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ANÁLISE BIBLIOMÉTRICA DOS ESTUDOS SOBRE A AVALIAÇÃO DA MATURIDADE DA INDÚSTRIA 4.0 NAS PMES
BIBLIOMETRIC ANALYSIS OF STUDIES ON INDUSTRY 4.0 MATURITY ASSESSMENT IN SMES
ANÁLISIS BIBLIOMÉTRICO DE ESTUDIOS SOBRE LA EVALUACIÓN DE LA MADUREZ DE LA INDUSTRIA 4.0 EN PYMES

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RESUMO

Introdução: Esta pesquisa pretende contribuir para a organização e análise da literatura científica relacionada com a Avaliação do Nível de Maturidade Digital da Indústria 4.0 (I4.0) em pequenas e médias empresas (PMEs). Destaca-se a relevância contínua da transformação digital, impactando as PMEs e oferecendo oportunidades de integração na economia global.
Objetivo: O objetivo principal é utilizar técnicas bibliométricas para analisar e organizar a literatura científica disponível na avaliação do Nível de Maturidade Digital da I4.0 em PMEs. Pretende-se contribuir para compreender as tendências de pesquisa, identificar lacunas de conhecimento e fornecer orientações para futuras investigações.
Métodos: Realização de uma revisão abrangente da literatura, abrangendo artigos publicados entre 2011 e 2023 nas plataformas Web of Science (WoS) e SciVerse Scopus (Scopus), pela forte reputação, extenso conteúdo e citações globais. Utilização de técnicas bibliométricas facilitadas pelo VOSviewer e pelo software R-studio´s Bibliometrix R para processamento e análise de dados.
Resultados: A análise da literatura revelou insights significativos, incluindo a escassez de pesquisas recentes sobre a avaliação do nível de maturidade digital de PMEs no contexto da I4.0. Identificação de tendências de pesquisa, artigos notáveis com base em citações e publicações, bem como reconhecimento de autores frequentemente citados.
Conclusão: A importância do estudo reside na análise minuciosa da literatura existente, na avaliação de tendências de pesquisa chave e na identificação de lacunas, fornecendo insights valiosos. As direções propostas e as prioridades para futuras pesquisas destacam a necessidade de investigações adicionais sobre o nível de maturidade digital das PMEs no contexto da I4.0 e áreas como avaliação de desempenho e competências de gestão.

Palavras-chave: análise bibliométrica; indústria 4.0; modelos de preparação; PMEs; VOSviewer; R-studio´s Bibliometrix

ABSTRACT

Introduction: This research aims to contribute to the organization and analysis of scientific literature related to the Assessment of the Digital Maturity Level of Industry 4.0 (I4.0) in small and medium-sized enterprises (SMEs). The continuous relevance of digital transformation is emphasized, impacting SMEs and providing opportunities for integration into the global economy.
Objective: The primary goal is to use bibliometric techniques to analyze and organize the available scientific literature in assessing the Digital Maturity Level of I4.0 in SMEs.
It aims to contribute to understanding research trends, identifying knowledge gaps, and providing directions for future research.
Methods: Conducting a comprehensive literature review, covering articles published between 2011 and 2023 on the Web of Science (WoS) and SciVerse Scopus (Scopus) platforms, were utilized for their strong reputation, extensive content, and global citations.Employing bibliometric techniques facilitated by VOSviewer and R studio's Bibliometrix R software for data processing and analysis.
Results: Literature analysis revealed significant insights, including the scarcity of recent research on assessing the digital maturity level of SMEs in the context of I4.0. Identification of research trends, notable articles based on citations and publications, as well as recognition of frequently cited authors.
Conclusion: The significance of the study lies in the thorough analysis of existing literature, evaluation of key research trends, and identification of gaps, providing valuable insights. Proposed directions and priorities for future research, highlight the need for further investigations into the digital maturity level of SMEs in the context of I4.0 and areas such as performance assessment and management skills.

Keywords: bibliometric analysis; industry 4.0; readiness Models; SMEs; VOSviewer; R-studio´s Bibliometrix

RESUMEN

Introducción: Esta investigación tiene como objetivo contribuir a la organización y análisis de la literatura científica relacionada con la Evaluación del Nivel de Madurez Digital de la Industria 4.0 (I4.0) en pequeñas y medianas empresas (PYMEs). Se destaca la continua relevancia de la transformación digital, impactando a las PYMEs y ofreciendo oportunidades de integración en la economía global.
Objetivo: El objetivo principal es utilizar técnicas bibliométricas para analizar y organizar la literatura científica disponible en la evaluación del Nivel de Madurez Digital de la I4.0 en PYMEs. Se busca contribuir a la comprensión de las tendencias de investigación, identificar lagunas de conocimiento y proporcionar orientación para futuras investigaciones.
Métodos: Realización de una revisión exhaustiva de la literatura, abarcando artículos publicados entre 2011 y 2023 en las plataformas Web of Science (WoS) y SciVerse Scopus (Scopus), por su sólida reputación, amplio contenido y citas globales. Empleo de técnicas bibliométricas facilitadas por VOSviewer y el software R-studio´s Bibliometrix R para el procesamiento y análisis de datos.
Resultados: El análisis de la literatura reveló ideas significativas, incluyendo la escasez de investigaciones recientes sobre la evaluación del nivel de madurez digital de las PYMEs en el contexto de la I4.0. Identificación de tendencias de investigación, artículos destacados basados en citas y publicaciones, así como el reconocimiento de autores frecuentemente citados.
Conclusión: La importancia del estudio radica en el análisis exhaustivo de la literatura existente, la evaluación de tendencias clave de investigación y la identificación de lagunas, proporcionando perspicacias valiosas. Las direcciones y prioridades propuestas para futuras investigaciones resaltan la necesidad de investigaciones adicionales sobre el nivel de madurez digital de las PYMEs en el contexto de la I4.0 y áreas como la evaluación del rendimiento y habilidades de gestión.

Palabras clave: análisis bibliométrico; industria 4.0; modelos de preparación; PYMEs; VOSviewer; Bibliometrix de R-studio

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INTRODUCTION

Companies across industries share the challenge of developing strategies for technological innovation. Assessing their digital maturity within Industry 4.0 (I4.0) is essential for fostering growth and identifying areas for improvement, enabling them to achieve their strategic objectives.

A thorough review of diverse studies on I4.0 maturity is critical to provide a clear, comprehensive, and holistic perspective. Such analysis will help clarify and consolidate existing findings, offering more precise insights into the progress made in this field.

In recent years, there has been a significant global surge in initiatives to implement I4.0 technologies explicitly tailored for small and medium-sized enterprises (SMEs), driven by the substantial benefits these technologies offer. However, the shift toward digitalization remains relatively recent in certain countries and regions. SMEs, which play a vital economic role, face distinct challenges, including limited financial resources, restricted human capital, and limited access to advanced technological expertise. These factors make the transition to I4.0 both essential and challenging, particularly for SMEs in industrial sectors, where they represent a significant part of the economic landscape.

Focusing on industrial SMEs is especially relevant because, unlike larger companies, they often lack robust strategies or sufficient capital to adopt new technologies rapidly and effectively. Assessing their level of digital maturity is therefore crucial to understanding their specific needs and provides valuable insights for informing public policy and strategic planning to enhance their competitiveness. This study addresses a significant gap in the existing research, as much of the I4.0 literature primarily focuses on large enterprises. By concentrating on SMEs, this study seeks to contribute to analyzing and integrating an extensive body of literature on this emerging topic, offering a current understanding of the state of the art and identifying future research directions.

To assess the digital maturity of industrial SMEs, this study follows a research plan structured in several phases. First, a comprehensive review of the existing literature was conducted to identify and consolidate critical studies on maturity within Industry 4.0, focusing on SMEs. A qualitative approach was employed, using a systematic review methodology to organize the data and uncover gaps and trends in digitalization strategies. The document is structured to reflect this approach: following the introduction, the literature review synthesizes the most relevant studies. The methodology section then outlines the analysis procedures and selection criteria for the study sample, followed by the analysis of the results and discussion. The conclusion offers recommendations for public policy and directions for future research, providing a thorough and practical understanding of the digital maturity of SMEs in the context of Industry 4.0.

1. LITERATURE REVIEW

The Fourth Industrial Revolution, or Industry 4.0 (I4.0), is a new industrial cycle incorporating various emerging technologies to advance digital solutions. This revolution significantly influences factory settings, ushering in crucial changes, particularly in production and operational effectiveness (Sanders et al., 2016). The projected economic impact of this industrial revolution is substantial, as it improves operational efficiency and stimulates the creation of new business models, services, and products (Hermann et al., 2016).

Industry 4.0 represents the latest productive paradigm propelling the Fourth Industrial Revolution. Embracing this novel approach presents challenges, particularly for companies, including small and medium-sized enterprises (SMEs). To create a practical roadmap, companies in the early stages need to use tools and Maturity Models (MMs) to assess their current level of maturity in implementing digital practices related to Industry 4.0. These tools help plan a roadmap for improvement and development. Over the past few years, various MMs tailored for Industry 4.0 have been developed across different sectors (Rafael et al., 2020).

Small and medium-sized enterprises (SMEs) play a crucial role in creating industrial value but have been insufficiently studied in Industry 4.0 (Müller et al., 2018). Ensuring the competitiveness of SMEs relies on adopting Industry 4.0. Hence, it is crucial to evaluate and analyze readiness factors to facilitate the incorporation of Industry 4.0 in SMEs (Sriram & Vinodh, 2021).

The authors, Pirola et al. (2020), argue that SMEs are aware of the Industry 4.0 phenomenon but still have an intermediate readiness level. This is because the management of these companies is taking initial steps to identify the most suitable strategy for addressing the Industry 4.0. There is also a need to accelerate the adoption of new technologies to drive the organizational strategy of their companies (Godina et al., 2020). Most SMEs lack a comprehensive understanding of how the concepts and technologies of Industry 4.0 are implemented and what future benefits they may bring.

Industry 4.0 challenges industrial companies, especially SMEs, regarding management, organization, and technology (Horváth & Szabó, 2019). However, these companies lack understanding in implementing technologies and assessing their current level of technology implementation to drive improvement. Recognizing the high importance of evaluating the adoption patterns of Industry 4.0 technologies in industrial companies, Frank et al. (2019) suggest a framework outlining various technological tiers within Industry 4.0. This framework visually represents the levels of adoption for these technologies and the consequences of such adoption for industrial companies.

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Small and medium-sized enterprises need to keep pace with the digital transformation set by larger companies. To achieve this, it is crucial for SMEs to assess their level of digital maturity. Various models and tools are currently available for this purpose (Kljajić Borštnar & Pucihar, 2021). Companies use different readiness models to evaluate their maturity level before taking the initial steps in implementing Industry 4.0. Numerous investigations have been conducted on Industry 4.0 readiness models, revealing variations in the dimensions of readiness. Furthermore, there is a lack of empirical validation for the readiness model across diverse sectors or organizations, as Antony et al. (2023) noted. Nevertheless, these models have gained increasing relevance for industrial companies, particularly SMEs, aiming to gain sustainable and competitive advantages (Safar et al., 2020).

According to the authors (Sehlin et al., 2019), a certain level of digital maturity can be correlated with a specific level of innovation and digital transformation. Small and medium-sized enterprises (SMEs) must assess their readiness and maturity before starting a Smart Manufacturing journey (Rahamaddulla et al., 2021). The digital maturity of companies is linked to industrial, policy, and regional foundations (Chen et al., 2022). Companies must self-assess to determine if they are prepared to thrive and evolve in the Industry 4.0 (Ünal et al., 2022). Digital maturity models can scientifically help companies assess their level of digital maturity, identify weaknesses, and then formulate improvement strategies (Han et al., 2022).

Several authors, including Santos & Martinho (2020), Pirola et al. (2020), Rauch et al. (2020) and Amaral & Peças (2021), among others, have developed models to assess the level of implementation of Industry 4.0 technologies. Assessing this status in the industrial sector is vital but presents challenges since there is no universally agreed-upon term, and the obtained information is not explicitly designed for Industry 4.0 concepts (Castelo-Branco et al., 2019). The maturity measurement in Industry 4.0 should adhere to a scalable framework across levels until the objective is met. Consequently, it is recognized that evaluating maturity levels is crucial for companies to enhance their competitiveness.

Teichert (2019) illustrates that the maturity of digital transformation is a comprehensive concept that needs more consideration in future research. Moreover, the dimensions used in different models to assess digital maturity can vary considerably, with some models incorporating transformational resources beyond digital elements. The author emphasizes that organizational culture is recognized as a dimension specifically associated with digital maturity, already in specific models. This underscores the increasing significance of organizational culture as a facilitator in digital transformation endeavors.

Rauch et al. (2020) developed an easily applicable readiness assessment model for SMEs, offering an overview of existing Industry 4.0 concepts to support the formulation of their strategy for adopting Industry 4.0. The model provides a practical and flexible framework that helps SMEs assess their digital readiness and develop a tailored, incremental strategy for implementing Industry 4.0 technologies based on their needs and resources.

Chonsawat & Sopadang (2021) empirically proposed a maturity model to assess an organization's readiness for the digital era, emphasizing the need for a structured approach to understanding digital maturity. Their model highlights key dimensions such as technology adoption, organizational culture, and strategic alignment, providing organizations with a roadmap for progressing through digital transformation stages. Similarly, Bánhidi et al. (2020) stress the importance of assessing readiness levels to formulate more effective strategies for digital transition. Their study concludes that readiness assessments enable organizations to identify gaps, allocate resources effectively, and prioritize digital initiatives based on their current capabilities, thus enhancing the success of the digital transformation process.

The significance of being digitally prepared for transformations has gained more attention recently. However, prior research has not focused on the specific elements of digital readiness linked to digital transformation outcomes in a specific context (Trischler & Li-Ying, 2022). Various maturity models offer a structure for professionals to develop a roadmap, smoothing the initial journey and boosting adoption rates. This, in turn, contributes to the ongoing enhancement of the digital transformation process (Kirmizi & Kocaoglu, 2022). Some prominent models include the Industry 4.0 Maturity Index (Kagermann et al., 2013), which evaluates technological maturity in manufacturing, and the Digital Maturity Model by Westerman et al. (2014), which focuses on organizational readiness and digital capabilities. Additionally, the SMART Industry Readiness Index (SIRI) and Digital Transformation Maturity Model developed by organizations such as Deloitte and McKinsey are widely used to assess the digital maturity of SMEs, offering tailored frameworks to guide the adoption of Industry 4.0 technologies. These models help organizations identify gaps, prioritize improvements, and track their digital progress systematically.

Industry 4.0 has gained significant attention from researchers due to its benefits, numerous studies, and the availability of readiness and maturity models from a technological perspective (Nafchi & Mohelská, 2020). While there are various assessments of readiness for digital transformation in Industry 4.0, existing literature contributes to a better understanding, particularly among authors who have explored this topic, including those who have identified differences between small and medium-sized enterprises (SMEs) (Lassnig et al., 2022).

This revolution significantly impacts factory operations, driving transformation through the integration of advanced technologies such as IoT, AI, and automation. Assessing digital maturity levels in Industry 4.0 requires a scalable measurement framework

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spanning various stages, from initial adoption to fully realizing digital transformation goals. A bibliometric analysis of the existing literature reveals a convergence in the understanding that digital maturity models offer crucial support in guiding this transition. Several studies emphasize the importance of assessing maturity as a continuous process, where organizations progress through different readiness levels (Rauch et al., 2020; Chonsawat & Sopadang, 2021). However, divergent approaches are evident, particularly regarding the specific criteria and dimensions used to assess maturity, with some models focusing on technological infrastructure.

In contrast, others prioritize organizational culture and human capital. Additionally, gaps persist in the literature regarding how smaller SMEs with limited resources can effectively adopt these models. While much of the research targets large enterprises, there remains a significant need for more practical frameworks tailored to the unique challenges faced by SMEs in their digitalization journey.

2. MATERIALS AND METHODS

2.1 Data

This study employs a bibliometric approach with quantitative techniques applied to bibliometric data, following a predefined set of steps. Initially, two widely recognized bibliographic database search platforms, Web of Science (WoS) and SciVerse Scopus, were utilized for their strong reputation, extensive content, and global citations. These platforms provided access to articles published by well-known publishers (de Oliveira et al., 2019). The data collection spanned from 2011 to 2023, focusing on research on models assessing the digital maturity level for Industry 4.0 in industrial SMEs. The reliability of the bibliometric analysis hinges on the quality of these research platforms. The subsequent step involved a scientific bibliographical survey aligning Industry 4.0 principles with models for evaluating the digital maturity level of small and medium-sized industrial companies (SMEs). The third and final step comprised data acquisition from databases, followed by detailed processing, analysis, and discussion.

Data analysis was facilitated through visualization using VOSviewer version 1.6.18 (Van & Waltman, 2018) software and the Bibliometrix R software from R Studio (Aria & Cuccurullo, 2017). VOSviewer, a visualization tool, aided in interpreting bibliometric maps, even when dealing with large datasets. The bibliometric review assisted in evaluating main themes and trends in publications on the subject and identifying primary journals publishing them (Treinta et al., 2014).

This analytical approach creates a visual representation by tracing connections between elements used in different studies (Zupic & Cater, 2015; Xiao & Watson, 2019). It facilitates grouping relevant information on a given subject, portraying the growing scenario of scientific publications and their evolution in scientific knowledge bases. Researchers have adopted this methodology to position their research in the field (dos Santos & Kobashi, 2009). Bibliometric analysis, as per Hood and Wilson (2001), has become increasingly widespread and is now a standard practice in various domains of scientific research.

This analytical methodology is gaining importance and visibility as it provides crucial information about influence, specifications, and trends within a given research domain. It objectively evaluates conventional standards of scientific research (Du & Teixeira, 2012; Cobo et al., 2015; Manriquez et al., 2015; de Oliveira et al., 2019). Following Pritchard's (1969) model, bibliometric analysis involves applying mathematical models with specific statistical algorithms to documents and communication databases. Various perspectives on this analytical method emphasize its ability to measure results in scientific literature and evaluate their impact in a specific area through quantitative, mathematical, and statistical approaches.

Given the significant expansion of literature, the initial step involved a bibliometric analysis to identify the most relevant, recent, and highly recommended studies on the topics covered. The objective was to establish a correlation between different studies on digital maturity assessment for Industry 4.0.

From the portfolio of articles identified at the end of the inclusion stage, metadata analysis was carried out using VOSviewer software and the Bibliometrix R software from R Studio for accurate counting of journals and years of publication. The number of publications per year was determined with accurate metadata, and a graph was generated in Microsoft Excel.

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2.2 Methods

As mentioned, the stages of bibliometric analysis, adapted from Zupic and Cater (2015), are as follows: (1) study design: defining the objective, choosing the database, and setting the filters to be applied to delimit the sample; (2) data collection and processing: selecting, capturing, and processing bibliometric data after applying the filters defined in the previous step; (3) data analysis: using software for bibliometric analyses; (4) interpretation: interpreting and describing the findings. Figure 1 illustrates the sequence of procedures adopted to obtain the results.

The sample was obtained through the following procedure:

- Definition of the research period (2011-2023);
- Identification of search keywords;
- Selection of scientific articles;
- Conducting bibliographic research on the Web of Science and Scopus platforms;
- Obtaining the available dataset for analysis;
- Bibliographic analysis of the data obtained from different databases;
- Visualization and mapping of the results in VOSviewer and R studio's Bibliometrix R software;
- Selection of the most relevant authors and impactful themes;
- Interpretation and analysis of the results.

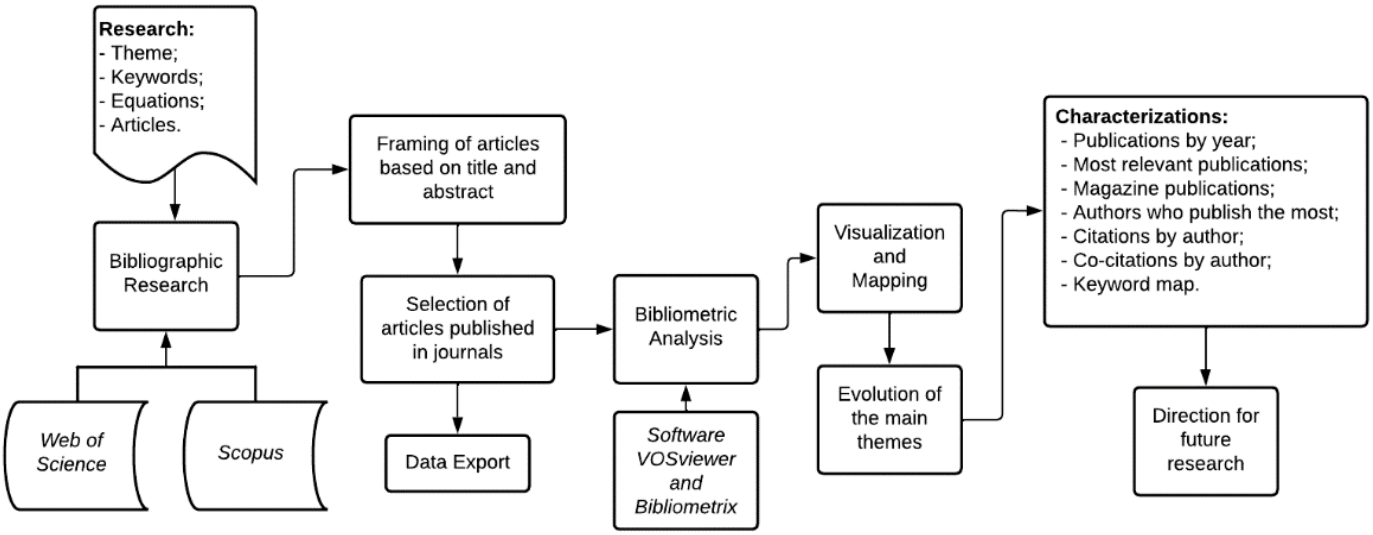

Figure 1 - Flowchart of the methodology used for research and bibliometric analysis.

Keywords were input into databases to gather comprehensive published data on the topic. The Web of Science (WoS) and Scopus databases were utilized, resulting in Survey 1 and 2, respectively, as outlined in Table I. To enhance the bibliometric analysis and leverage potential interactions with the VOSviewer software, a combination of WoS and Scopus databases was employed, complemented by R Studio's Bibliometrix R software.

A comprehensive overview of research trends, productivity, and collaborations was obtained to discern advances and gain insights into Industry 4.0 (I4.0) maturity assessment. The study formulated the following research questions (RQ) to be addressed in the course of the results:

RQ1. How has scientific productivity evolved regarding the assessment of maturity levels in I4.0?

RQ2. How is the collaborative research network structured in this field?

RQ3. What patterns characterize research trends in this domain?

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Table 1 - Research Equations for Bibliometric Analysis.

Gathering data for the bibliometric analysis						
Keywords (Web of Science)						
	TS="industry 4.0"		**TS="maturity model"**		**TS="industrial SMEs"**	**Results**
Search 1	OR TS="smart manufacturing" OR TS="manufacturing 4.0" OR TS="smart factory" OR TS="digitization 4.0" OR TS="digitalization 4.0" OR TS="digital transformation" OR TS="factory 4.0" OR TS="fourth industrial revolution" OR TS="fourth industrial" OR TS="4th industrial"	AND	OR TS="readiness model" OR TS="readiness level" OR TS="readiness assessment" OR TS="digital readiness" OR TS="assessment model" OR TS="maturity model development" OR TS="status maturity" OR TS="digital transformation maturity model" OR TS="maturity assessment" OR TS="maturity level" OR TS="evaluation model" OR TS="dimensions" OR TS="frameworks" OR TS="Foresight maturity" OR TS="maturity index"	AND	OR TS="evaluation model" OR TS="region" OR TS="small and medium-sized enterprises" OR TS="dimensions"	**468**
Keywords (*Scopus*)						
	TITLE-ABS-KEY "industry 4.0"		**TITLE-ABS-KEY "maturity model"**		**TITLE-ABS-KEY "industrial SMEs'**	**Results**
Search 2	OR "smart manufacturing" OR "manufacturing 4.0" OR "smart factory" OR "digitalization 4.0" OR "digital transformation" OR "factory 4.0" OR "fourth industrial revolution" OR "fourth industrial" OR "4th industrial"	AND	OR "readiness model" OR "readiness level" OR "readiness assessment" OR "digital readiness" OR "assessment model" OR "maturity model development" OR "maturity status" OR "digital transformation maturity model" OR "maturity assessment" OR "maturity level" OR "evaluation model" OR "dimensions" OR "frameworks" OR "Foresight maturity" OR "maturity index"	AND	OR "evaluation model" OR "region" OR "small and medium-sized enterprises" OR "dimensions"	**621**

The examination of this flowchart involved two main phases. Firstly, a performance analysis summarized key research indicators such as publication counts and citations. This covered publication rates categorized by journal, research area, author, affiliation, and country. Secondly, a scientific mapping was conducted to visualize the intellectual framework. This included an analysis of citations and co-authorships, as well as an exploration of themes and research topics through co-citations, bibliographic coupling, and co-occurrence analysis.

The study followed a methodological flowchart based on Donthu et al. (2021) and incorporated the Preferred Reporting Items for Systematic Reviews and Meta-Analysis for Scoping Review (PRISMA-ScR) guidelines by Tricco et al. (2018). A methodology was adopted to ensure no replication and to maintain complete transparency in the review process, as illustrated in Figure 2.

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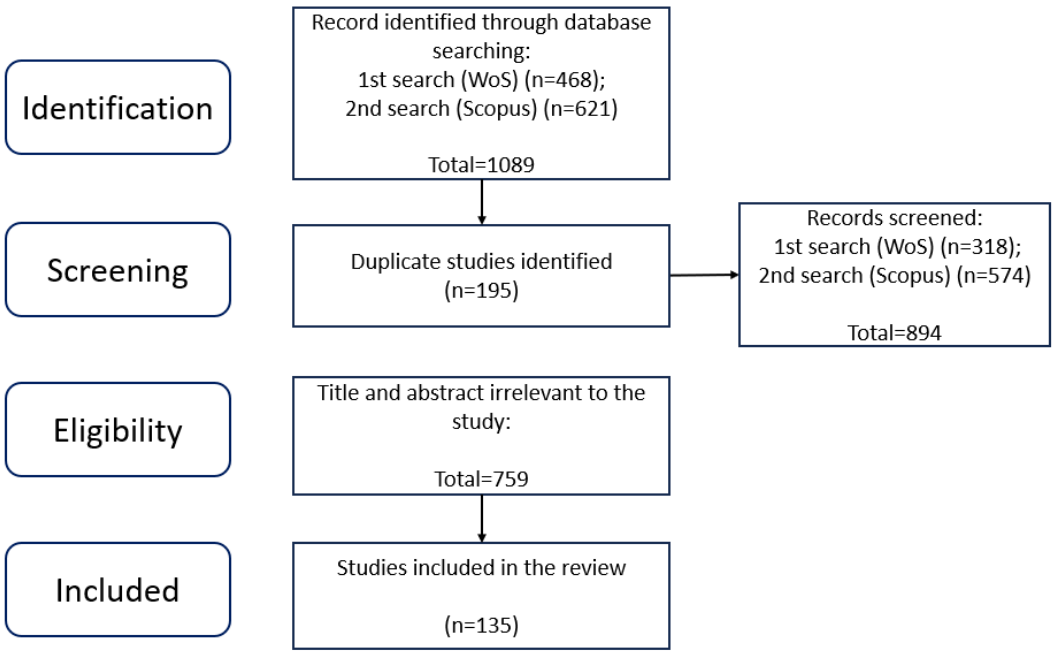

Figure 2 - PRISMA-ScR flow diagram.

In this bibliometric study, a total of 468 and 621 articles were gathered from the Web of Science and Scopus databases, respectively. These articles were instrumental in compiling information on models assessing the digital maturity level in Industry 4.0 and conducting a comprehensive review of the pertinent literature. The analysis revealed significant publications, influential authors, emerging trends, and patterns, contributing to a deeper understanding of the developmental phase of Small and Medium-sized Enterprises (SMEs). Certain countries exhibited an emerging trend, signalling a relatively recent phenomenon. This emphasizes the significance of the present study in offering insights and consolidating a substantial body of literature on this evolving subject. The thorough review of the current literature aims to establish a foundation for exploring the state of the art in future research.

For each search, the terms “Industry 4.0”, “Maturity model”, and “Industrial SMEs” were combined with various related keywords. In both Search 1 and Search 2, results from the Web of Science and Scopus databases were exported and organized into fields such as author names, article/publication titles, year of publication, source title, total number of citations, abstracts, author keywords, document type, database, link, references, and language.

To ensure greater consistency in standardizing the databases, publications without titles, references, and keywords were initially excluded in the early phases of both Search 1 and Search 2, eliminating 759 publications. Subsequently, during a later stage, 195 duplicate articles were identified and removed. However, in the third phase, through a meticulous analysis of abstracts and keywords, a total of 135 publications relevant to the topic were identified in both WoS and Scopus and were utilized in developing this research.

3. RESULTS

3.1. Bibliometric Analysis

This segment employs specific bibliometric techniques to assess publication trends and disseminate scientific knowledge regarding digital maturity studies in SMEs within the industrial sector. The analysis aims to examine the scientific output in this field and highlight critical issues for future research, as Caviggioli and Ughetto (2019) outlined. The objective is to deepen the understanding of published works evaluating Industry 4.0 maturity by utilizing co-citation maps, co-occurrence analysis, and identifying the most frequently cited articles and authors. The following section presents the results of the bibliometric analysis conducted on 135 selected articles, following the PRISMA-ScR methodology for selection and filtering. These works were evaluated and found to be valuable in addressing the research questions of this study. The bibliometric analysis was conducted to determine the number of publications and the journals in which they were disseminated.

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3.1.1. Year of Publication

Figure 3 shows the chronological progression of articles published on this topic. Searches in the WoS and Scopus databases were conducted from 2011 to 2023, focusing on scientific publications exploring various approaches to assessing SMEs' Industry 4.0 maturity level. A steady increase in publications on this subject has been observed since 2018, with notable growth in 2021 and 2022. The initial bibliometric analysis of the portfolio of 135 articles involved mapping these publications over time. This analysis tracks the annual number of articles published, as shown in Figure 3, where the number of articles is represented on the vertical axis and the timeline on the horizontal axis.

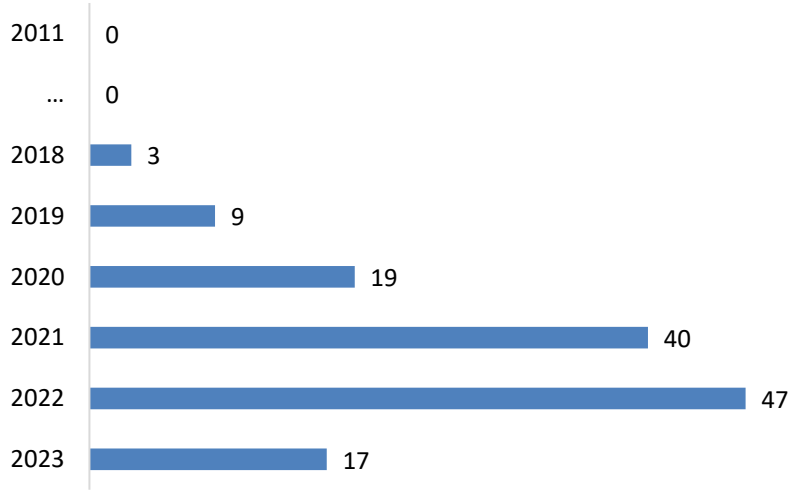

Figure 3 - Year of publications with the highest number of articles.

3.1.2. Distribution of the most cited publications by countries

This second analysis examines the countries with the highest number of global citations in studies on this topic, extending beyond the original study sample. This shift in criteria aims to capture broader global trends and identify the countries making the most significant contributions to the field, independent of their inclusion in the primary sample. Considering highly cited publications from various regions, this analysis provides a more comprehensive view of global knowledge dissemination. It highlights the leading countries in research on digital maturity and Industry 4.0. Table II shows Brazil ranks first in citations, followed by the United Kingdom, Italy, the Czech Republic, Portugal, and India.

Table 2 - Distribution of publications by most cited countries.

Country	N. of Citations
Brazil	2464
United Kingdom	1742
Italy	1427
Czech Republic	610
Portugal	400
India	327
Russia	291
Sweden	210
USA	209
Germany	128

Figure 4 analyzes the contributions to scientific production by country regarding the assessment of Industry 4.0 maturity. The countries with the most significant number of publications on this topic include *Turkey*, *Germany*, *United Kingdom*, *China*, *Brazil*, *Italy*, *India*, *Portugal*, and *United States*.

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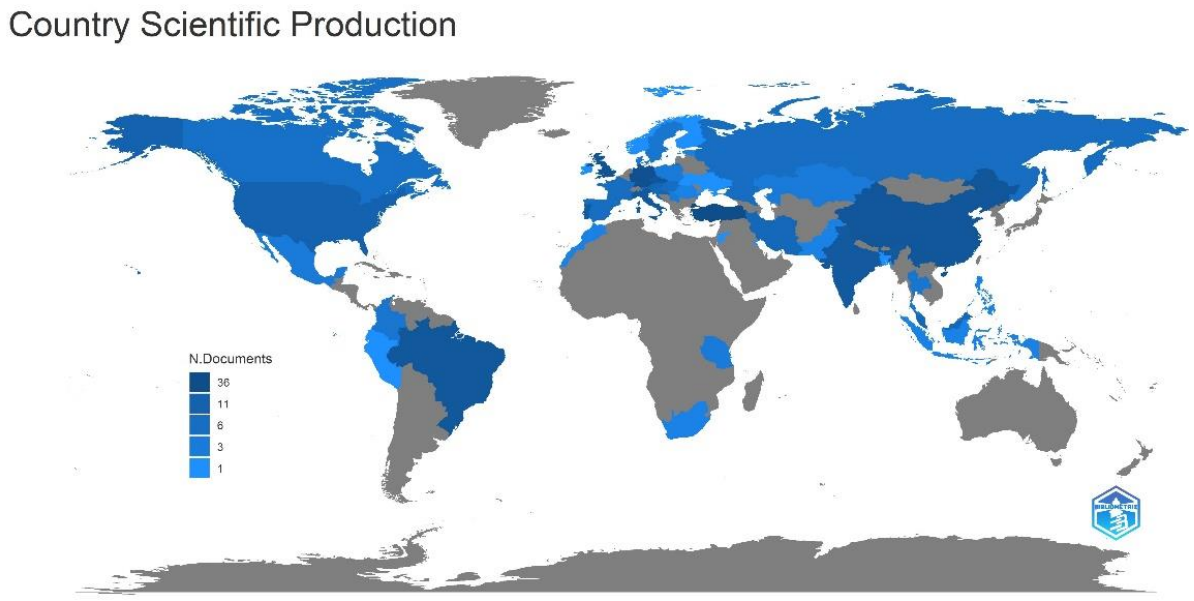

Figure 4 - Country scientific production collaborations.

3.1.3. Type of Journal

This section identifies prominent journals that have significantly impacted studies related to digital maturity in Industry 4.0 within SMEs based on their high publication frequency. Notably, this study focuses exclusively on journal articles. The influence of these journals within their scientific fields can be assessed by examining their impact factors, as available in the databases. Key journals with a substantial volume of publications on this topic include *Sustainability*, *Journal of Manufacturing Technology Management*, *Applied Sciences-Basel*, *International Journal of Innovation Management*, *International Journal of Production Economics*, and *Production Planning & Control*, as shown in Table III.

Table 3 - Publications of most relevant articles by journal.

Sources	N. of Documents
SUSTAINABILITY	14
JOURNAL OF MANUFACTURING TECHNOLOGY MANAGEMENT	7
APPLIED SCIENCES-BASEL	6
INTERNATIONAL JOURNAL OF INNOVATION MANAGEMENT	3
INTERNATIONAL JOURNAL OF PRODUCTION ECONOMICS	3
PRODUCTION PLANNING \& CONTROL	3
SUSTAINABILITY (SWITZERLAND)	3
ADVANCES IN PRODUCTION ENGINEERING \& MANAGEMENT	2
APPLIED SCIENCES (SWITZERLAND)	2
BUSINESS HORIZONS	2
CHIANG MAI UNIVERSITY JOURNAL OF NATURAL SCIENCES	2

Figure 5 shows the growth in journal publications on this topic in recent years, highlighting a marked increase in interest since 2018.

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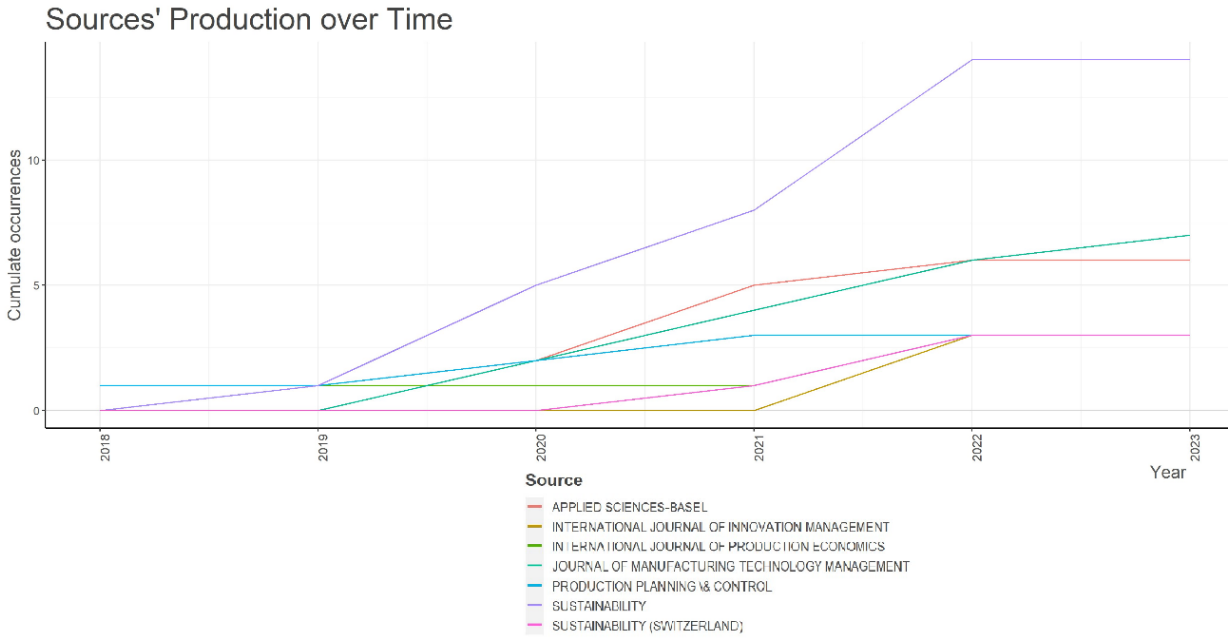

Figure 5 - Publications of the most relevant articles over de last few years, by journal.

3.1.4. Most relevant publications in last years

This section seeks to enhance understanding of recent influential articles. Publications were categorized according to citation counts from databases such as WoS and Scopus, as presented in Table IV. Each article was carefully reviewed to confirm its relevance to the study's theme. The list includes the 20 most pertinent articles from recent years focused on assessing Industry 4.0 maturity in SMEs.

Table 4 - Most relevant publications in recent years.

Ranking	Author	Title	Year	Citation
1	Bibby & Dehe, 2018	"Defining and assessing industry 40 maturity levels case of the defence sector"	2018	391
2	Teichert, 2019	"Digital transformation maturity a systematic review of literature"	2019	329
3	Santos & Martinho, 2020	"An industry 40 maturity model proposal"	2020	218
4	Wagire et al., 2021	"Development of maturity model for assessing the implementation of industry 40 learning from theory and practice"	2021	207
5	Pirola et al., 2020	"Digital readiness assessment of italian smes a casestudy research"	2020	191
6	Rauch et al., 2020	"A maturity levelbased assessment tool to enhance the implementation of industry 40 in small and mediumsized enterprises"	2020	96
7	Lootah et al., 2022	"Defining smes 40 readiness indicators"	2022	78
8	Pech & Vrchota, 2020	"Classification of small and mediumsized enterprises based on the level of industry 40 implementation"	2020	72
9	Amaral & Peças, 2021	"A framework for assessing manufacturing smes industry 40 maturity"	2021	51
10	Çınar et al., 2021	"A framework for industry 40 readiness and maturity of smart manufacturing enterprises a case study"	2021	49
11	Hein-Pensel et al., 2023	"Maturity assessment for industry 50 a review of existing maturity models"	2023	46
12	Kljajić Borštnar & Pucihar, 2021	"Multiattribute assessment of digital maturity of smes"	2021	45
13	Tripathi & Gupta, 2021	"A holistic model for global industry 40 readiness assessment"	2021	38
14	Chonsawat & Sopadang, 2021	"Smart smes 40 maturity model to evaluate the readiness of smes implementing industry 40"	2021	24
15	Hizam-Hanafiah et al., 2021	"Change readiness as a proposed dimension for industry 40 readiness models"	2021	19
16	Haryanti et al., 2023	"The extended digital maturity model"	2023	17
17	Sándor & Gubán, 2021	"A measuring tool for the digital maturity of small and mediumsized enterprises"	2021	14
18	Kırmızı & Kocaoglu, 2022	"Digital transformation maturity model development framework based on design science case studies in manufacturing industry"	2022	12
19	Ünal et al., 2022	"Application of the maturity model in industrial corporations"	2022	9
25	Merdin et al., 2022	"Digital transformation digital maturity model for turkish businesses"	2022	3

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3.1.5. Analysis of the authors who have published the most

The bibliometric analysis reveals that, among 130 authors, only 105 have published at least one article with a minimum of five citations. Not all of these 105 entries within the network are interconnected. The most extensive connected set includes 48 items, as shown in Figure 6. Key contributors to this field include Bibby, Brodny, Chonsaw, Pech, Marcon, Frederi, and Amaral. Figure 6 illustrates that the number of publications per author does not necessarily correlate with citation count. As a result, some authors with numerous publications may not be among the top 20 regarding citations. Conversely, some authors with fewer publications may have lower citation counts, yet their work remains highly relevant to this study.

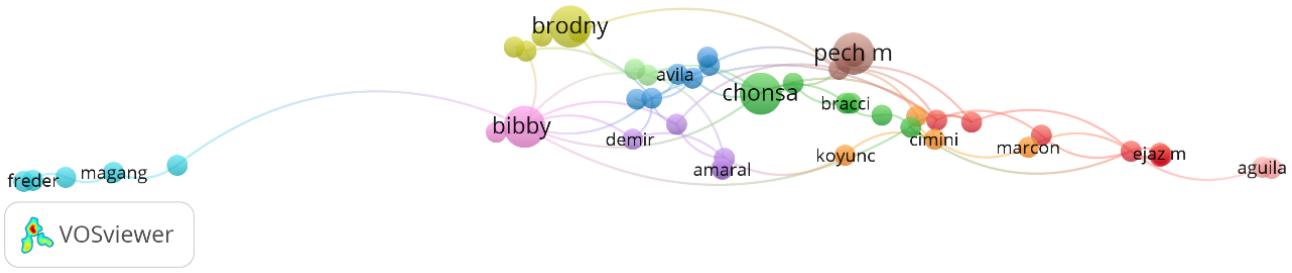

Figure 6 - Network overlay of the most prolific authors, connected to each other, obtained by VOSviewer.

3.1.6. Analysis of co-citations by author

In this analysis, 3972 co-cited authors were identified, each with at least 20 co-citations. Out of 4650 authors, only 12 were co-cited 20 or more times.

Figure 7 illustrates the most frequently cited sources, organized into various co-citation groups. When these references are cited, they form a network that highlights common themes and helps identify critical authors in co-cited studies.

Upon reviewing Figure 7, they created it using VOSviewer, and three main clusters emerged, each representing the number of co-citations per author. For instance, in the right (green) cluster, prominent authors with the highest co-citation counts include the European Commission, Kagermann, and Siemens. In the left (red) cluster, authors such as Schumacher, Schuh, Gokalp, de Carolis, Hair, and Leyh are more frequently co-cited and exhibit more robust interconnections. Only three authors, Mittal, Muller, and Ghobakhloo, are notably co-cited in the blue cluster.

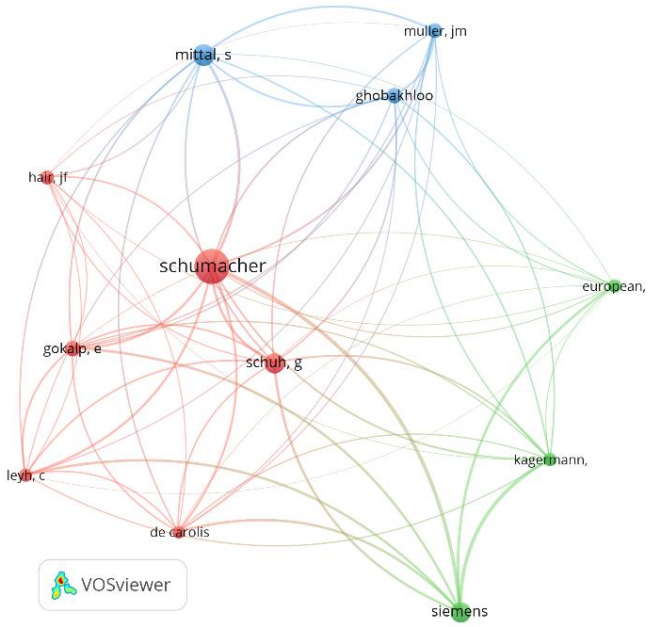

Figure 7 - Network overlay with clusters of co-citations by author obtained using VOSviewer.

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3.1.7. Keyword co-occurrences analysis by author

In the analysis of keyword co-occurrence by authors, shown in Figure 8, four clusters stand out, each represented in different colors on the left side of the figure. In the first cluster (red), the most frequently used keywords include “digital transformation”, “digitalization”, “digital maturity”, and “digital maturity model”, which consistently appear together. The second cluster (blue) is centered around the keywords “SMEs”, “readiness”, and “maturity model”, commonly used together by a specific group of authors. In the green cluster, the keywords include “industry 4.0”, “smart manufacturing”, “manufacturing”, “4th industrial revolution”, and “maturity models”. The yellow cluster contains the keywords “industry 4.0”, “SME”, and “sustainability”.

It is important to note that all clusters share a standard connection with the keyword “industry 4.0”. This highlights a clear joint research focus across clusters, with keywords such as “industry 4.0”, “SME”, “digital transformation”, and “maturity model” appearing frequently together.

The image on the right illustrates the timeline of these keyword clusters. Significant publications featuring the keywords “digital maturity models”, “digital maturity”, and “maturity models” began gaining prominence in late 2019 and have remained relevant to the present day. Initially, the most common keywords in publications on this topic were “industry 4.0”, “smart manufacturing”, “manufacturing”, and “sustainability”.

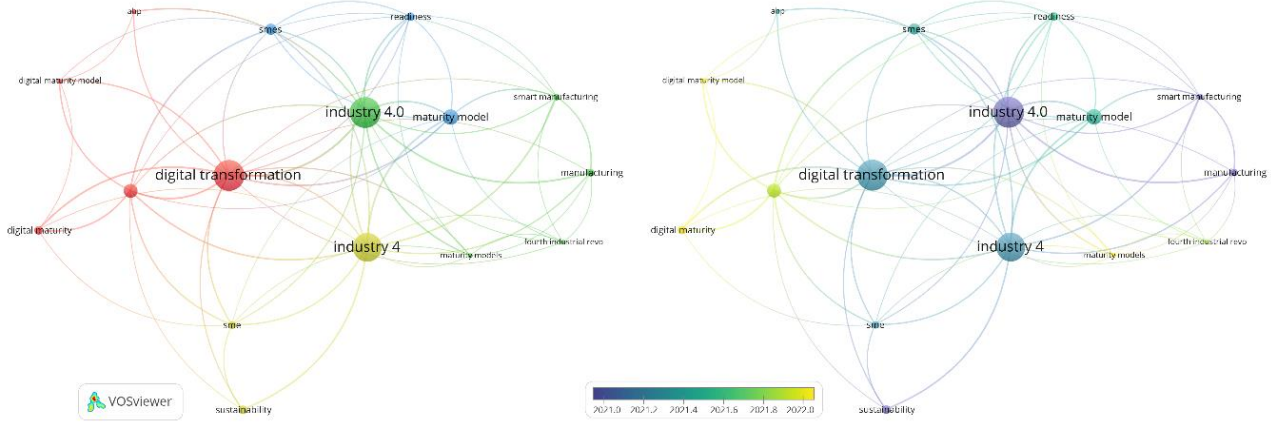

Figure 8 - Network overlay of keyword co-occurrences by Authors (classified by cluster and year of publication).

3.1.8. Keyword co-occurrences analysis

The co-occurrence map was created by analyzing all keywords used in the research, combining data from the Web of Science (WoS) and Scopus databases. Using VOSviewer software, a co-occurrence analysis visually represents the network of nodes derived from the literature. A total of 380 frequently used words in article titles, abstracts, and keywords were identified, with 31 keywords meeting the criterion of appearing at least five times. For each of these 31 keywords, the total strength of co-occurrence links with other keywords was calculated. Figure 9 displays these keywords in the co-occurrence graph, where each circle's size corresponds to the respective keyword's strength, along with its frequency in recent years.

On the left side of Figure 9, the connections between these keywords are illustrated by links in the graph, revealing their relationships through the clusters formed. In co-occurrence analysis, the total link strength indicates when two keywords appear together in the same document within each cluster. Five main clusters emerge, highlighting the connections between keywords. The most frequently used and correlated keywords in the articles reviewed include “lean manufacturing”, which appears in most publications, followed by “industry 4.0”, “digital transformation”, “maturity model”, “SMEs”, and “readiness”, among others.

On the right side of Figure 9, a key finding related to the yellow cluster is visible, which shows a connection between the keywords “maturity models”, “SMEs”, and “industry 4.0”. These keywords are central to the research and are closely interconnected. Notably, they only appear together in scientific publications starting from early 2022.

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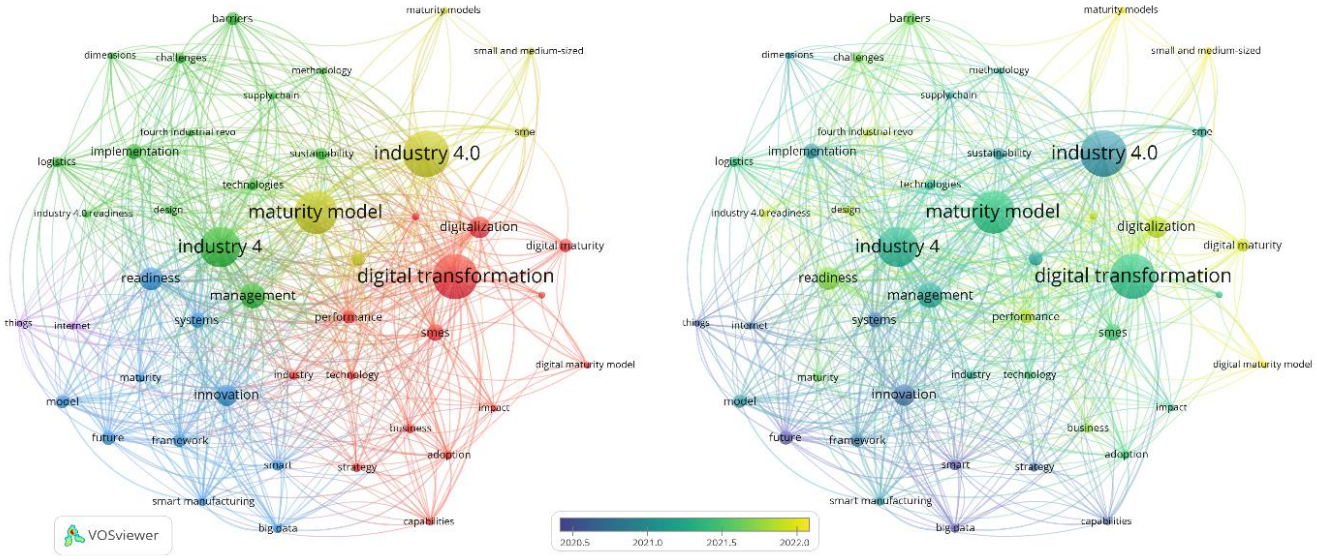

Figure 9 - Network overlay of keyword co-occurrences (classified by cluster and year of publication).

This study used the Bibliometrix R software to create a keyword cloud. Figure 10 presents the most significant keywords from the examined articles. These keywords, frequently used by authors, are crucial for understanding research trends and forming clusters as they establish connections between various elements. Each word's size reflects the keyword's importance and frequency in the publications included in this study.

Figure 10 - Keyword map obtained using Bibliometrix R software.

CONCLUSION

The findings of this study reveal a significant surge in research related to Industry 4.0 and the evaluation of digital maturity levels in SMEs since 2018. This growth trend is expected to continue, aligning with broader technological advancements and the increasing emphasis on digital transformation across industries. Using bibliometric analysis, leveraging tools such as VOSviewer and Bibliometric R software, allowing for the creation of detailed maps and data extraction from WoS and Scopus databases, facilitating the identification of critical networks within the field. These networks include scientific publications, influential journals, highly cited authors, and frequently used keywords, providing a comprehensive overview of the research landscape.

When comparing the results of this study, several converging and divergent trends emerge. The literature on digital maturity models in SMEs is relatively recent. Still, it is increasing, indicating a shift in focus from large to small companies in the context of Industry 4.0. This is in line with the growing interest in addressing the unique challenges of SMEs in adopting digital technologies. However, although several studies emphasize the importance of digital maturity for large enterprises, the specific impact of digital maturity models on SME performance remains underexplored, highlighting a notable gap in the literature. This study fills this gap

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by offering insights into the rapidly expanding body of work on digital maturity in SMEs and its potential impact on their performance.

Furthermore, bibliometric analysis underscores an increasing focus on the intersection between digital technologies and business strategy, with key themes such as business model innovation, global value chains, collaboration, and performance emerging as focal points in recent research. There has also been a notable increase in developing and exploring digital maturity models, which are crucial for guiding SMEs through total transformation.

Despite these valuable contributions, the study has some limitations. One limitation is the dependence on two primary databases, WoS and Scopus, which, although extensive, may not cover all relevant publications. Expanding the analysis to include other reference databases, such as Google Scholar or IEEE Xplore, could provide a more holistic view of the research landscape and reveal additional insights. Furthermore, although the study identifies trends in this domain, it does not delve into the methodologies and approaches used in digital maturity models, which could have provided more detailed practical guidance for SMEs. Future research could address this issue by conducting more granular analyses of the methodologies underlying these models and exploring their direct effects on SME performance.

In conclusion, the study emphasizes the need for continued exploration of digital maturity models, particularly in the context of SMEs, and the growing importance of these models in defining corporate strategies for digital transformation. Future work should aim to refine these models, assess their impact on SME performance, and expand the bibliometric analysis scope to include additional databases and regions.

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AUTHOR'S CONTRIBUTION

Conceptualization, A.G., P.R. and A.J.M.C.; data curation, A.G; formal analysis, A.G., P.R. and A.J.M.C.; investigation, A.G.; methodology, A.G.; supervision, P.R. and A.J.M.C.; validation, P.R. and A.J.M.C.; writing-original draft, A.G.; writing-review and editing, P.R. and A.J.M.C.

CONFLICT OF INTERESTS

The authors declare no conflict of interest.

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