v. 1, n. 1, 2024

International Journal of Exact Sciences

DIGITAL MATURITY IN INDUSTRY 4.0: A BIBLIOMETRIC REVIEW OF EVALUATION MODELS FOR SMALL AND MEDIUM ENTERPRISES

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Abstract: The present study, utilizing bibliometric techniques, aimed to structure and analyze the existing scientific literature on Digital Maturity Assessment Models for Industry 4.0, explicitly focusing on small and medium-sized enterprises (SMEs). Despite digital transformation not being a new phenomenon, it continues to be a crucial and relevant concept, significantly impacting SMEs and presenting a valuable opportunity for their integration into the global economy. This research involved a comprehensive review of the scientific literature and a bibliometric analysis to uncover key trends and insights in this field. The study identified the primary research trends and highlighted the ten most influential articles based on citation count and publication frequency. Furthermore, it pinpointed the most cited authors, offering greater clarity on the development level of SMEs in their integration and preparation for the Industry 4.0 paradigm. This analysis provides valuable insights into SMEs' current state and future directions of digital maturity, facilitating their transition into a more technologically advanced and competitive environment.
Keywords: Industry 4.0, Maturity models, SMEs, Bibliometric analysis.

INTRODUCTION

This study was based on data collected from the Web of Science and Scopus databases between 2011 and 2022, focusing on Digital Maturity Assessment Models for Industry 4.0 in small and medium-sized enterprises (SMEs). The main motivation for this study was to identify existing scientific production, adopting a bibliometric analysis with the aid of the VOSviewer software, version 1.6.18 (Van & Waltman, 2022). The choice of this method allowed a visual representation of the relationships between several items present in several studies, as demonstrated by Zupic & Cater (2015) and Yu & Maria (2019). This type of analysis facilitates the grouping of relevant information on a specific topic, providing an insight into the growing universe of publications in scientific knowledge databases and their evolution. This methodology has been adopted as a fundamental tool for researchers to position their research (Santos & Kobashi, 2009). According to Hood and Wilson (2001), bibliometric analysis has been widely used and has become a widespread practice in several areas of knowledge over the years. This methodology stands out for providing essential information on the influence, specifications and trends in a research area, offering an objective assessment of traditional scientific research standards (Du & Teixeira, 2012; Cobo et al., 2015; Manriquez et al., 2015; de Oliveira et al., 2019). Pritchard (1969) describes bibliometric analysis as the application of mathematical models and statistical algorithms to communication documents and databases, with a focus on measuring the results of scientific literature and evaluating its impact in a given area, using quantitative, mathematical and statistical methods. Given the vast expansion of literature in the area, a bibliometric analysis was chosen to identify the most relevant, recent and recommended studies on the topic, especially those that explore the correlation between Industry 4.0, digital maturity assessment models and industrial SMEs.

In this study, 431 publications were identified in the Web of Science and 990 publications in Scopus, which contributed to the collection of the most recent studies on the digital maturity of SMEs in the context of Industry 4.0. The in-depth analysis of this literature highlighted the main publications, authors, trends and patterns, providing greater clarity on the level of development of SMEs in their integration and preparation for the new Industry 4.0 paradigm.

Thus, an emerging trend and a phenomenon that is still recent in certain countries and regions is highlighted, reinforcing the importance of this study by providing a comprehensive analysis and integrating the updated literature on this emerging topic, establishing a solid foundation for future explorations of the state of the art.

THEORETICAL TABLE

The industrial sector has been essential for the economic development of countries and regions. The transformations that have occurred in the sector, both in production and management, have revolutionized the increase in productivity and improved people's quality of life (Santos et al., 2018). The First Industrial Revolution, at the end of the 18th century, marked the transition from manufactured work to steam-powered machines (Bitkom et al., 2016). In the 20th century, the use of electricity in production systems drove the Second Industrial Revolution, characterized by mass production and the division of labor (Santos et al., 2018). The Third Industrial Revolution, which began in the 1970s and is still ongoing, is defined by electronics and Information Technology (Santos et al., 2018).

In recent decades, the development of Information Technologies and their integration into production processes have brought benefits throughout the value chain. The introduction of new concepts, such as internet-based production, not only improves communication between manufacturers, customers and suppliers, but also creates new ways of responding to customers through new business models (Urbikain et al., 2017).

The concept of Industry 4.0 arises from the convergence of several technological advances involving products and processes (Schmidt et al., 2015). Industry 4.0 ensures greater operational efficiency, productivity gains, growth, improved competitiveness, and the development of new business models (Kagermann et al., 2013; Bauernhansl et al., 2014).

The Fourth Industrial Revolution has a significant impact on manufacturing environments, introducing decisive changes, especially in production and operations performance (Sanders et al., 2016). The economic impact of this revolution is expected to be substantial, promoting greater operational efficiency, as well as the development of new business models, services and products (Hermann et al., 2016).

For companies, particularly SMEs, to integrate into Industry 4.0, it is essential that they study and assess their economic and financial capabilities, adopting strategic measures to apply in the required contexts. The barriers in this transition can be overcome by resolving digital security and protection issues, standardizing communication methods, and improving work organization, in addition to considering investment in research and development (Smit et al., 2016).

Some SMEs have managed to optimize their production digitally, gaining adequate capabilities for change, although for some researchers this is still not enough to compete with larger companies, given the high cost and complexity of implementing advanced technologies (Sommer, 2015).

In many European SMEs, manufacturing activities account for around 20% of jobs (Wadhwa, 2012). Therefore, it is crucial to implement Industry 4.0 in SMEs, promoting their integration into digital value chains and facilitating the implementation of specialised digital services, in addition to increasing data collection for better production control (European Commission, 2016).

Erol et al. (2016) highlight that companies face difficulties in adopting Industry 4.0 technologies, and Schumacher et al. (2016) point out problems in the practical

implementation of these technologies. This highlights the need to assess the current state of companies in relation to this issue, using models for assessing digital maturity for Industry 4.0. Proença and Borbinha (2016) define maturity as an assessment criterion that determines the current state, identifying and assessing strengths, weaknesses and opportunities. Maturity refers to the consolidation of general and specific practices into predefined processes that improve the overall performance of a specific objective, company, or other domain of interest (de Souza & Gomes, 2015). Lichtblau et al. (2015) state that maturity models highlight some obstacles to the successful implementation of Industry 4.0 in industrial companies, especially in SMEs.

In view of these challenges, maturity and assessment models become essential tools to help companies adapt to the concept of Industry 4.0.

METHODOLOGY

The methodology used in this study was initially based on the selection of the most relevant and appropriate bibliographic databases for the research, namely: Web of Science (WoS) and Scopus, which are widely recognized and cited worldwide. These research platforms allow access to thousands of articles published by leading publishers, thus ensuring the quality and comprehensiveness of the bibliographic review (de Oliveira et al., 2019). The choice of these databases is crucial, as the validity of the bibliometric analysis depends directly on the quality of the information sources used.

In the second step, a detailed bibliographic survey was carried out on the principles of Industry 4.0, with a specific focus on models for assessing the level of digital maturity applicable to small and medium-sized industrial enterprises (SMEs). This step was essential to contextualize the study and identify the main trends and challenges faced by SMEs in the adoption of advanced technologies.

Finally, in the third step, the data collected from the selected databases were processed, analyzed and discussed in detail. The analysis of these data was carried out using the VOSviewer software, which allowed the mapping and visualization of the relationships between the various results obtained. This process enabled an in-depth understanding of the dynamics and patterns present in the scientific literature on Industry 4.0 and digital maturity in Small and Medium-sized Enterprises.

RESEARCH CLASSIFICATION

This article presents a bibliometric study that uses specific techniques to measure the production and dissemination rates of scientific knowledge on Industry 4.0, with a particular focus on digital maturity assessment models for SMEs. This study includes both quantitative and qualitative analysis, as illustrated in Figure 1.

PROCEDURES USED

The following procedure was adopted to obtain the sample:

- Definition of the research period;
- Identification of the research keywords;
- Selection of scientific articles;
- Conducting bibliographic research on the Web of Science and Scopus platforms;
- Obtaining the set of available data for analysis;
- Bibliographic analysis of the data obtained from the different databases;
- Visualization and mapping of the results in the VOSviewer software;

- Selection of the most relevant authors and the themes with the greatest impact;

- Interpretation and analysis of the results.

DATA COLLECTION, POPULATION AND SAMPLE

Keywords related to the topic in question were carefully selected and entered into the aforementioned databases, with the aim of obtaining the largest possible volume of relevant publications. Thus, several designations were combined in both databases, using the corresponding equations, which resulted in Search 1 in the Web of Science database (Table 1) and Search 2 in the Scopus database (Table 2).

Thus, the designations "industry 4.0", "maturity model" and "industrial SMEs" were combined with several correlated keywords for each of the searches. In both Search 1 and Search 2, the data were exported from the databases (WoS and Scopus) and organized in an Excel file, containing the following fields: Authors' names, Article/publication title, Publication year, Source title, Total number of citations, Abstracts, Author keywords, Document type, Database, Link, References and Language.

RESULTS

CHARACTERIZATION OF BIBLIOGRAPHICAL ANALYSIS

A total of 1421 publications were obtained, 431 from the WoS database and 990 from the Scopus database, as illustrated in Table 3.

In order to standardize the databases in a more coherent manner, in the first phase, in both Research 1 and Research 2, publications that did not have a Year, Title, References or Keywords were excluded, resulting in the elimination of 178 publications. In a second phase, through a detailed analysis of the Abstracts and Keywords, 1028 publications were identified that did not fit the theme in question and were therefore discarded. Subsequently, in a third phase, 38 duplicates were found and eliminated. Thus, from an initial total of 1421 publications obtained from the different databases, only 177 were considered relevant for the development of this research.

After analyzing all the titles, abstracts, keywords and, in some cases, the full article itself, only the documents that presented a clear relationship between the different models for assessing digital maturity in Industry 4.0 for Small and Medium-sized Enterprises were selected.

YEAR OF PUBLICATION

The figure 2 shows the chronological evolution of the publication of articles on this topic. The searches carried out in the WoS and Scopus databases cover the period from 2011 to 2022, since the concept of Industry 4.0 emerged in 2011. However, with regard to scientific publications in these databases on models for assessing the level of digital maturity in Industry 4.0 for SMEs, the first article was published only in 2015. Since then, there has been a growing evolution in the number of publications on this topic, with a particularly sharp increase in the last three years. In the current year of 2022, there are still many studies in the submission and publication phase, which will probably increase the total number of publications, exceeding the numbers recorded to date.

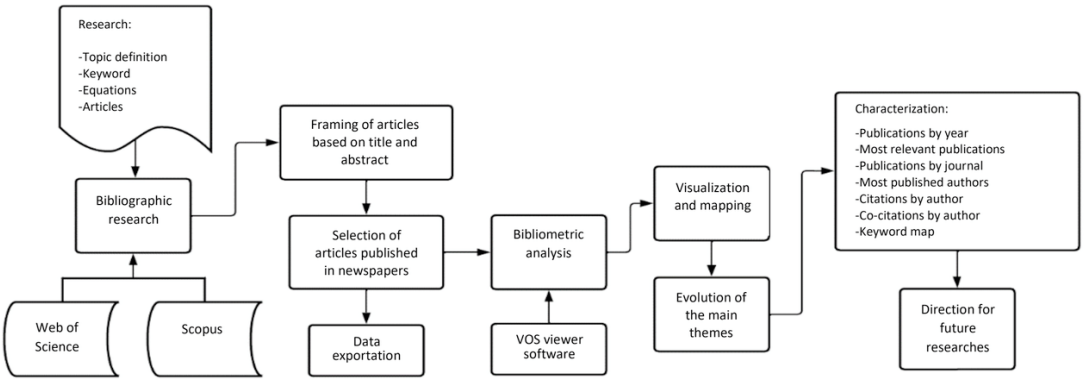

Figure 1: Flowchart of the methodology used for bibliometric research and analysis.

Keywords: Web of Science								
	TS="industry 4.0"		TS="maturity model"		TS="industrial SMEs"		Results
Research 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"		**431**

Table 1: Keyword selection research on the Web of Science platform.

Keywords: Scopus								
	TITLE-ABS-KEY "industry 4.0"		TITLE-ABS-KEY "maturity model"		TITLE-ABS-KEY "industrial SMEs"		Results
Research 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"		**990**

Table 2: Keyword selection research on the Scopus platform

				Excluded								
Research	WoS	Scopus	WoS + Scopus	Absence Year	Absence Title	Absence of reference	Abstract and keywords	WoS	Scopus	WoS + Scopus	Duplications	Total
1 e 2	431	990	1421	92	62	24	1028	74	141	215	38	**177**

Table 3: Search results: WoS and Scopus.

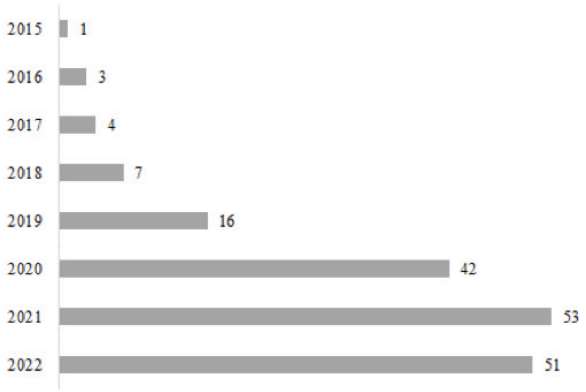

Figure 2: Year of publications with most articles.

TYPE OF MAGAZINE

In this section, it was possible to identify the main journals with the highest incidence of publications and the most influential in studies related to the assessment models of the digital maturity level of SMEs in Industry 4.0. The analysis of the various publications obtained through the WoS and Scopus databases revealed that this study focused exclusively on articles published in scientific journals. It is important to highlight the journals that contributed the most to the impact on the scientific community, which can be assessed by the impact factors available in these databases. This indicator is crucial to understand which journals lead in terms of knowledge dissemination and influence in the field of study.

The main journals that stand out with the largest number of publications on this topic are: the "*Sustainability*"; the "*Journal of Manufacturing Technology Management*"; the "*Technological Forecasting and Social Change*"; the "*Applied Sciences (Switzerland)*"; the "*International Journal of Innovation and Technology Management*"; the "*International Journal of Production Economics*"; among others, as illustrated in Figure 3.

MOST RELEVANT PUBLICATIONS IN RECENT YEARS

The aim of this subsection is to gain a deeper understanding of the most influential articles in the literature over the last few years. The ranking of published articles was compiled based on the analysis of citations in the different databases, WoS and Scopus, as illustrated in Table 4. However, all articles were read in full to ensure that their content is aligned with the theme of this study. The list includes the 10 most relevant articles from the last few years, focused on the thematic area of assessment models for the digital maturity level of industrial SMEs in Industry 4.0. These articles stand out for their significant contribution to the advancement of knowledge and practice in this area, serving as a fundamental reference for researchers and practitioners.

Frank et al. (2019) proposed a layered framework for Industry 4.0 technology, highlighting the different levels of adoption of these technologies and their implications for industrial firms. Müller et al. (2018) outlined a qualitative approach to understand the implications of Industry 4.0 along the value chains of industrial SMEs, facilitating the assessment of companies' digital maturity by managers. Bibby and Dehe (2018) developed an assessment model that measures the level of implementation of Industry 4.0 around three dimensions: "Factory of the Future", "People and Culture" and "Strategy".

Ghadge et al. (2020) analyzed the impact of Industry 4.0 implementation on the supply chain of industrial firms and developed a model to validate the successful implementation of these technologies. Kamble et al. (2020) studied the performance metrics relevant to the assessment of small and medium-sized enterprises' investments in Industry 4.0 enabling technologies. Brozzi et al. (2020) presented evidence that industrial companies

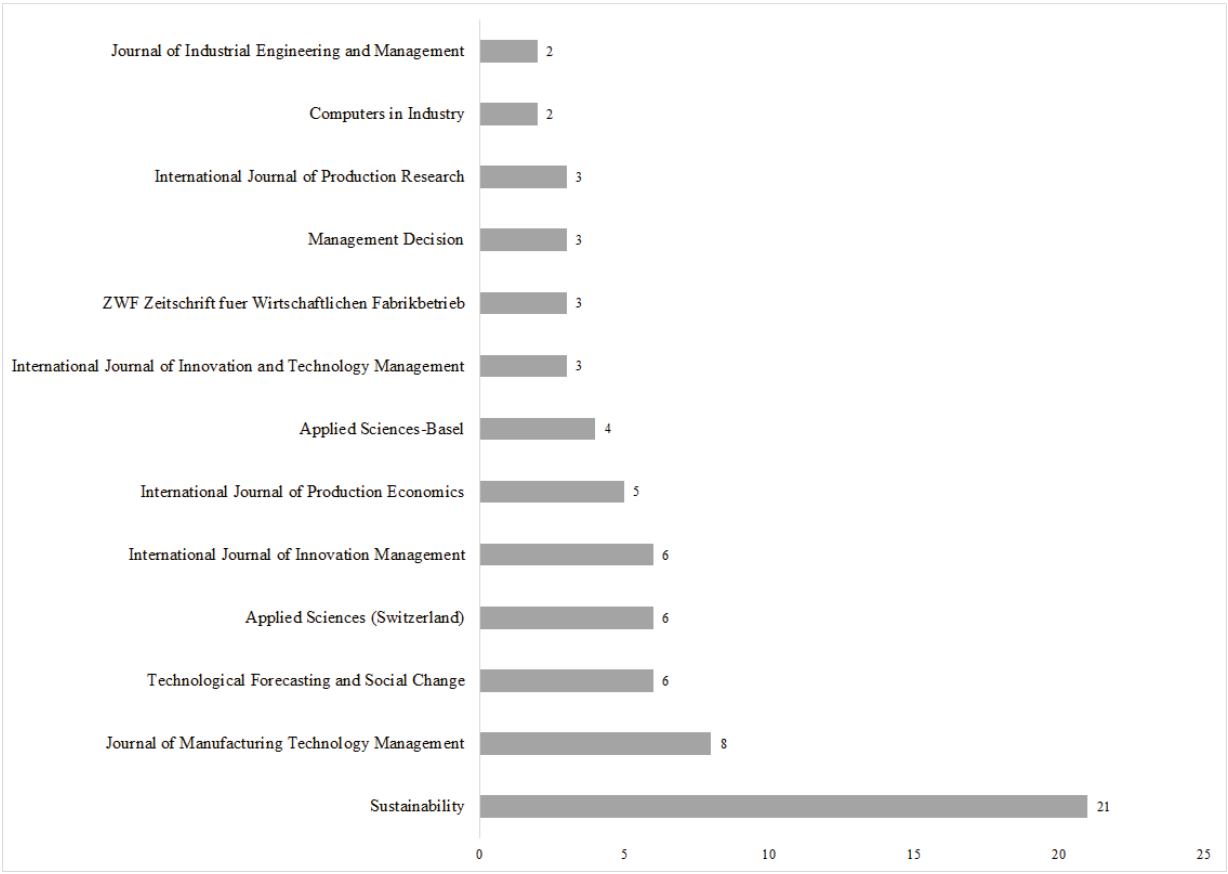

Figure 3: Publications of articles by journal.

Ranking	Author	Year	Title	Quotes
1	Frank A.G., Dalenogare L.S., Ayala N.F.	2019	"Industry 4.0 technologies: Implementation patterns in manufacturing companies".	887
2	Müller J.M., Buliga O., Voigt K.-I.	2018	"Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0".	484
3	Bibby L., Dehe B.	2018	"Defining and assessing industry 4.0 maturity levels–case of the defence sector".	153
4	Ghadge A., Er Kara M., Moradlou H., Goswami M.	2020	"The impact of Industry 4.0 implementation on supply chains".	132
5	Kamble S.S., Gunasekaran A., Ghadge A., Raut R.	2020	"A performance measurement system for industry 4.0 enabled smart manufacturing system in SMMEs- A review and empirical investigation".	104
6	Brozzi R., Forti D., Rauch E., Matt D.T.	2020	"The advantages of industry 4.0 applications for sustainability: Results from a sample of manufacturing companies".	67
7	Mittal S., Khan M.A., Purohit J.K., Menon K., Romero D., Wuest T.	2020	"A smart manufacturing adoption framework for SMEs".	63
8	Pirola F., Cimini C., Pinto R.	2020	"Digital readiness assessment of Italian SMEs: a case-study research".	56
9	Santos R.C., Martinho J.L.	2020	"An Industry 4.0 maturity model proposal".	51
10	Rauch E., Unterhofer M., Rojas R.A., Gualtieri L., Woschank M., Matt D.T.	2020	"A maturity level-based assessment tool to enhance the implementation of industry 4.0 in small and medium-sized enterprises".	29

Table 4: Publication of more relevant articles.

consider the implementation of Industry 4.0 to be an advantage for environmental protection and social sustainability.

Mittal et al. (2020) explored the needs and challenges faced by SMEs in integrating Industry 4.0, identifying the difficulty these companies have in evaluating their own structures. Pirola et al. (2020) developed an appropriate model to assess the level of digital maturity of industrial SMEs in the context of Industry 4.0. Santos and Martinho (2020) created a tool to assess the level of maturity of industrial companies in implementing Industry 4.0 concepts. Rauch et al. (2020) also contributed with an assessment model so that SMEs can measure their level of implementation in Industry 4.0. These studies are essential to understanding the current state and challenges of SMEs in the transition to Industry 4.0, providing models and tools that facilitate this transition and help companies position themselves competitively in the global market.

CHARACTERIZATION OF BIBLIOMETRIC ANALYSIS

AUTHORS WHO HAVE PUBLISHED THE MOST

From the results obtained through bibliometric analysis, in a universe of 449 authors, Müller, J., Rauch, E., Zhang, J., Marcon, E. and Ghadge, A. stand out as the main researchers who publish the most on this topic. However, it is important to note that the number of publications per author, as illustrated in Figure 4, does not always correlate with the highest citation index.

This implies that some authors with a greater number of published articles do not appear in the top 10 citations, which may be an indicator of the differentiated relevance and impact of their work.

On the other hand, some authors with few publications may have highly cited works, indicating the quality and importance of their specific contributions, even if they do not have a large number of articles. Figure 4, obtained through analysis with VOSviewer, reveals that the most prolific authors are located near the center of the map, which denotes the centrality and influence of these authors in the publication network on digital maturity assessment models in Industry 4.0 for SMEs. This visualization helps to understand the dynamics of publications and to identify the main contributors to the field of study.

QUOTES BY AUTHOR

The criterion for inclusion in the bibliometric data was defined as a minimum of one article and one citation per author. Among the 449 authors analyzed, only 331 met this requirement.

Müller is the author with the largest number of published articles (6 articles), being cited 818 times, which places him in fourth position among the most cited authors. On the other hand, Frank, with only 4 published articles, is the most cited author worldwide on this subject, accumulating 1080 citations in the WoS and Scopus databases. Ayala, occupying the second position, has 2 published articles and 1033 citations. Dalenogare, with only one published article, is the third most cited author, with 887 citations. These data are displayed on the citation density map by author, obtained through VOSviewer, as illustrated in Figure 5.

These results show that the number of publications is not always directly related to the number of citations, which may indicate that some works, even in smaller numbers, have a significant impact on the field of study. Citation analysis helps to identify the authors whose contributions are most influential and recognized by the scientific community.

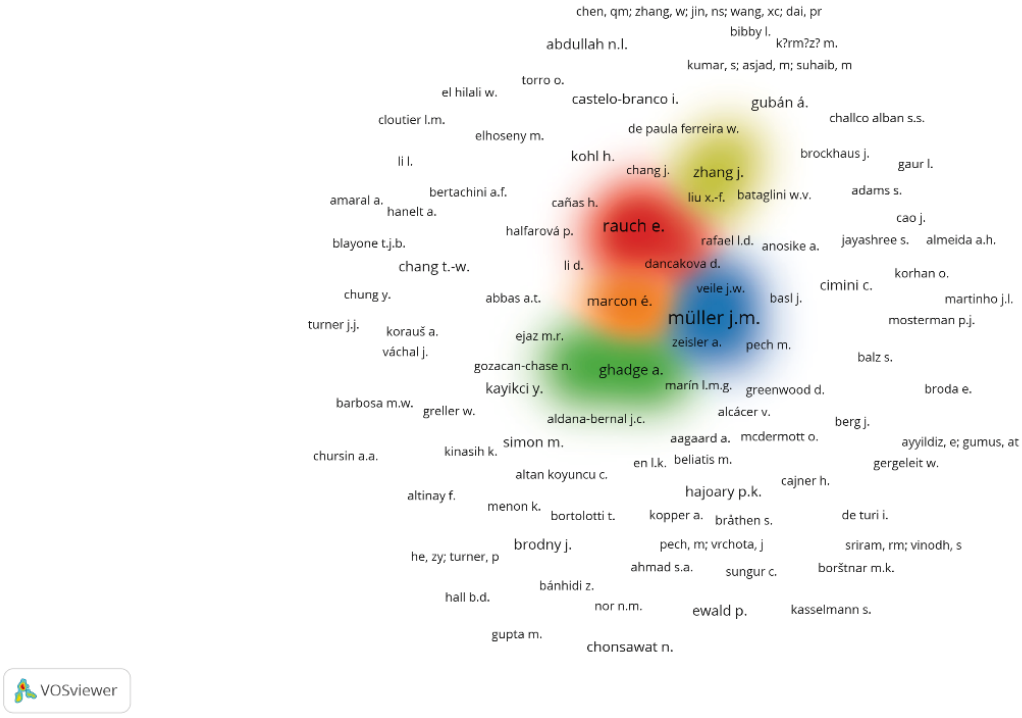

Figure 4: Map of authors who published the most obtained by VOSviewer.

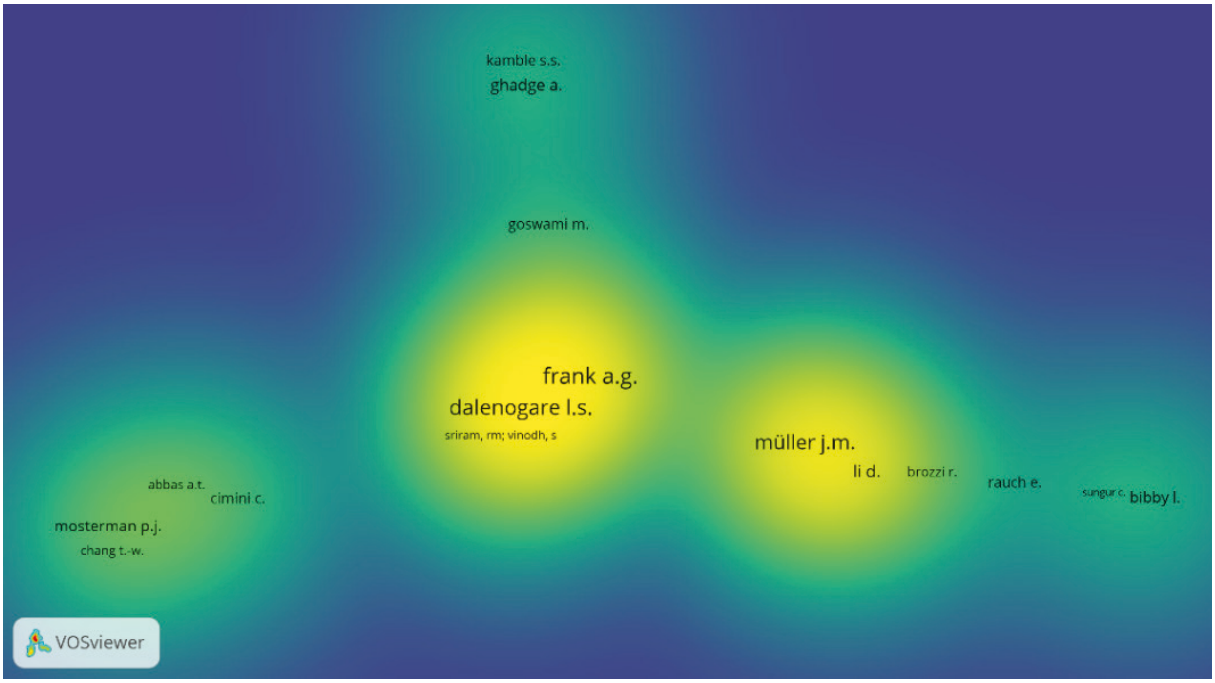

Figure 5: Citation density map by author obtained by VOSviewer.

Of the 331 main authors who have at least one article and one citation in our database, only 32 are interconnected, as illustrated in Figure 6. This low number of connections and citations can be explained by the relative novelty of the topic related to models for assessing the level of digital maturity of SMEs in Industry 4.0. In addition, the citations counted are limited to the WoS and Scopus databases, which may restrict the visibility and recognition of the works.

Despite this, authors such as Frank, A., Müller, J., and Dalenogare, I. stand out, as they are the most cited and considered the most influential in the study of this topic between 2018 and 2020. These authors serve as a reference for other subsequent works, developed by researchers such as Marcon, E., Mosterman, P., Chang, T., Li, D., and Bibby, I., among others. These studies are essential for the continued development of the field and reflect the growing importance of research on digital maturity in Industry 4.0 for SMEs.

CO-CITATIONS BY AUTHOR

We identified 83 co-cited authors, each with at least 20 co-citations, i.e., these 83 authors are co-cited at least 20 times in conjunction with other works.

The figure 7 highlights the most frequently used references, organized into different co-citation clusters. These references are frequently cited together, indicating that when an article cites an author, it is common for other articles to also cite other related authors, creating a co-citation network that reflects the predominant lines of thought in the field. This makes these authors key reference points in the co-cited studies.

The analysis presented in Figure 7, obtained through VOSviewer, highlights four main clusters, each showing the number of co-citations per author. For example, in the cluster located on the right, the authors with the highest number of co-citations include Schumacher, A., Romero, D., Wuest, T., Sihn, W., Erol, S., and Schuh, G. On the other hand, on the left side of the map, it is possible to see that the authors Frank, A. and Gunasekaran, A. are highlighted for having a high number of co-citations. These clusters illustrate the interconnection and influence of the works of these authors in the area of studies on digital maturity and Industry 4.0 for SMEs.

The co-citation density map by author, presented in Figure 8, allows us to analyze the works of the most co-cited authors. Among the 83 authors identified, each one is co-cited at least 20 times. Among them, the authors Müller, J., Frank, A., Schumacher, A., Sihn, W., and Romero, D. stand out, as they are among the most frequently co-cited. This density map provides a clear visualization of how these authors are interconnected in the literature, showing the relevance and influence of their works in the study of digital maturity in Industry 4.0 for SMEs.

CO-OCCURRENCY OF KEYWORDS

By analyzing the keyword map, shown in Figure 9, it is possible to identify the words most frequently used in the titles, abstracts and keywords of the articles in our database, appearing in at least two articles. As illustrated in Figure 9, each keyword is represented by a circle, the size of which corresponds to the frequency of use of that word in the articles published on the topic under study. The larger circles indicate the most common keywords, reflecting the most discussed and most relevant topics in research on digital maturity in Industry 4.0 for SMEs. This visualization helps to identify the predominant trends and focuses in the current literature. It is clearly visible that the word "industry 4.0" is present in the majority of publications, followed by the word: "*digital transformation*", "*smes*", "*implementation*", "*readiness*", "*digital maturity*

International Journal of Exact Sciences ISSN 2966-1153 DOI https://doi.org/10.22533/at.ed.153112401072

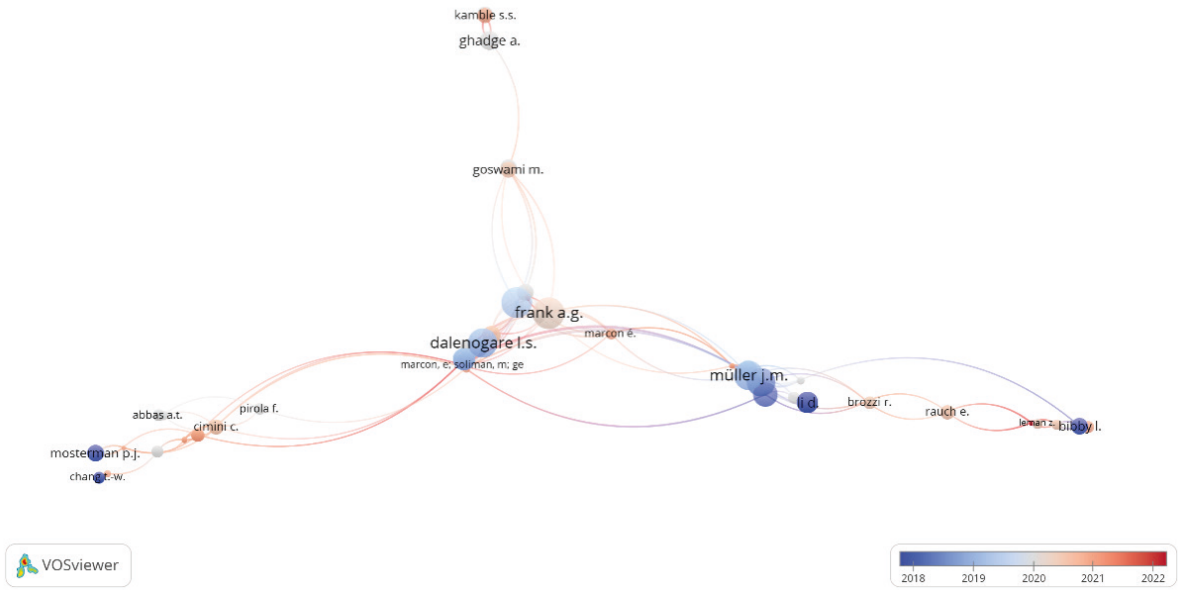

Figure 6: Citation map by author obtained by VOSviewer.

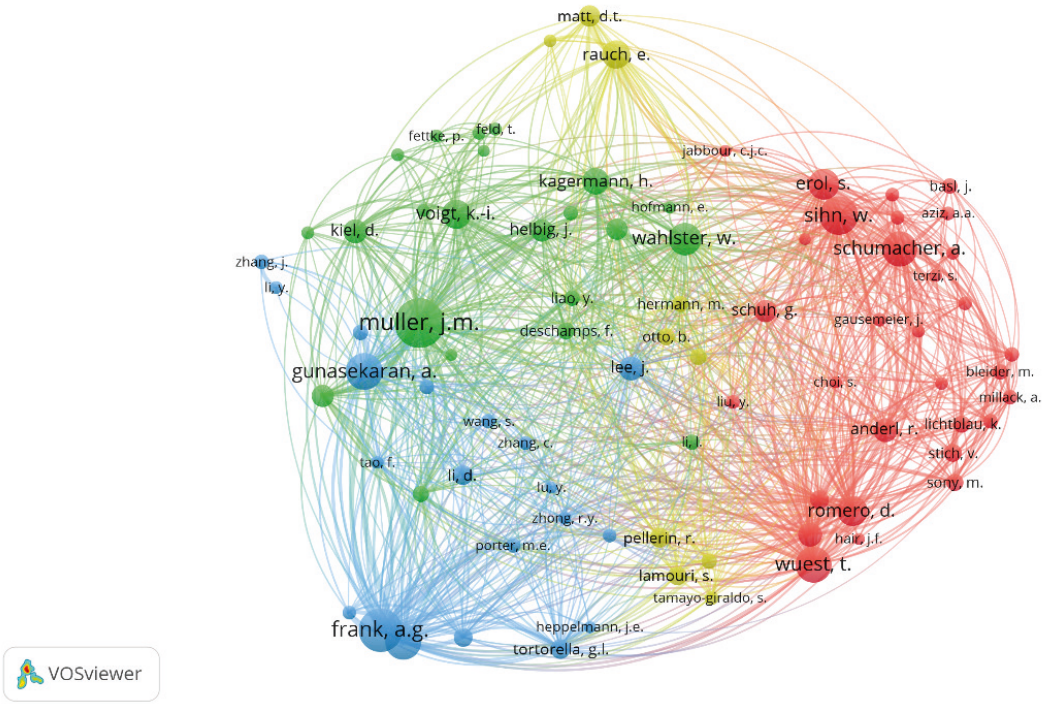

Figure 7: Co-citation map by author obtained by VOSviewer.

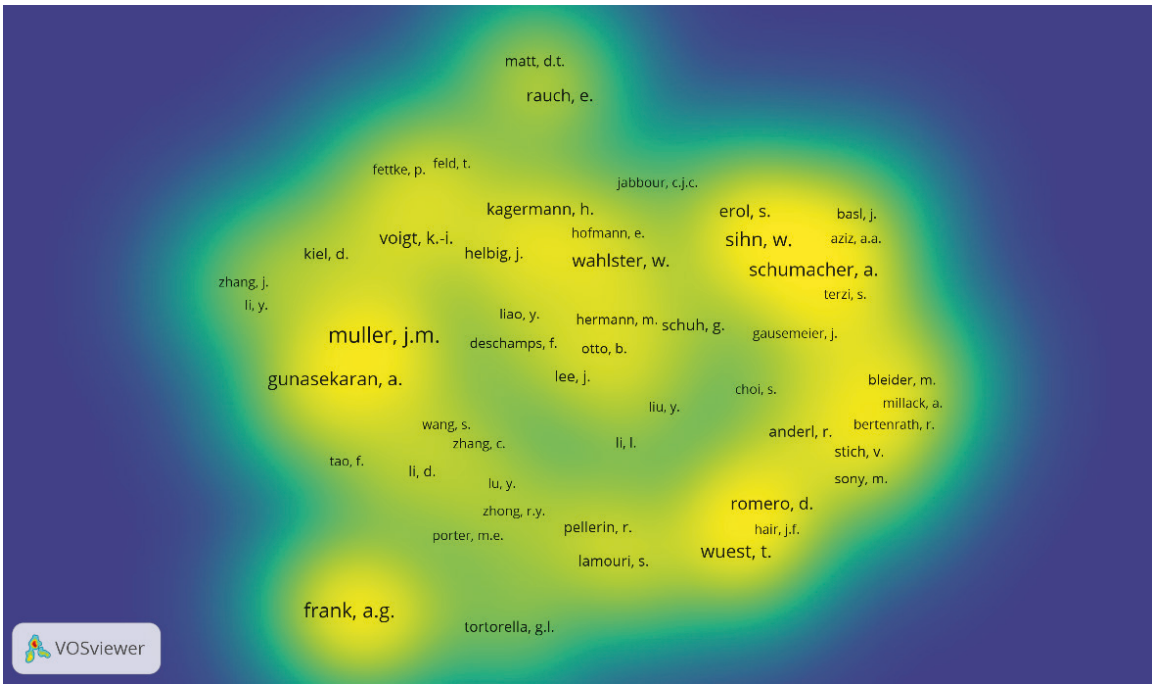

Figure 8: Co-citation density map by author obtained by VOSviewer.

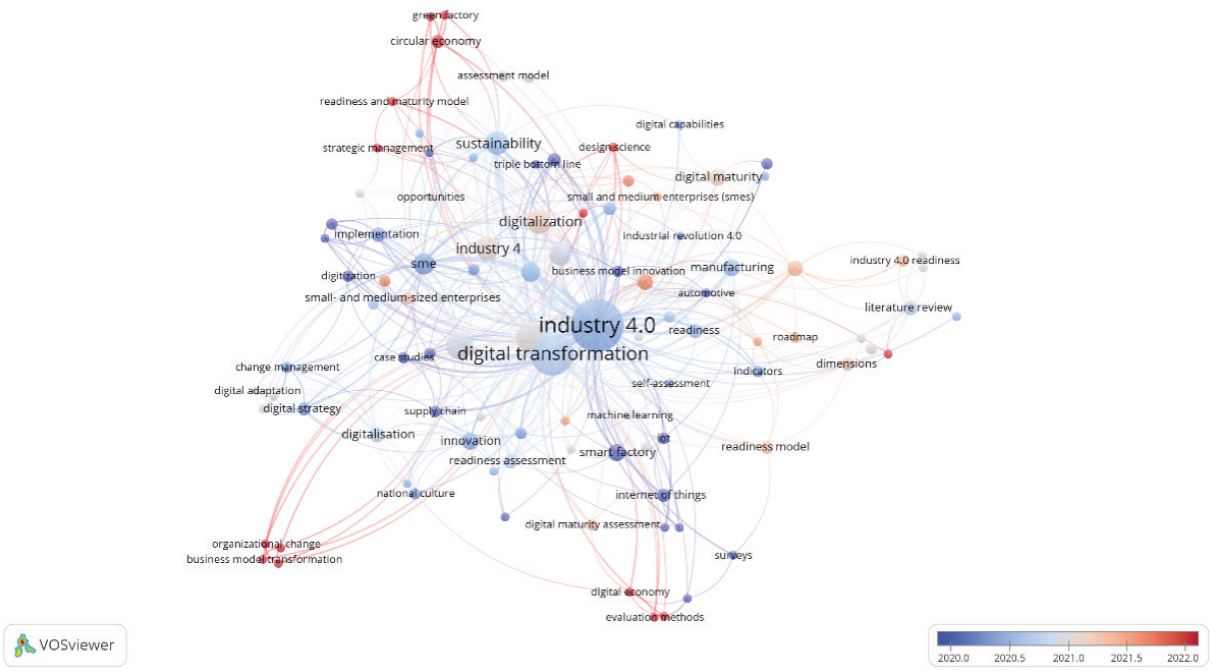

Figure 9: Keyword map obtained by VOSviewer.

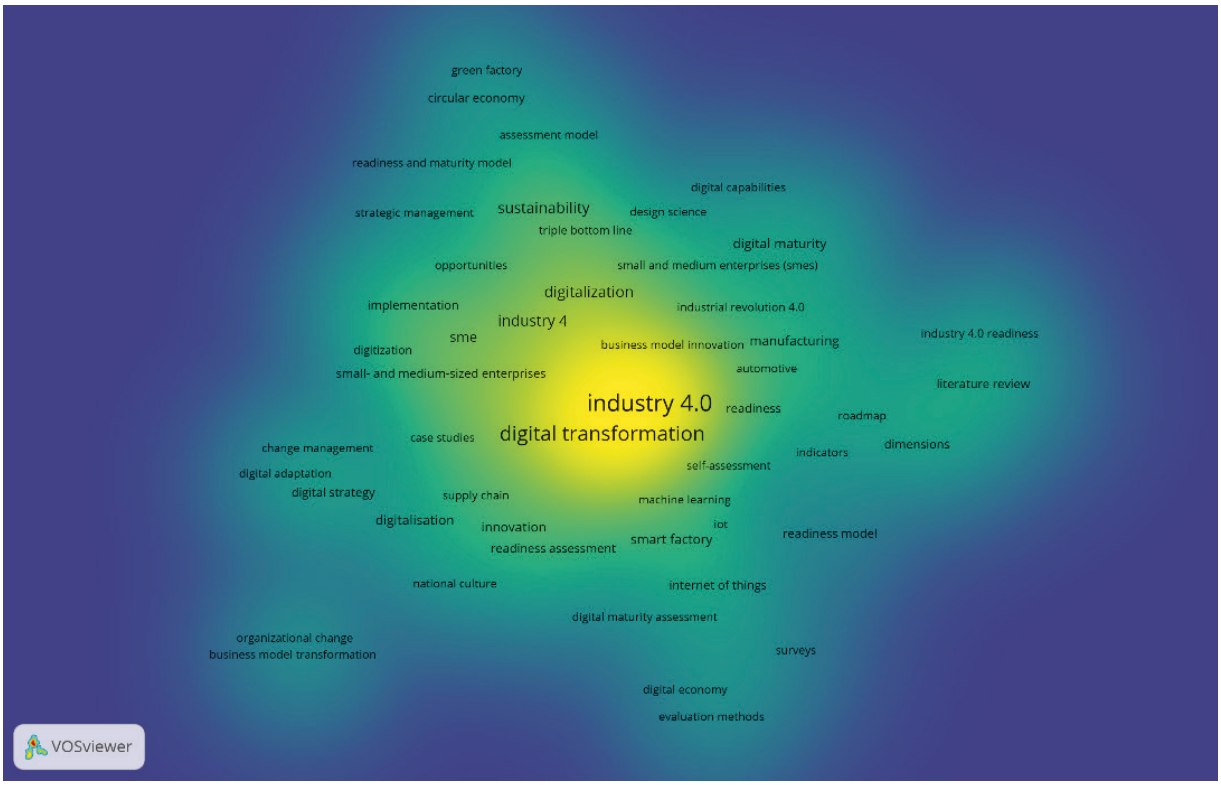

Figure 10: Keyword density map obtained by VOSviewer.

assessment" "*business model*", "*sustainability*", "*manufacturing*", "*smart factory*", among others.

In the keyword density map, presented in Figure 10, it can be seen that the most frequently used words in publications are "industry 4.0" and "digital transformation". On the other hand, specific keywords related to the scope of this study, such as "maturity models", "digital maturity" and "Small and Medium Enterprises" still have a relatively low frequency of use.

This indicates that there are fewer publications directly addressing the correlation between these terms. This scenario suggests an opportunity to deepen and expand the literature on the assessment of digital maturity in SMEs ("Small and Medium Enterprises") in the context of Industry 4.0, highlighting the need for more studies and publications focused on these specific areas.

CONCLUSION

The results showed that research on models for assessing the digital maturity levels of SMEs in Industry 4.0 has been growing significantly since 2019, with a tendency to continue to increase. This increase reflects a growing interest in the exploration and application of these tools in small and medium-sized companies.

The bibliometric analysis, carried out with the help of the VOSviewer software, facilitated the creation of maps and the extraction of information from the WoS and Scopus databases. This analysis allowed the construction of networks of scientific publications, identification of the most relevant journals, most cited authors, and the most used keywords.

The results indicate that the existing literature is relatively recent, but is growing exponentially, with a continuous upward trend. The analysis revealed that research

is increasingly focused on the impact of the adoption of digital technologies on business strategies, highlighting innovation in business models, global value chains, collaboration and performance, in addition to digital maturity models.

This study identified significant relevance in publications on models for assessing the level of digital maturity for Industry 4.0 in small and medium-sized enterprises (SMEs).

For future research, it is recommended to focus on the relationship between the different digital maturity models and understanding the impact of these models on the performance of SMEs. In addition, it would be valuable to conduct a bibliometric analysis using other reference databases to complement the findings and expand the understanding of the state of the art in this research area.

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