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Article

The landscape of Industry 4.0 and business model innovation: A scientometric analysis of research trends and emerging patterns

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Abstract: In Industry 4.0, the business model innovation plays a crucial role in enabling organizations to stay competitive and capitalize on the opportunities presented by digital transformation. Industry 4.0 is driven by digitalization and characterized by integrating various emerging technologies. These technologies can potentially change traditional business models and create new value propositions for customers. This paper aims to analyze and review the research papers through a bibliometric approach scientifically. The data were extracted from reputable Clarivate Web of Science (WoS) Core Collection sources from 2010 to 2023 (June). However, the publication started in 2018 for the research fields. The results show that scientific publications on research domains have increased significantly from 2020. VOSviewer, R Language, and Microsoft Excel were utilized for analysis. Bibliometric and Scientometric approaches conducted to determine and explore the publication patterns with significant keywords, topical trends, and content clustering better discussions of the publication period. The visualization of the data set related to research trends of Industry 4.0 in relation to Business Model Innovation resulted in several co-occurrence clusters namely: 1) Business Model Innovation; 2) Industry 4.0; 3) Digital transformation; and 4) Technology implementation and analysis. The study results would identify worldwide research trends related to the research domains and recommendations for future research areas.

Keywords: business model innovation; Industry 4.0; bibliometric; scientometric; co-word analysis; content analysis; web of science

1. Introduction

The advent of Industry 4.0 underscores the significance of business model innovation in promoting organizational competitiveness and harnessing the potential offered by digital transformation. The traditional business models suitable for Industry 3.0 have encountered some challenges, now entering Industry 4.0, new business models are needed to adapt to the business environment of the new era. As a paradigm shift characterized by digitalization, Industry 4.0 integrates technologies such as the internet of things, big data analytics, artificial intelligence, and cloud computing. These technological advancements have the ability to disrupt traditional business models while simultaneously creating novel value propositions for customers. Additionally, by digitizing physical assets and integrating them into digital ecosystems, Industry 4.0 enables collaboration opportunities and co-creation within value chains. Therefore, it is imperative for organizations to adopt a creative approach in reassessing their current business models in order to explore novel strategies that successfully use digital technology and take full advantage of the abundant opportunities presented in this new era. The utilization of digital technologies of Industry 4.0, the internet of

things, and big data is leading to significant transformations in the operations and procedures of enterprises. These transformations profoundly impact how companies generate, distribute, and obtain value (Mariani et al., 2023). Nevertheless, despite significant financial commitments towards digital transformation, organizations frequently have difficulties effectively leveraging the advantages, leading to a phenomenon known as the digital dilemma (Ancillai et al., 2023). In the era of Industry 4.0, enterprises need to adapt to the diversified transformation content.

Organizations should maintain their ability to innovate and be competitive in today's fast-evolving market landscape; it is vital to increase the relation between their business models and Industry 4.0 strategies in parallel with business opportunities. They have a tremendous opportunity to enhance operational excellence, increase efficiency, and create more valuable products and services for their customers while implementing the Industry 4.0 initiatives. Those initiatives emphasize process automation, data interchangeability, effective management of massive data, and intelligent technology selection and utilization. Moreover, to fully realize the growth potential in the business environment, business structures will need to be modified in accordance with the necessary drivers of business approaches. In addition, they can successfully embrace the technical breakthroughs that are already available for the development areas.

There are essential innovative business aspects to be considered while the alignments processed with industry 4.0, such as data is the crucial element for any business; therefore, the decision-making process should improve with all types of data management perspective, efficiency in process management also reduces the cost, in this manner predictive maintenance and analysis minimize the downtime and keep operations smooth. Innovation for services and products should always be the target point to reach a high level of provision, commitment, and customized outcomes. Industry 4.0 also ensures that sustainability and resource optimization are critical in business success, producing environmental impact by doing the right things within proper business models that result in the economical use of the sources. Moreover, customized products and services enhance the unique customer experience and relations in a positive manner; this is the result of the competitive advantage in any market to be turned into successful business models and achievements.

Having better adaptation of Industry 4.0, organizations act for investing the right technologies, this step is of course vital at the beginning. However, following the business models should also be data-driven, customer-centric, adaptable with all the various technology perspectives, robustness, etc.

The primary goal of this research project is to explore the current knowledge requirements by conducting a thorough examination and evaluation. This statement underscores the significance of various enterprises in capitalizing on the prospects brought forth by the fourth industrial revolution. The outcomes of this study provide valuable insights for both the academic and industrial sectors. This study establishes a basis for future research on the digital transformation of manufacturing by evaluating the existing body of literature.

Researchers can utilize the identified theoretical and methodological approaches as a starting point for their investigations. Overall, this systematic approach offers a broader view of the current degree of digital transformation we are currently a part of.

It provides researchers with a foundation for further exploration, highlights areas for future research, and highlights the benefits and opportunities associated with embracing digital technologies. In other words, this study provides a systematic review of bibliometric data to analyze two study areas: "Industry 4.0 and business model innovation".

Furthermore, the purpose of this study is to identify and investigate the various research streams that pertain to Industry 4.0 in connection to business model innovation that are published in academic journals. Both bibliometric co-word and content analyses were used by the authors. In order to conduct the analysis of the research keywords, this study made use of the Web of Science Core Collection database. In light of this, the research questions have been constructed thoroughly:

(RQ1) What are the most occurred keywords?

(RQ2) What are the key trends in word dynamics for the research field?

(RQ3) What main themes and contents in the current state of the dataset?

The paper is structured as following: Research Methodology is explained in Section 2; descriptive bibliometric findings, co-word, and thematic content analyses in Results and Analysis Section 3; implications, and suggestions for future research along with discussions are presented in Section 4 as Discussion and Conclusion parts.

2. Research methodology

2.1. Research design

"Bibliometrics" refers to a statistical methodology utilized for examining bibliometric publication data across diverse academic platforms, encompassing peer-reviewed journal articles, books, book chapters, conference proceedings, periodicals, review papers, and associated reports. In addition to bibliometric tools, several analysis methods can be employed in a literature review. This approach facilitates a more profound and all-encompassing understanding of a specific field of study and the patterns observed in its scholarly literature.

To perform the search strategy in the defined database, we conducted an approach which is supported by the literature as follows: "1) selecting the database, 2) obtaining the keywords for search strings that are relevant to our research domains, 3) screening the initial findings of results of materials, 4) removing the unnecessary or unrelated publications (exclusive criteria), 5) having identified most relevant keywords, titles, and abstracts for co-word analysis by using text mining, 6) clustering the data set for content analysis and discussing the findings of clusters accordingly" (Kulakli and Arikan, 2023; Kulakli and Shubina, 2020a; Moreno-Guerrero et al., 2020).

2.2. Data collection and search strategy

Our study investigates the relationship between Business Model Innovation and Industry 4.0 by accessing the Clarivate Web of Science Core Collection, which papers indexed in, specifically the Science Citation Index Expanded (SCI-EXP) and the Social Sciences Citation Index (SSCI). This analysis focuses on Business Model Innovation within the context of Industry 4.0. The study focused exclusively on Web

of Science (WoS) articles, which is widely recognized as the primary database for collecting and examining scientific literature (Van Nunen et al., 2018).

To construct the search strategy, the strings used as of ([TOPIC] "industry 4.0" OR "I4.0") AND ([TOPIC] "business model innovation"). The findings were 70 publications in "ALL" categories, and the period was 2010–2023; however, the publications started in 2018. The exclusive language criteria as "English" applied and resulted in 69 publications. Further, the "paper title", "abstracts", and "keywords" were screened for all initial findings. Two records removed from the data set, and the final documents resulted in 67 peer-reviewed journal articles.

2.3. Procedure of data analysis

To investigate concerns pertaining to research on the intersection of Industry 4.0 and Business Model Innovation, we employed bibliometric Co-Word and Content analyses within the realm of research domains. Our analysis focused on publications from 2018 onwards, as the study of Industry 4.0 with business model innovation represents an emerging and expanding research area that has gained significant interest in recent academic journal publications. The process of co-word analysis was performed utilizing the help of the R programming language, explicitly employing text mining and bibliometric programs. A relevant dataset was extracted for additional analysis in Microsoft Excel for descriptive. Concurrently, the ultimate dataset underwent analysis using VOSviewer to facilitate data visualization and content analysis clustering. Comprehensive literature research was also utilized to examine the findings pertaining to cluster themes thoroughly. Following previous scholarly research (Faraji et al., 2022; Galletta et al., 2022; Kulakli and Shubina, 2020a; Kulakli and Shubina, 2020b; Li et al., 2020), the utilization of co-word and social network analysis, along with clustering techniques, is employed to delineate the conceptual framework within research areas.

Consequently, the authors comprehensively examined all publications, beginning with thoroughly analyzing the title and abstract. This was followed by meticulously evaluating each paper's introduction, findings, conclusions, and debates. The program was utilized to assist in identifying and selecting content analysis results, explicitly focusing on the topicality of clusters to determine their relevance to study domains.

3. Results and analysis

3.1. Descriptive findings

The research results were reported that scientific production on the industry 4.0 in relation to Business Model Innovation research field have 67 records in the Web of Science (WoS) Core Collection database. All of the papers are written in English language. The descriptive findings of the publications depicted that most of them corresponded to peer-reviewed journal articles (45/67, 67.16%), followed by review articles (17/67, 25.37%) and early access (5/61, 8.19%). The top four publishers among nine are Elsevier (n = 27), MDPI (n = 21), Emerald Group Publishing (n = 7), Springer Nature (n = 4). Its beginnings date back to 2018. From that year until June

2022 production has increased steadily. From 2021 to 2022, the publication counts tripled, showing a dramatic increase in the published results.

WoS Core Collection subject category data set is used to categorize the related research domains under the top five major subjects of 24 in total, comprising topics with at least 10 publications as follows: Business (n = 30), Environmental Sciences/Environmental studies (n = 16 each), Green Sustainable Science Technology/Management (n = 15 each) and Regional Urban Planning (n = 10). There are 31 publication sources in the data set. The most productive Journals are Sustainability (n = 13), Technological Forecasting and Social Change (n = 9), Journal of Business Research (n = 7), Industrial Marketing Management (n = 4), Energies/Journal of Business Industrial Marketing (n = 3 each), Business Strategy and the Environment/IEEE Access/Journal of Cleaner Production/Processes and Production Planning Control (n = 2).

Table 1. Descriptive findings.

Descriptive Statistics about Dataset	**Results**
Timespan	2018:2023
Sources (Journals, Books, etc)	31
Annual Growth Rate %	47.58
Document Average Age	1.54
Average citations per doc	39.7
Keywords Plus (ID)	235
Author's Keywords (DE)	234
Authors	234
Authors of single-authored docs	2
Co-Authors per Doc	3.81
International co-authorships %	46.27
Document Types	
Article	45
Article; early access	5
Review	17

There are 234 authors/co-authors in **Table 1** from 39 countries leading Italy, Germany, England, Sweden, France, People R. China, Spain, and the remaining 32 countries. 144 institutions worldwide contributed to the domain fields. The most productive organizations with ($n \geq 3$) publication count as listed following Parthenope University Naples, University of Erlangen Nuremberg, University of Padua, University of Urbino, Linkoping University, Lulea University of Technology, and University of Bologna. The citations report of the 67 publications in **Figure 1** derived from the WoS Core Collection statistics between 2018 and 2023 (until June) showed that the average number of citations per item is 40.69. The total cited paper in that period is 2848 in **Figure 1** and H-index is 21. The top ten publication's citation count is 2145 (average n = 45.1 per item).

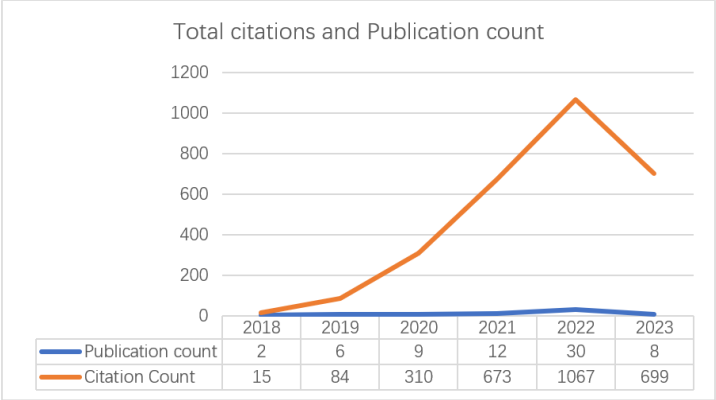

Figure 1. Total citations and publication count.

3.2. Co-word analysis

Callon et al. (1986) introduced the co-word analysis technique in 1986, Researchers have used co-word analysis to identify trends in the bibliometric structure of several fields (Kulakli and Arikan, 2023; Kulakli and Shubina, 2020a). Therefore, co-word analysis has been recognized as an effective text mining and theme content analysis technique (Malacina and Teplov, 2022). The articles may be more closely related and correlate more strongly if keywords frequently appear together (co-occurrence) (Su and Lee, 2010; Aria and Cuccurullo, 2017).

The frequency of the keywords in records are revealed with co-word analysis. "Author Keywords" and "Keywords Plus" are the main two types of attributes for bibliometric research. "Author keywords" are the phrases that authors choose to use for their works, and "Keyword Plus" also contains terms from the pre-set list of linked research fields that the editorial specialists of Web of Science journal developed.

Table 2 displays the most relevant key terms that occurred in publications related to the industry 4.0 and Business Model Innovation domains. The keyword distribution resulted as Keyword Plus (ID) (n = 235) and Author's Keywords (DE) (n = 234). The most frequent Author Keywords included "industry 4.0", "digital transformation", "business model innovation", "digital servitization", and "digitalization". The most frequent Keyword Plus terms included similarly "business model innovation", "industry 4.0", "framework", "future", "big data", and "technologies/technology".

Table 2. Top 10 keywords.

	Author Keywords (DE)	Occurrences	Keyword Plus (ID)	Occurrences
1	industry 4.0	39	business model innovation	41
2	digital transformation	16	industry 4.0	28
3	business model innovation	13	framework	17
4	digital servitization	11	future	16
5	digitalization	8	big data	12
6	sustainability	7	technologies	12
7	servitization	6	research agenda	11
8	innovation	5	technology	11
9	internet of things	5	dynamic capabilities	10
10	manufacturing	5	internet	10

A "word cloud," frequently referred to as a "tag cloud," is a visual portrayal of textual data (Li et al., 2015). The derivation of keywords might be obtained from several sources or a specific text corpus (Ravšelj et al., 2022). According to the database structure of Web of Science, four major components need to be considered when examining a word cloud. These components are the abstract, the paper's title, the author's keywords (DE), and keyword plus (ID). The focal terms and tags are highlighted, usually consisting of words or phrases that are assigned distinct font sizes and colors according to their significance and in consideration of the frequency of the textual information pertaining to the main categories. The use of bold and larger-sized words indicates the heightened significance and increasing level of interest that researchers attribute to the respective topics they pertain to (Kulakli and Birgun, 2020). In order to perform a co-word analysis and generate a word cloud that visually represents the impact of words according to their frequency in the literature, it is a frequent practice to gather both keywords from the articles inside a dataset in order to obtain a comprehensive understanding of science mapping based on search tactics (Kulakli and Shubina, 2020b; Rajagopal et al., 2017).

Figure 2 demonstrates the frequent words in each of the categories. The term "business model innovation" has the highest among the corpus text in Keyword Plus, followed by "Industry 4.0". There is not significantly higher level of notations on the word cloud, rest of the terms are very less occurrences only "future" and "framework" have higher visibility. In Author Keywords, "Industry 4.0" has shown high visibility and occurrence while "digital transformation" and "business model innovation" are shown secondary important keywords as well as "digital servitization". In paper titles and abstracts, "industry", "digital", "business" and "innovation" are common and significant attributes while "research" is higher in abstracts occurrences. Both keywords' terms show similar patterns.

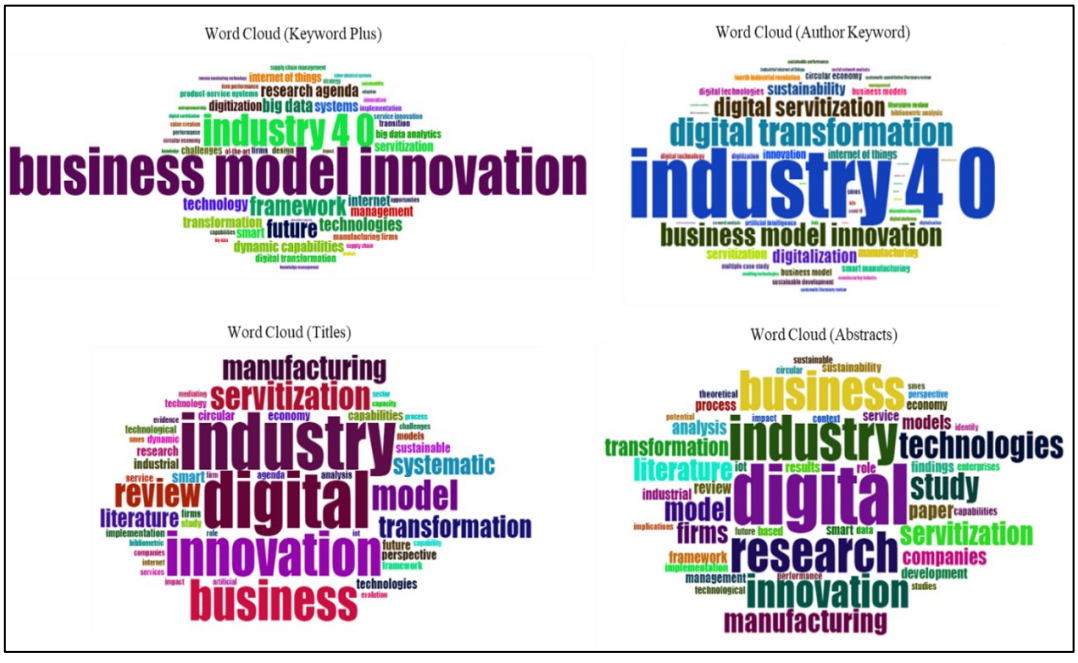

Figure 2. Word clouds.

In order to evaluate the changes in keyword usage during the study period, the most prominent key terms were employed to generate a graph depicting the increase of these terms over time, as illustrated in **Figure 3**. The repetition trend of each word, as indicated by the frequency of its occurrences in the dataset during the search process, signifies the instances of its appearance. The graph visually represents the annual distribution of keywords and provides insight into the direction of trends, whether they are moving upwards or downwards concerning the trend line. In order to analyze the trends in topic domain interest and significance within the field of research, it is possible to observe the prevalence of certain terms and keywords across a specific time frame. Identifying emerging topics in academic research is of growing relevance, as it enables scholars to concentrate on contemporary subject areas and potentially yield significant discoveries that propel these disciplines forward (Kulakli and Shubina, 2020b).

Figure 3. Word dynamics-growth.

Figure 3 demonstrates the top ten-word dynamics-growth of Industry 4.0 in relation to Business Model Innovation research fields in four different parameters (author keywords, keyword plus, title, and abstract). Although the dataset represents similar growth for all parameters, mainly the growth started from the year 2020. The "Business Model Innovation" and "Industry 4.0" show higher growth rates in the Keyword Plus, whereas "Industry 4.0" is the highest in the Author Keywords. The term "Digital", "Industry", "Business", and "Innovation" have raised the highest in Titles. The Abstract also shows similar patterns as Title. The common growth pattern for all of them starts from 2020 and rises onwards.

3.3. Content analysis

The dependable indicator of a stronger link and association among publications is commonly regarded as the frequency of keyword co-occurrence (Mohammed, et al., 2015; Rajagopal et al., 2017). According to Mohammed et al. (2015), content analysis is valuable for gathering significant topics in various study fields (Cronin and George, 2023). Relying solely on keyword analysis is insufficient for gaining a comprehensive understanding of the present intellectual structure and its intricate relationships (Kulakli and Arikan, 2023). Hence, conducting a thematic content analysis is imperative to comprehensively elucidate the interrelationships among the many sub-topics (Kulakli and Arikan, 2023; Kulakli and Shubina, 2020b). The thematic content analysis methodology was utilized to investigate the second study issue, which pertains to identifying the primary themes, subjects, and clusters that arise within the existing intellectual framework. The utilization of this approach is suitable for the examination of the classification of the chosen articles within the process of review (Birgün and Kulaklı, 2020; Khasseh et al., 2017).

To detect the intellectual structure and the relationship among the publication dataset, we conducted a cluster analysis by using thematic perspective using VOSviewer software (Sun et al., 2023). As depicted in **Figure 4**, there are four main thematic clusters from 67 articles. According to VOSviewer algorithm, the software automatically creates tag names (nodes) from Keyword Plus, Author's Keywords, Publication Titles, and Abstracts. The co-occurrence of these nodes are as follows:

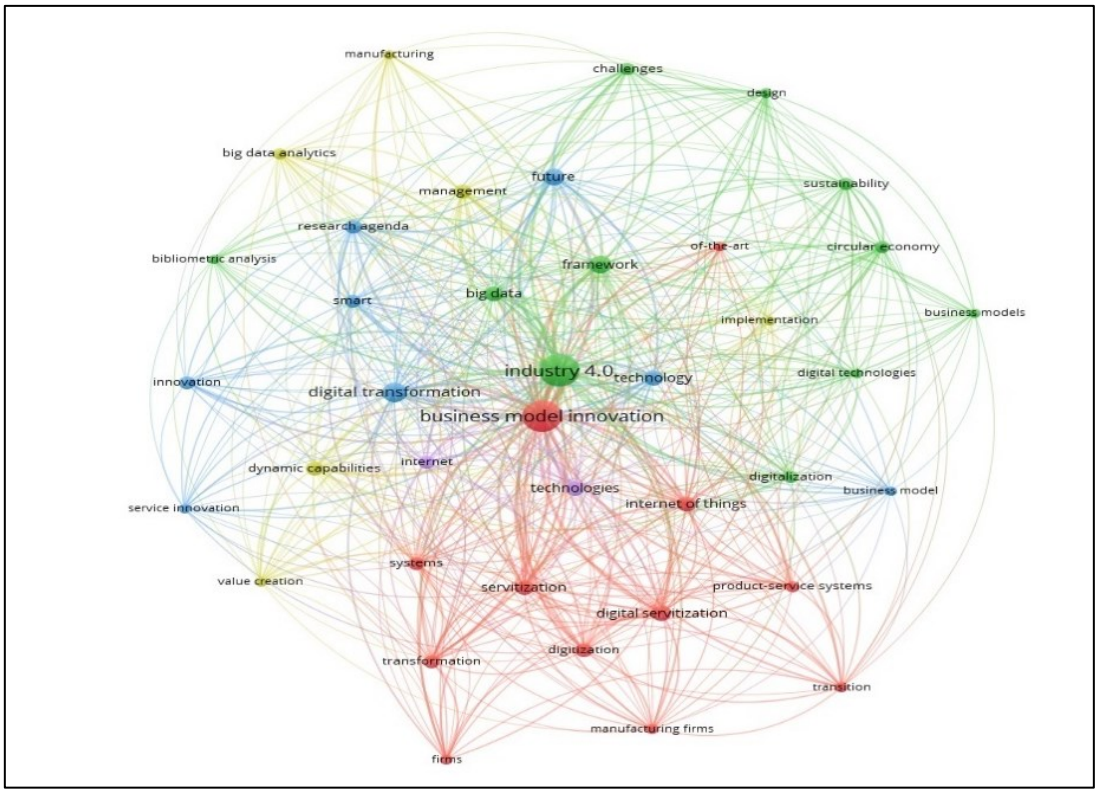

Figure 4. Thematic clusters.

235 occurrences in "Keyword Plus", 234 in "Author Keywords", 290 in "Paper Titles", and 1916 in "Abstracts". The illustration of the main thematic clusters is sorted

by relevance and different colors represented in the diagram for the industry 4.0 in relation to Business Model Innovation. The visualization of the research trends of the domains resulted in four co-occurrence clusters leading to some of the topic areas mentioned as follows: 1) Business Model Innovation, 2) Industry 4.0, 3) Digital transformation, and 4) Technology implementation and analysis.

Figure 5 shows the density visualization of the clusters to highlight their differences (based on **Figure 4**). VOSviewer provides different settings for the results to demonstrate various usages to increase clarity and the relations between research domains. In other words, items are represented by their label similarly to the network visualization (**Figure 5** left side) and the overlay visualization (**Figure 5** right side). Each point in the item density visualization has a color that indicates the density of items at that point.

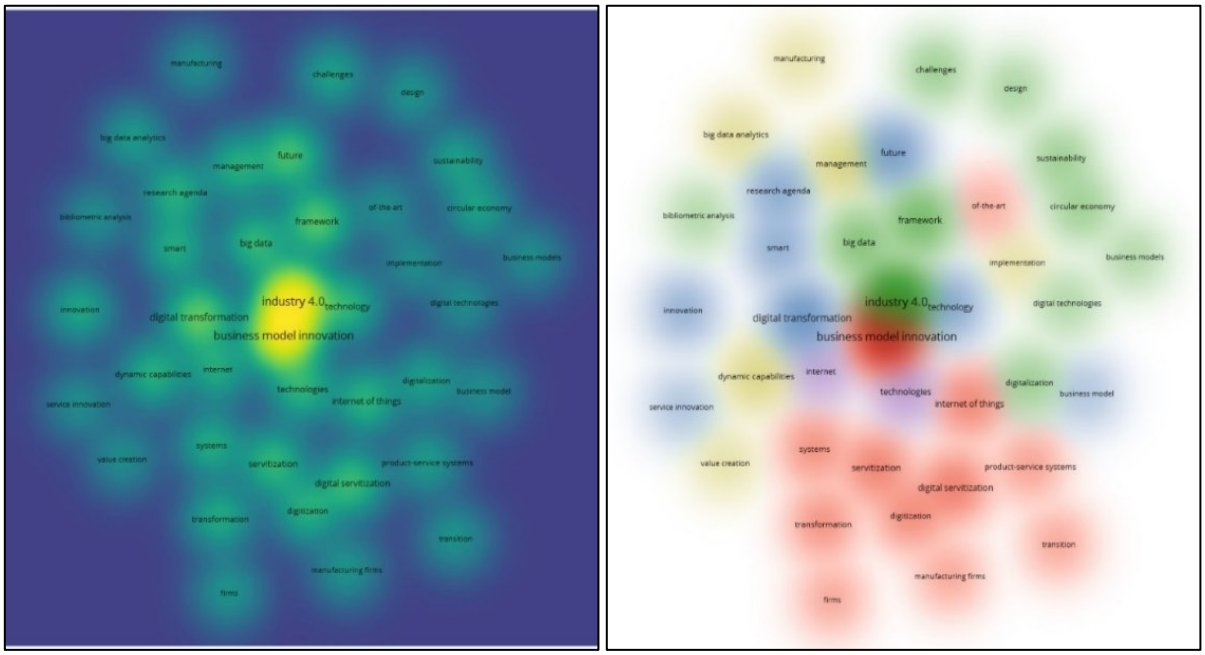

Figure 5. Density visualization for clusters.

Cluster 1: Business Model Innovation

Among the clusters, business model innovation theme has prevailed clearly and undeniably. The rise of Industry 4.0 has highlighted the significant potential of digital platforms in transforming business models and inter-company relationships, which are crucial aspects of industrial marketing (Veile et al., 2022). Current literature mostly sheds light successfully on the evolving landscape of IoT-driven business models, specifically in the context of business-to-business manufacturing firms (Marcon et al., 2022). However, it underscores the importance of adapting to service-oriented approaches and leveraging IoT technologies to create customer value (Galvani et al., 2022). Thus, there seems to be a need for tools such as a digital servitization map, which may serve as a valuable technique for firms, enabling them to strategically navigate the complexities and transformations brought about by IoT adoption (Paiola and Gebauer, 2020).

The Internet of Things (IoT) holds significant economic potential, but current revenues have not met expectations since business model innovations require not only

a technical potential but also creative implementations and executions (Gómez-Cruz et al., 2022). This is especially challenging for IoT solution providers in industrial settings, where accurately assessing the value of IoT offerings is crucial for market success (Baltuttis et al., 2022) Digitalization and digital platforms positively impact both business model innovation and the capability reconfiguration of organizations (Xie et al., 2022). They enable organizations to explore new business models and adapt their capabilities to meet the changing demands of the digital era (Szabo et al., 2020). Digital platforms have been extensively utilized in business-to-consumer industries, but their adoption in the business-to-business (B2B) sector is relatively recent (Siuta-Tokarska et al., 2022).

In order to reflect the true potential of business model innovations, scholars have extensively studied the effects of artificial intelligence (AI) on workplace outcomes, however, a comprehensive scholarly review of research regarding how AI can transform business models is lacking (Pereira et al., 2023). Industry 4.0 technologies have served business model innovation alternatives and, in this way, they have significantly enhanced the potential of servitized products, expanding the scope and responsiveness of stakeholders (Galvani and Bocconcelli, 2022). The organization of digital manufacturing is disrupted, blurring the lines between users and producers and enabling new functionalities (Schiavone et al., 2022). In the digitalized global economy, there is a growing disconnect between technology and economics, necessitating the redesign of business models (Stawiarska et al., 2021).

The implementation of Industry 4.0, undoubtedly, brings about changes to a company's business model. However, not all companies fully utilize the new technological capabilities or explore new digital revenue streams. In the market for industrial goods, subscription business models are becoming increasingly popular (Benkhati et al., 2023). While only a few companies have adopted subscription offerings in their portfolio, more companies are now considering implementing them (Burger et al., 2023). In other words, Industry 4.0 continuously creates opportunities for manufacturing companies to embrace servitization, leading to the rise of digital servitization (Iriarte et al., 2023). Thus, business model innovation is crucial for gaining and maintaining competitive advantages (Heubeck and Meckl, 2022).

Cluster 2: Industry 4.0

Industry 4.0 is a research area focused on manufacturing innovation, integrating knowledge from various academic fields (Agostini and Nosella, 2021). However, there is a lack of research on the organizational aspects of implementing Industry 4.0, despite the abundance of published work on different Industry 4.0 topics (Nayernia et al., 2022). The emergence of Industry 4.0, driven by technologies like the Internet of Things (IoT), significantly impacts firms' strategies. How small and medium enterprises can effectively navigate the transition to an IoT-based business model alongside their existing models is of great value when it comes to navigating these changing ways of doing business. The primary focus seems to stay on managing the evolution and coexistence of these business models (Paiola et al., 2022).

Recent literature highlights Industry 4.0 technologies as facilitators of servitisation (adding digital services to existing products), while businesses are encouraged to adopt a circular economy (Lu et al., 2024). However, the integrated role of Industry 4.0 in such a circular economy and servitization has received limited

attention until now (Atif et al., 2021). Servitization and Industry 4.0 are deemed as quite transformative trends in industrial companies (Frank et al., 2019). Digitalization transforms solution providers' business models and influences their decisions on firm boundaries within ecosystems (Eigner and Stary, 2023). This requires alignment among the business models of multiple firms in the ecosystem (Kohtamäki et al., 2019).

Industry 4.0 is the digitalized transformation of manufacturing, covering both production and service industries (Savastano et al., 2019). Industry 4.0 marks an era of tremendous interconnectedness between machines, devices, human beings, and systems (Murmura et al., 2021). The fourth industrial revolution, Industry 4.0, driven by digital transformation, is rapidly advancing and reshaping society (Müller and Däschle, 2018). Companies can benefit from improved efficiency, sustainability, customization, and flexibility in this new era by adopting digital technologies and developing appropriate strategies (Hernandez Korner et al., 2020).

While Industry 4.0 represents an evolution in factory operations, many manufacturers have yet to capitalize on its possible revolutionary opportunities (Calabrese et al., 2021). There appears to be a scarcity of literature on the application of sustainable business models in operational contexts with regards to Industry 4.0 (García-Muiña et al., 2020). Industry 4.0 has been a major concept that framing the "societal, economic, and technological environment", especially in the last decade. Exposed to ongoing digital transformation, companies can exploit opportunities offered by Industry 4.0 and are forced to manage inherent risks and challenges. However, studies on opportunities and barriers relevant to implementing Industry 4.0 for companies are scarce (Vuksanović Herceg et al., 2020).

With the benefits of Industry 4.0, economic sustainability, such as production efficiency and business model innovation, emerges as immediate outcomes, paving the way for socioenvironmental sustainability functions like energy sustainability, emission reduction, and social welfare improvement (Ghobakhloo, 2020). Industry 4.0 significantly impacts all companies, especially manufacturing companies' business models (Müller and Buliga, 2018). In the past decade, there has been significant growth in the smart and resilient transformation of specially manufacturing firms (Sofic et al., 2022).

Cluster 3: Digital Transformation

In recent years, there has been an increase in discussions about the role of digital technologies in enabling a circular economy. The advancement of digital manufacturing technologies has made it feasible to utilize circular resources more effectively and efficiently in this digital transformation era (Khan et al., 2022). Considering all these digitalization movements, companies ought to find effective ways to develop their unique digital servitization strategies and operations, enabling them to leverage the potential of Industry 4.0 and servitization in order to create and sustain value (Münch et al., 2022). In this respect, industry plays a crucial role in driving economic development (Zizic et al., 2022). However, introducing modern technologies and the growing complexity of products and production directly affect industrial enterprises and workers, necessitating adaptation and adjustment to these changes (Beliatis et al., 2021).

Although the importance of ecosystem transformation is acknowledged, research on the interlink between digital servitization and ecosystems remains fragmented and

lacking in depth (Kolagar et al., 2022). The impact of digital technologies on innovation performance is widely acknowledged, but little research has explored whether additional factors condition this relationship and contribute to innovation outcomes (Kastelli et al., 2022). The intersection between digital transformation and innovation has gained significant attention in recent years, leading to numerous discussions and publications (Kamp et al., 2023). However, existing literature seems to lack a comprehensive and unbiased overview of the current research state in this area (Mersico et al., 2023). Thus, there is a need for a thorough and objective review that analyzes the research themes at the intersection of digital transformation and innovation (Gao et al., 2022).

There is a growing interest and emphasis on digitalization and digital transformation in shaping companies' competitive advantages (Tortora et al., 2021). The existing literature has overlooked the importance of a firm's experience and knowledge as a valuable asset for value creation in digital servitization, particularly concerning Industry 4.0 technologies (Paiola et al., 2021). Manufacturing firms are aiming to leverage digitalization by adopting digital servitization. However, many companies still struggle to unlock the full value of Industry 4.0 due to the need for effective ecosystem partnerships (Adamik et al., 2022). While there is growing interest in leveraging digital technologies for servitization, there is limited understanding of the factors that motivate firms to adopt a digital servitization strategy (Coreynen et al., 2020).

In the digital age, companies have the opportunity to enhance both sustainability and competitiveness by leveraging new technologies (Dressler and Paunovic, 2021). These digital technologies can enable the integration of especially circular economy principles into businesses, leading to innovative business models and the transformation of product design and value chains (Chang et al., 2022). The impact of digital technologies on businesses, particularly in the context of Industry 4.0, is gaining significance (Rahman et al., 2022). However, synthesizing existing research remains challenging. There seems to be a significant and clear gap in the literature on how Industry 4.0 transforms companies in all industries through a knowledge management perspective (Ardito et al., 2022). However, the intersection between the circular economy and digital technologies still requires further research and exploration (Bressanelli et al., 2022).

Cluster 4: Technology Implementation and Analysis

In order to reap the benefits arising from these impressive changes, companies need to implement profound ways to make meaning out of these otherwise mere potential advantages. Traditional industries have been undergoing rapid transformations due to the adoption of digital technologies. These technologies have brought about significant changes in various aspects of these industries, leading to new opportunities and challenges (Zhang et al., 2023). Furthermore, all industries and sectors may benefit from the digital transformation of Industry 4.0 (Russo et al., 2022). In this regard, the transformation of manufacturing enterprises through servitization plays a crucial role in driving the current high-quality development of the manufacturing industry (Henríquez et al., 2022). This shift towards more service-oriented offerings brings significant advancements and opportunities in various sectors (Cao et al., 2022). Many companies (mainly manufacturing firms) increasingly

adopt servitization as a competitive strategy, offering combined product-service solutions.

Digital technology holds promise for advancing the circular economy by improving production and consumption practices (Riso and Morrone, 2023). However, there seems to be a lack of clarity regarding the specific functions of digital technologies that are most beneficial for enhancing circularity and their application in different circular economy strategies (Liu et al., 2022). The transition to digitalization and Industry 4.0 presents new opportunities and advantages for industrial firms, leading to digital servitization. However, achieving successful digital servitization requires significant changes in resources, organizational structures, work practices, infrastructure, and culture (Chirumalla et al., 2023).

Technology companies have the potential to capitalize on opportunities by creating innovative business models centered around the utilization of technologies. This strategic approach allows them to offer unique value propositions to their customers and stakeholders (Ramanathan et al., 2023). Scholars have recognized the significant impact of the industry 4.0 phenomenon, which is anticipated to reshape various elements of business value chains (Omar et al., 2019). As a result, there has been a growing interest in studying and analyzing industry 4.0 from a management perspective (Mariani and Borghi, 2019). Despite the anticipated transformative impact of Industry 4.0 on industrial value creation, there still seems to be a lack of research examining its effects on business models (Müller, 2019). This ultimately accentuates the significance of this topic.

Figure 6 shows the co-occurrence network of WoS subject categories. Most of the papers are categorized under business-management, environmental studies, green and sustainable science with various engineering sub fields. The stronger link appears (in bold nodes) as business linked to management and regional and urban planning, while other stronger links are among environmental studies, green, sustainable and technology with environmental science.

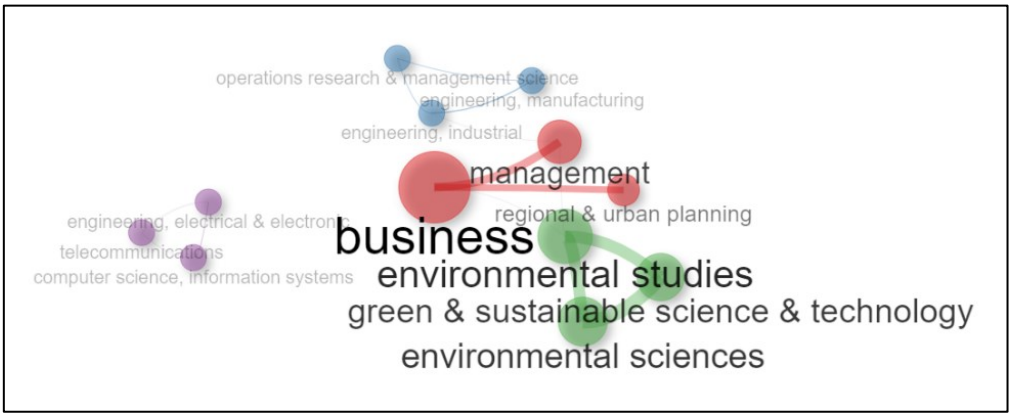

Figure 6. Co-occurrence network of subject categories (WoS).

4. Discussion and implications

The incorporation of digital technologies in Industry 4.0 is revolutionizing conventional business models. It allows companies to generate novel value propositions and interact with customers creatively. For instance, data-based value

creation and propositions have become critical in understanding customer preferences and needs. Subsequently, this acquired knowledge is employed to tailor items and services, hence augmenting the total client experience and happiness. Furthermore, Industry 4.0 promotes the shift from business models focusing solely on products to ones prioritizing system-oriented solutions. This implies that corporations are transitioning from selling standalone products to offering comprehensive solutions or platforms comprising a range of products and services. This transition facilitates the ability of organizations to offer clients more comprehensive and integrated solutions, potentially resulting in heightened customer loyalty and the establishment of recurring revenue streams.

In the context of the industry 4.0 age, establishing and nurturing strong customer relationships is of utmost importance to achieve commercial success. In order to effectively acquire feedback, comprehend evolving tastes, and engage in value co-creation with customers, it is imperative for companies to construct and uphold robust client relationships. In order to promote ongoing connection, involvement, and collaboration with customers, organizations must utilize digital platforms and technologies. Moreover, Industry 4.0 also encourages the adoption of a more agile and flexible approach to operations and supply chain management inside enterprises. This enables enterprises to promptly address client demands and adapt to market fluctuations, enhancing operational effectiveness and diminishing expenses. Additionally, the successful deployment of Industry 4.0 requires organizations to undergo a transformation in their essential resources and competencies.

The present study has successfully discovered four distinct clusters that hold substantial importance and their implications. These clusters are referred to as "Business Model Innovation," "Industry 4.0," "Digital Transformation," and "Technology Implementation and Analysis." The emergence of these clusters can be attributed to the research undertaken and the depiction of the co-occurrence network in this study. The specific themes within these clusters highlight the key areas of future research trends in the context of Industry 4.0 and its relationship with business model innovation (Chasin et al., 2020). The industry 4.0 is observed to exert a direct and substantial influence on the invention of business models, the usage of technology, and the development of digital transformations and capabilities (Chen, 2021). Industry 4.0 facilitates novel domains within various clusters of change, expedites the pace of change, and presents innovative avenues for advanced applications.

Furthermore, it is evident that there is a substantial proliferation of collaborative endeavors due to the advent of Industry 4.0, which facilitates immediate availability of information and real-time interactions. Prioritizing real-time data utilization is a significant focus in forthcoming products and services, such as servitization (Lei et al., 2023). Another crucial aspect to consider is the concept of value creation, which is increasingly recognized as a significant determinant of success in upcoming enterprises and business models (Leminen et al., 2020). In addition, the architecture of Industry 4.0 has emerged as an important focal point that encompasses the integration of value creation, value design, and value proposition. By implementing a more efficient system architecture, future organizations can gain a competitive advantage over their rivals by creating a unique, refined, and environmentally sustainable edge (Warner and Wäger, 2019). The services in the emerging era of

advanced technology are anticipated to be mainly derived from comprehensive large-scale data analyses. As a result, various industries are projected to undergo significant transformations, albeit to differing extents, during this evolutionary process.

Various mechanisms exist through which Industry 4.0 can facilitate the emergence of novel business models. The utilization of artificial intelligence has the potential to enable organizations to enhance the level of personalization of their products and services. The utilization of robotics facilitates the automation of operations that human agents once performed within enterprises. The utilization of the Internet of Things (IoT) has the potential to reduce the acquisition and examination of data by enterprises in real time. The utilization of this data holds the potential to enhance decision-making processes and streamline operational efficiency. The phenomenon of Industry 4.0 encompasses a more extensive inclination towards digitization in conjunction with the aforementioned specialized technologies. The current trend results in the amalgamation of the physical and digital realms, generating novel prospects for generating business models. For instance, enterprises today possess the capability to develop novel products and services that integrate both tangible and virtual components. Additionally, they can create novel business models that revolve around the sharing of data and resources. The following are instances of business model innovations facilitated by the advent of Industry 4.0:

- Subscription-based business models: have become increasingly prevalent in various industries, as numerous businesses have adopted this approach to sell their products and services. This enables enterprises to develop consistent revenue streams and create more intimate connections with the customers they serve.
- Pay-per-use business models: enable firms to generate revenue by charging customers based on their usage of products and services, as opposed to the traditional method of charging for the outright purchase of the products or services. This approach may present a heightened efficacy in income generation, particularly for enterprises that provide commodities or amenities characterized by inconsistent utilization.
- Platform-based business models: enable organizations to establish platforms to connect buyers and sellers. This approach has the potential to effectively align the availability of goods and services with consumer demand, thereby opening up avenues for enterprises to make more income.

The aforementioned instances represent a limited selection of the numerous ways in which Industry 4.0 has the potential to drive innovation in business models. With the ongoing advancement of technology, it is anticipated that many novel and inventive business models will arise.

Moreover, research on business model innovation investigates how businesses adapt and generate novel business models in order to capitalize on the opportunities arising from Industry 4.0. Therefore, the impact of Industry 4.0 on Business Models could be highlighted as:

- The Practice of Making Decisions Based on Data: the advent of Industry 4.0 has facilitated the acquisition of substantial volumes of real-time data from several origins, encompassing machinery, sensors, and consumers. A data-driven

approach enables firms to enhance decision-making processes, streamline operations, and deliver tailored consumer experiences.

- Product and Service based systems: the implementation of Industry 4.0 technology enables organizations to transition from a traditional business model of selling individual products to a more advanced approach of providing integrated product-service systems. For example, manufacturers have the capability to offer maintenance services by utilizing real-time data obtained from interconnected machines. This enables them to enhance performance and minimize periods of inactivity for their clients.
- Supply Chain Integration: the advent of Industry 4.0 enables the seamless integration of supply chains, hence fostering the development of more efficient and agile networks. Organizations have the capability to monitor inventory in a live manner, forecast demand, and enhance logistical operations, leading to reduced expenses and enhanced adaptability.
- Customization: the integration of advanced technologies within the context of Industry 4.0 enables firms to provide individual clients with highly tailored and personalized products or services that are specifically designed to meet their unique needs and preferences.
- Collaborative Innovation: Industry 4.0 facilitates collaborative innovation by establishing connectivity channels between enterprises and their external counterparts, including partners, suppliers, and customers. The openness above has the potential to facilitate the collaborative generation of novel solutions, services, and even complete business models.

5. Limitations

Our work, like any other article published in an academic document, has several kinds of limitations. There is no definitive method for reviewing pertinent sources. This research used the Web of Science database, a dynamically updated resource that includes the most recent papers, journals, and citations. Consequently, future bibliometric investigations of a particular subject will uncover significant changes. Another constraint of the research is that the bibliometric analysis was restricted to document types found in journals, including articles, conference papers, editorials, and reviews, which were only published in English. Subsequent investigations might focus on other databases such as Scopus, while also integrating data from supplementary sources such as books and languages other than the current one. This research used R Bibliometrix and VOSviewer software for data analysis and visualization. In subsequent studies, alternative bibliometric analysis tools might be used to verify the results and identify any differences. Future study in the research area should expand by including a number of variables that have a significant influence on the field rather than business model innovation. Numerous innovation models in relation to Industry 4.0 would be the another's focus areas. Therefore, although well-crafted, clear, and comprehensive content limits are important, they alone are not sufficient and may not always result in a well-organized review. This might limit the generalizability of our findings.

6. Conclusion

Industry 4.0 offers significant opportunities for businesses to innovate and transform their models to stay competitive in a digitally connected world. However, successful business model innovation in the context of Industry 4.0 requires careful consideration of technological, organizational, and societal factors. Research in progress plays an important role in guiding businesses and strategy makers adapting to the evolving environment of the fourth industrial revolution.

In the context of Industry 4.0, business model innovation enables organizations to maintain their competitive position and take advantage of the opportunities and business practices offered by digital transformation. Thus, Industry 4.0 is driven by digitalization and gains momentum with the integration of technologies such as the internet of things, artificial intelligence, big data and cloud computing. By their nature, these technologies can make traditional business models difficult to implement and require new value propositions for customers. In addition, Industry 4.0 positively affects the digital transformation of physical assets and their integration into digital ecosystems, strengthening cooperation within the value chain and offering new opportunities for co-creation. As a result of the development of Industry 4.0, businesses should reconsider their current business models, focus on innovative approaches by using digital technologies in every field, and realize the important opportunities offered by Industry 4.0.

This study aims to explore the scientific trends and dynamics of growth interest of Industry 4.0 and Business Model Innovation, in highly scholarly academic publications. The study has three research questions: “the most occurred keywords in research domains”, “the key trends in word dynamics to show the trends in the knowledge field”, and “the main themes and contents in the current state of the dataset”. Although the number of papers is relatively low and the publication record started in 2018, overall increases can be seen in this research domain recently. The analysis included 67 articles published between 2018 and 2023 (June).

This study aimed to investigate publishing trends to provide valuable insights and research directions for individuals in academia, practitioners, and aspiring professionals interested in these subjects. The study underscores the importance of conducting additional investigations in order to enhance comprehension and foster better relationships. The current state of research on business model innovation within the framework of Industry 4.0 is characterized by its nascent stage. Nevertheless, an increasing amount of scholarly investigation is currently being conducted to examine the possibility of novel business models arising within this context. This research holds significance for enterprises seeking to maintain a competitive edge and generate novel avenues of value creation.

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