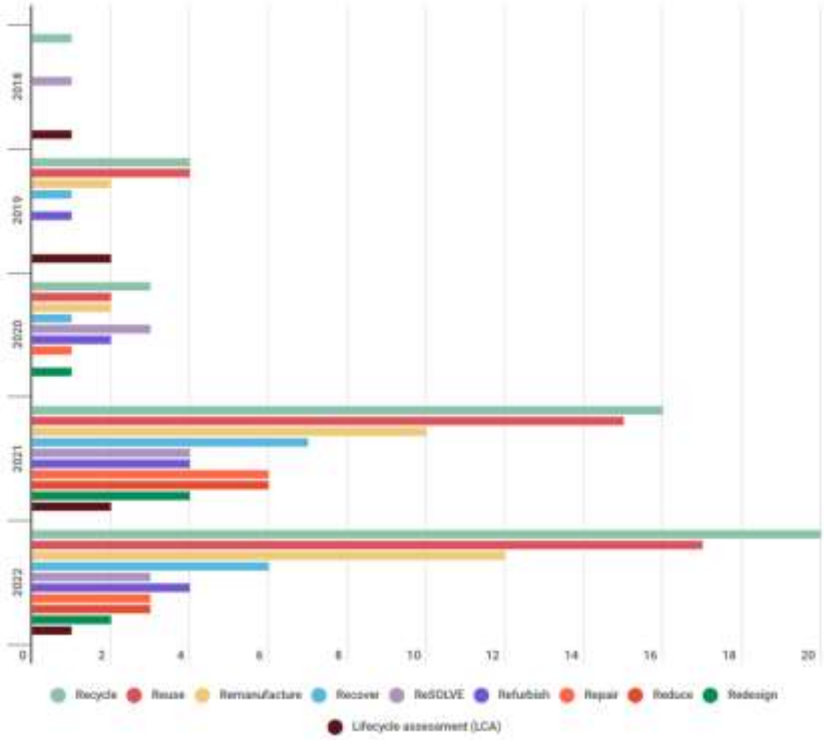
We observed that many I4.0 technologies emerged as drivers of CE practices. Conversely, CE practices support the effective utilization of I4.0 technologies, thereby influencing organizational performance. This information highlights the close relationship between I4.0 and CE and how they mutually reinforce each other.

Figure 11 - Industry 4.0 technologies cited.



Source: authors.

Figure 12 - Circular Economy approach cited.

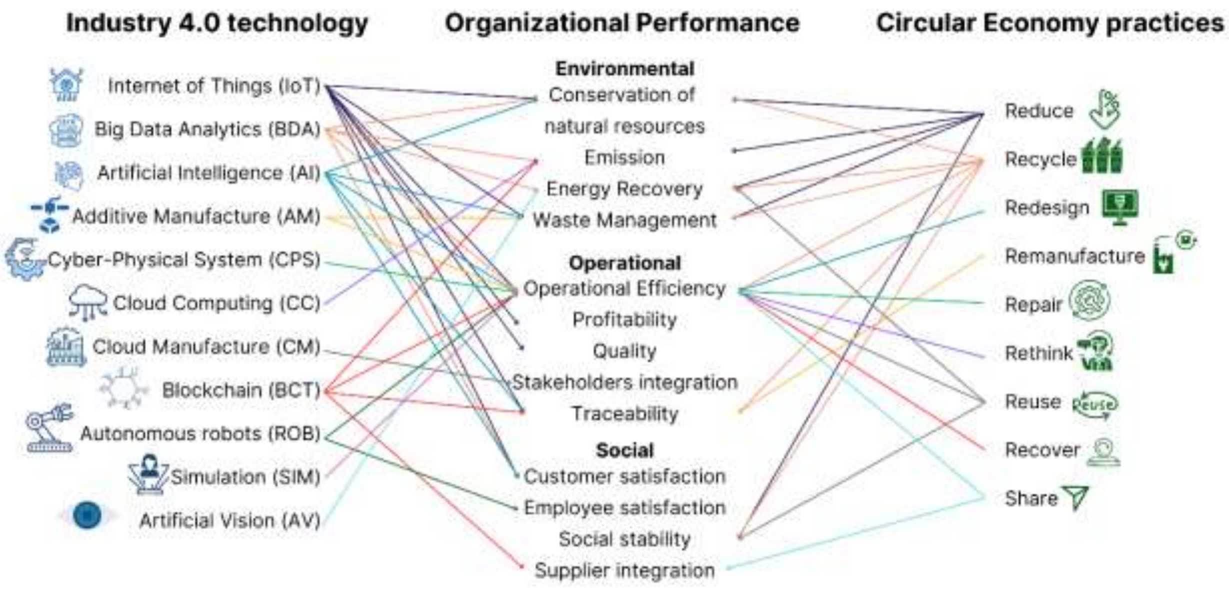


Source: authors.

We extracted the performance criteria from the papers, obtaining a list of 13 criteria, indicating the I4.0 technologies and CE practices associated with each criterion, with each criterion being mentioned by at least one author. Through content analysis, we verified that I4.0

technologies influence organizational performance, particularly when related to CE practices. Subsequently, these technologies and practices were correlated with environmental, operational, and social performance criteria, as presented in Figure 13.

Figure 13 – Conceptual framework integrating the relationships between I4.0 technologies, CE practices, and the influence on organizational performance.



Note: The I4.0 technologies are represented on the left side, while the CE practices found in the investigated sample are shown on the right side. Each technology and practice is assigned a distinct color. The arrows indicate that a relationship has been identified between these elements and organizational performance.

For the development of the conceptual framework (Figure 13), we considered 13 criteria: conservation of natural resources, emissions, energy recovery, waste management, operational efficiency, profitability, quality, stakeholder integration, traceability, customer satisfaction, employee satisfaction, social stability, and supplier integration. Establishing these criteria was necessary to develop a more robust conceptual framework, considering that direct relationship between certain criteria, I4.0 technologies, and CE is not always available in the literature.

To complete the other dimension of the conceptual framework, only I4.0 technologies and CE practices that have empirical evidence of association with specific criteria were selected. Similar to the criteria selection, overlaps were avoided, resulting in a more concise list of technologies and practices. Therefore, the following I4.0 technologies were chosen: Artificial Intelligence (AI), Additive Manufacturing (AM), Artificial Vision (AV), Blockchain (BCT), Big Data Analytics (BDA), Cloud Computing (CC), Cloud Manufacturing (CM), Cyber-Physical System (CPS), Internet of Things (IoT), Robotics (ROB), and Simulation (SIM). The CE practices included were recovery, recycling, redesign, reduction, remanufacturing, repair, rethinking, reuse, and share. Although “share” is not an "R" practice per se, it has been included in the list of practices due to its relevance in relation to technologies, such as blockchain and simulation, as part of the ReSOLVE framework.

Analyzing the rows in Figure 13 allows us to identify which criteria are more sensitive to different I4.0 technologies and CE practices. For instance, concerning the "conservation of natural resources," the integration of technologies such as IoT, BDA, and AI proves significant in supporting recycling and reduction practices. In the operational context, we also observe increased efficiency through the integrated use of technologies such as IoT, BDA, AI, AM, CPS, which aid in practices such as recycling, redesign, repair, reuse, and recovery.

The conceptual framework shows the earlier relationships in an organized way, demonstrating the connections between I4.0 technologies, CE practices, and their influence on organizational performance.

5. CONCLUSIONS

This paper analyzes the knowledge of the integration between I4.0 and CE and the influence on organizational performance, considering social, environmental and operational criteria. Therefore, an SLR was conducted to identify how this integration occurs over time. We identified a growth in publications in this area, especially in the recent years, with the Journal of Cleaner Production being the most relevant journal, receiving most of the publications. The majority of articles consisted of literature reviews and case studies, but there has also been an increase in the use of mixed methods research and multicriteria decision-making tools and other tools. The results also show the necessity of more studies on the macro level of CE, as well as studies that consider the influence of I.40-CE on social performance.

The content analysis of the articles revealed the criteria for environmental, operational, and social performance, as well as the I4.0 technologies and CE practices associated with each of these criteria. The conceptual framework presented in Figure 13 represents the answer to the research question, providing a clear structure to understand the integration (I4.0-CE).

The conceptual framework represents the most important contribution as it can be adopted for researchers and managers to understand and evaluate the performance impacts of each I4.0 technology and CE practice. Since this integration (I4.0-CE) is still not well-structured in the literature, the conceptual framework can be considered as a first step toward understanding and evaluating the integrated system (I4.0-CE). Thus, the advantages of the framework are twofold: it represents an advancement in the literature on this topic and guides practical evaluation for both managers interested in its application and researchers interested in developing new methods guided by the conceptual framework.

This paper also presents some limitations. First is related to the choice of strings adopted to select papers. Depending on the strings, the article selection may vary. Besides, the filtering criteria are also important and can affect the sample of selected articles. Therefore, future research could broaden the scope of this SLR by including other strings and adopting distinct filtering criteria. Unlike many SLRs on I4.0 and CE, supply chain practices were not included, limiting the framework only to practices of organizational performance. Considering that the circular supply chain is a relevant issue and many studies on that subject are been recently developed, this review could be expanded in that direction, considering the scope of digital and circular supply chains. Finally, empirical research could be made considering the selected variables presented in the theoretical framework in order to generalize the results, conducting, for example, surveys.

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