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Systematic Review

The Precipitative Effects of Pandemic on Open Innovation of SMEs: A Scientometrics and Systematic Review of Industry 4.0 and Industry 5.0

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Abstract: This research aims to study the pre-pandemic and pandemic-period Industry 4.0 and Industry 5.0 characteristics in SME research using scientometrics and systematic review using the PRISMA 2020 approach. A total of 691 articles were found in SCOPUS database using keywords ((“Industry 4.0” OR “Industry 5.0”) AND “SME”). However, 398 documents, which were either conference proceedings, reviews, book chapters or published in languages other than English, were excluded, and the remaining 221 articles that were published in SCOPUS indexed Journals were included in the study. This research adopted a novel mix of scientometrics and Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 recommendations for identifying the thematic evolution of pre-pandemic and pandemic-period Industry 4.0 and Industry 5.0 SME Research. The major findings of this systematic review are, (1) There is a conceptual shift among researchers in studying the Industry 4.0 adoption of SMEs during the pandemic period; (2) The pandemic period research focused on (a) human-centric approaches, (b) adoption/acceptance models, (c) cost-effective solutions, (d) COVID-19 impact and resilience, (e) artificial intelligence and predictive maintenance, and (f) the emerging role of open innovation in Industry 4.0 adoption of SMEs; (3) Though the concept of Industry 5.0 clearly emerged and supplemented industry 4.0, the keyword “Industry 5.0” is not widely adopted by researchers. From the systematic literature review, a conceptual model for assessing the Industry 4.0 adoption and digital transformation of SMEs, digital integration of value chains and participation in a global value chain for trade expansion and sustainable growth of SMEs is proposed.

Keywords: systematic review; pre-pandemic; COVID-19; industry 4.0; industry 5.0; SMEs; PRISMA

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1. Introduction

The third industrial revolution (Industry 3.0) was the adoption of conventional automation, and the fourth industrial revolution (Industry 4.0) is the transformation from conventional automation towards the adoption of tools and technologies that help smart manufacturing, which in turn supports the value network’s horizontal integration, the value chain’s digital integration, and the manufacturing system’s vertical integration [1,2] through information and communication technology. However, such a shift from the third industrial revolution’s business process to the fourth industrial revolution comes with several challenges, especially for small and medium-sized enterprises, due to limited resources, knowledge, finance, [3] and risks for the labor market [4,5]. Hence, Industry 5.0 was announced by the European Union, which emphasizes three core values: (a) the supply chain resilience, (b) positive conversion impact on society, and (c) sustainability [6]. This shift in industries will lead from Industry 4.0’s technological revolution to Industry 5.0’s “techno-social” revolution [7]. However, such shifts in Asian countries face a major challenge of Industry structure, because a large number of enterprises are micro, small, and medium enterprises (MSMEs). For example: In Thailand, as of 2020, 3,134,442 MSMEs

offering 12,714,916 jobs, representing 99.54% of all the enterprises and accounting for 71.70% share of all private sector employment [8], in European Union, it is estimated that more than 50% of the GDP contribution is from small and medium enterprises (SMEs), representing 99% of all the enterprises [9]. Hence, revolutionary shifts from "Industry 3.0/Industry 4.0" to Industry 5.0 will not be realistic in terms of the core values without including the SMEs. However, SMEs industry 4.0 transformation from industry 3.0 itself faces several challenges such as lack of resources, motivation, and knowledge; absence of open innovation and strategies; and fear of sustainability [10–12]. Thus, gaining insights into Industry 4.0 and Industry 5.0 research related to SMEs is inevitable for any researcher involved in this research domain. In particular, it is vital to understand the changing Industry 4.0/Industry 5.0 SME research themes during the COVID-19 pandemic situation [13,14]. However, to the best of the authors' knowledge, there is no published systematic review on pre-pandemic and during-pandemic Industry 4.0/5.0 characteristics of SMEs. Thus, there is a gap in literature. Therefore, this systematic review article aims to synthesize the SME-related Industry 4.0 and Industry 5.0 academic research published in the past seven years from 2015 to 2022 to identify evolving themes, research focus, and the role of Industry 4.0/5.0 in SME transformation. The materials and methods used in this study are presented in the next section. Further, descriptive analysis, thematic evolution of pre-pandemic and pandemic-period SME research in Industry 4.0 and Industry 5.0, PRISMA 2020 and systematic review, evolution of Industry 5.0 and its role in SME transformation, discussion, and conclusion are presented in the following sections.

2. Materials and Methods

2.1. The Approach

This research adopts the approach of a novel mix of scientometrics and systematic review using PRISMA 2020 (see Tables S1 and S2) to pursue its objective, since it is essential and more suitable for studying the thematic evolution of emerging industries and less explored themes [15]. Thus, the descriptive analysis and thematic evolution are presented using scientometrics [16–20] before presenting the systematic review. The systematic review using the PRISMA 2020 recommendations [21] is presented following the scientometrics.

2.2. Database, Keyword Selection and Date of Search

"Industry 4.0" and "Industry 5.0" are two broad terms widely used to mention the key "technology-based" development in the industrial production process. Their suitability for SMEs has been tested along with the evolution of Industry 4.0 and Industry 5.0. Hence, this research, based on its objectives, used three keywords ("Industry 4.0" OR "Industry 5.0") and ("SME") to filter the relevant works published in the SCOPUS database. The initial search results as of 15 May 2022 revealed that there are 619 documents indexed in the SCOPUS database.

2.3. Inclusion and Exclusion Criteria

The documents not published in the English language and other documents such as book chapters, conference proceedings, and review articles were excluded from the study. Thus, only articles published in peer-reviewed journals indexed in SCOPUS were selected for the study (n = 221).

2.4. Tools and Techniques

The Bibliometrix package [20] in R programming language [22] was used to analyze the scientometrics of the articles selected for the study (n = 221), and the same is presented in the next section.

3. Descriptive Analysis

The descriptive summary of the articles used in this study is presented in Table 1. The main information about the data and document types revealed that during the time span

of 2015–2022, 221 articles were published in 130 sources. With 664 authors at an average of 3.42 authors per article, the research in this domain is highly collaborative in nature. Only 19 documents were single-authored. Another important detail from the descriptive analysis is the average citations per document. The average number of citations per document in this corpus is 21.59, which shows that the articles published in this domain are highly referred. The document content, such as the author's keywords (n = 659) and Keyword Plus (n = 858), are presented in the next section.

Table 1. Descriptive.

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	2015:2022
Sources (Journals, Books, etc.)	130
Documents	221
Average years from publication	1.93
Average citations per document	21.59
Average citations per year per document	5.748
References (SCOPUS Database)	1
DOCUMENT TYPES	
article	221
DOCUMENT CONTENTS	
Keywords Plus (ID)	858
Author's Keywords (DE)	659
AUTHORS	
Authors	664
Author Appearances	758
Authors of single-authored documents	18
Authors of multi-authored documents	646
AUTHORS COLLABORATION	
Single-authored documents	19
Documents per Author	0.333
Authors per Document	3
Co-Authors per Documents	3.43
Collaboration Index	3.2

3.1. Annual Scientific Production

The annual scientific production, though small in numbers, has sharply grown since 2019, i.e., ever since the spread of the COVID-19 virus and pandemic. In 2015, there were only two studies published with a special focus on SMEs. However, this has increased to 33 articles in 2019, 69 articles in 2020, and 68 articles in 2021. In 2022, 25 articles were already published until May. Thus, the results of annual scientific production (Table 2 and Figure 1) prove that research interest in this domain grew during the pandemic period.

Table 2. Annual Scientific Production.

Year	Articles
2015	2
2016	1
2017	10
2018	13
2019	33
2020	69
2021	68
2022	25
Total	221

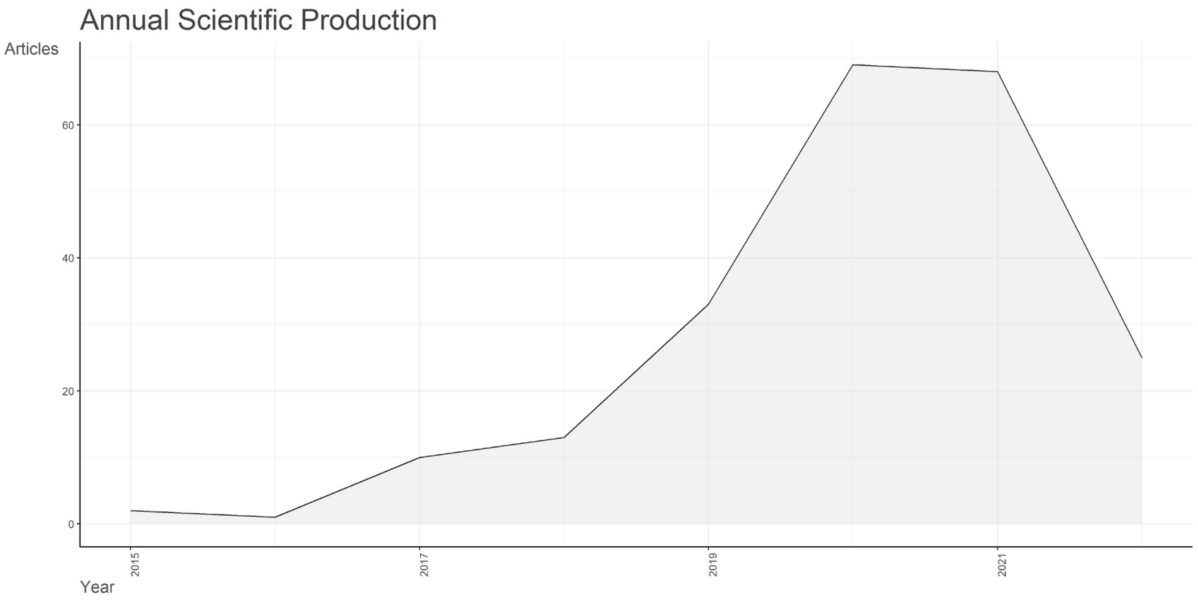

Figure 1. Annual Scientific Production.

3.2. Top 5 Sources of Industry 4.0 & 5.0 SME Research in Zone 1 (Bradford's Law)

Bradford law [23] applies Pareto distribution to group the articles in three different zones, namely Zone 1, Zone 2, and Zone 3. According to Bradford law (Table 3), the top five journals with the highest frequency of articles are "Sustainability", "Technological Forecasting and Social Change", "Journal of Manufacturing Technology Management", "Applied Sciences", and "Computers in Industry" with 19, 10, 8, 7, and 6 articles published in the time period, respectively.

Table 3. Top 5 Sources in Zone 1 (Bradford's Law).

Journal	Rank	Frequency
Sustainability (Switzerland)	1	19
Technological Forecasting and Social Change	2	10
Journal Of Manufacturing Technology Management	3	8
Applied Sciences (Switzerland)	4	7
Computers In Industry	5	6

3.3. Word Dynamics (Keyword Plus Growth Rate)

Figure 2 presents the cumulative occurrence of Keyword Plus and its growth rate during the time span of 2015–2022. Words such as "Decision making", "Digital Transformation", "Embedded systems", "Enterprise resource planning", "Flow Control", "Internet of Things", "Life Cycle", "Manufacturing Industries", "Smart Manufacturing", and "Supply Chains" emerged and grew during the timespan. Such Keyword plus growth rate infers that there is an evolution of new research themes in this field. Hence, the thematic evolution of Keyword Plus is analyzed and presented in the next section.

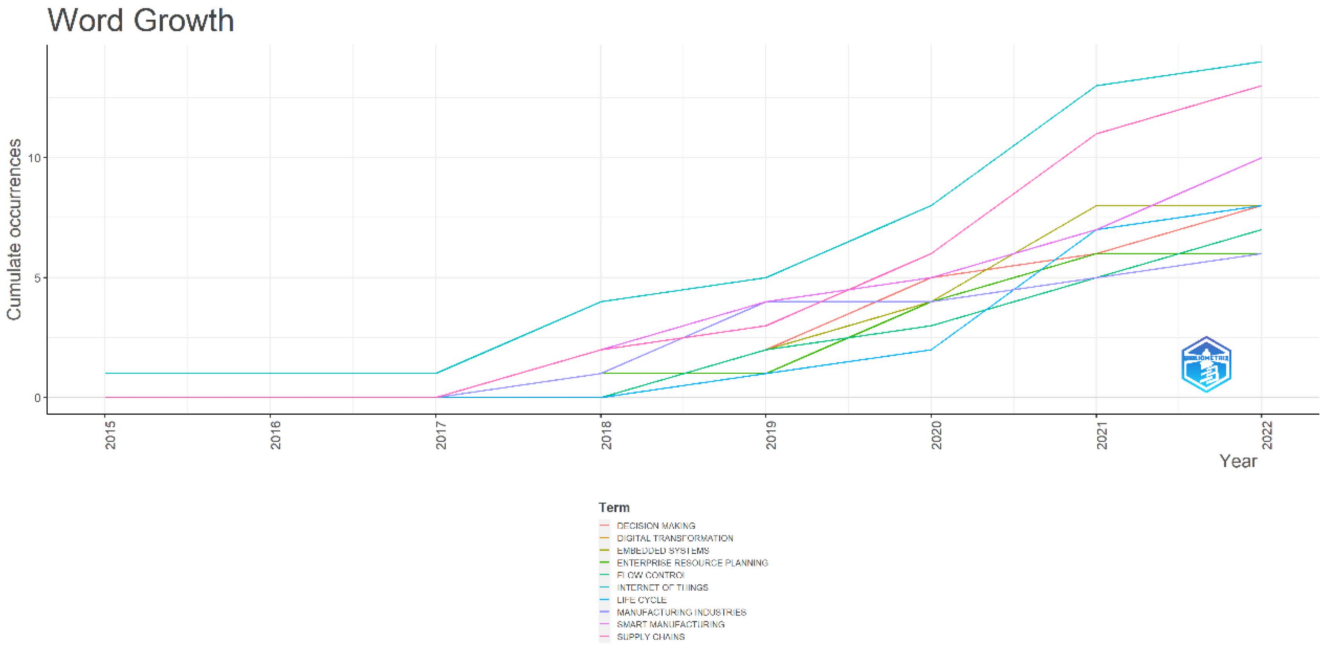

Figure 2. Work Growth (Keyword Plus).

3.4. Social Structure (Collaboration World Map)

The social structure (collaboration world map) shows (Figure 3) how the authors from different countries are collaborating in the research domain. The results revealed that the Authors from Malaysia had the highest number (n = 29) of international collaborations (Australia—3, United Kingdom—3, Canada—2, France—2, India—2, Indonesia—2, Iran—2, Pakistan—2, Armenia—1, China—1, Finland—1, Korea—1, Lithuania—1, Nigeria—1, Poland—1, Romania—1, South Africa—1, Thailand—1, USA—1) in this research domain. The second and third highest number of international collaborations were from Italy (n = 14) and United Kingdom (n = 14). Authors from Italy collaborated with authors from Austria (n = 2), France (n = 2), USA (n = 2), Brazil (n = 1), Canada (n = 1), Germany (n = 1), Pakistan (n = 1), Portugal (n = 1), Spain (n = 1), Thailand (n = 1), and United Kingdom (n = 1). Authors from United Kingdom collaborated with Authors from France (n = 4), Armenia (n = 1), Australia (n = 1), China (n = 1), Czech Republic (n = 1), Denmark (n = 1), Finland (n = 1), Hungary (n = 1), Netherlands (n = 1), Pakistan (n = 1), and Romania (n = 1). The authors from India had the fourth highest number (n = 11) of international collaborations (USA—3, United Kingdom—2, Australia—1, China—1, Finland—1. Hong Kong—1, Mexico—1, Romania—1). The fifth highest number of international collaborations were from USA (n = 10). The authors from USA collaborated with authors from Romania (n = 2), Slovakia (n = 2), Brazil (n = 1), Canada (n = 1), Denmark (n = 1), Finland (n = 1), Hong Kong (n = 1), and Mexico (n = 1). The other countries with international collaborations were Germany (n = 9), Poland (n = 8), Pakistan (n = 6), Spain (n = 5), Australia (n = 4), China (n = 4), Slovakia (n = 3), Czech Republic (n = 3), Turkey (n = 2), Cyprus (n = 2), Canada (n = 2), Austria (n = 2), Thailand (n = 1), Indonesia (n = 1), Ireland (n = 1), Portugal (n = 1), Romania (n = 1), And Serbia (n = 1). Thus, the results of the social structure (collaboration world map) reveal that the research in this domain is highly collaborative in nature.

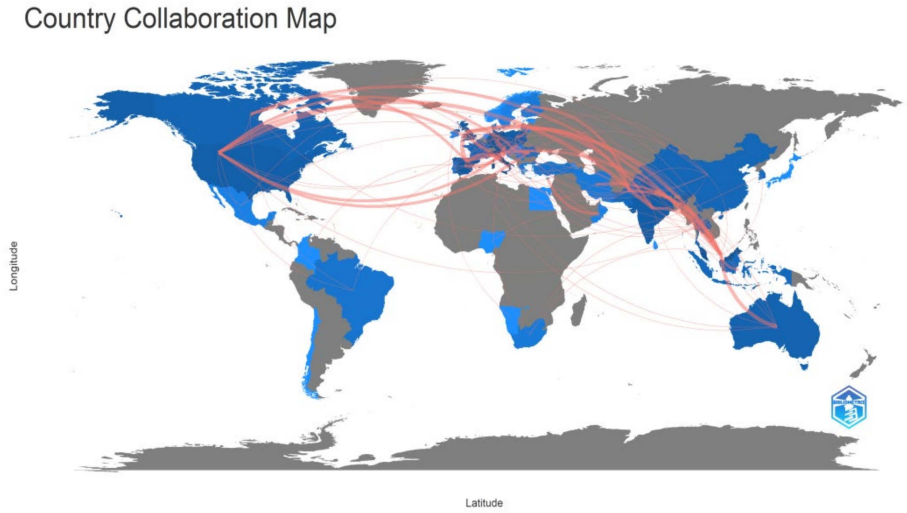

Figure 3. Social Structure of the Research.

4. Thematic Evolution of Industry 4.0 and Industry 5.0 Research since Pandemic

Co-word analysis [24] when visualized in two dimensions can provide insights of word growth [25] based on centrality and density. Hence, in continuity with the word dynamics, this research used 2018 as a cut-off point to divide the pre-pandemic and pandemic period research in this field. Several common terms such as "small and medium-sized enterprise", "small and medium enterprise", "industry", "Industry 4.0", "manufacture", "ecosystems", "surveys", "small and medium sized enterprise", "manufacturing", "sustainability", "developing countries", "case-studies", "industrial revolutions", "manufacturing companies", "small-and-medium enterprise", "design/methodology/approach", "international trade", "sme", "smes", "small and medium-sized enterprises", "innovation', "strategy", "technology", "manufacturing sector", "industrial research", "commerce", "Malaysia", "competition", "industrial development", "industrial enterprise", "company size", "business", and "conceptual framework" were carefully reviewed and removed to avoid vagueness in reporting. The results revealed three major developments: (1) Industrial economics-related studies moved towards sustainable development, (2) IoT (Internet of Things)-related studies expanded further into manufacturing process-related research and supply chain integration-related research, and (3) Manufacturing environment-related research evolved and merged with smart manufacturing (Figure 4).

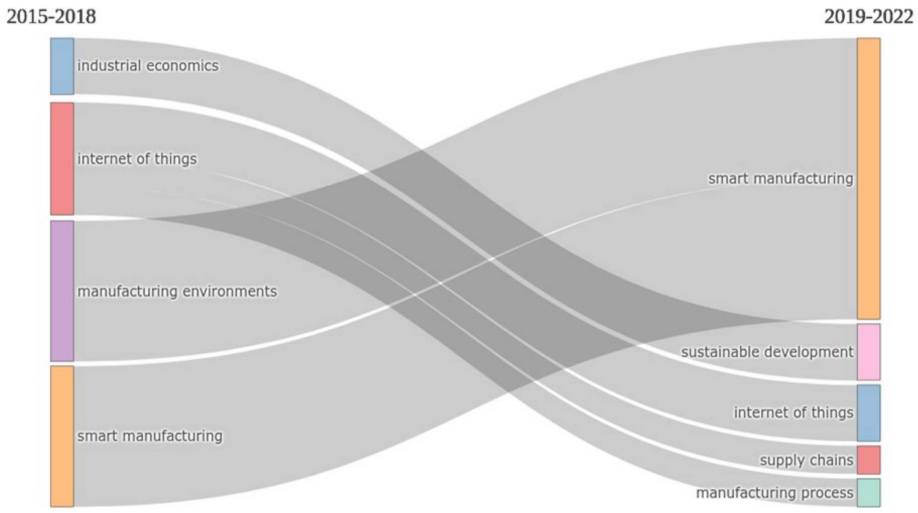

Figure 4. Thematic Evolution.

4.1. Pre-Pandemic Thematic Evolution (2015–2018)

The keyword "Industry 4.0" was first coined in 2011 [26] and gained attention all around the world in the same year. The evidence is distinct, with a near-equal number of articles published in conference proceedings. However, the first journal article related to the application of the "Industry 4.0" concept for SMEs in the SCOPUS database was published only in 2015. Hence, the first thematic evolution map was plotted for the time-period of 2015 to 2018. The results revealed that the "digitalization" of SMEs was a basic theme, and studies on the "manufacturing environment" and its "supply chain" were emerging themes. On the other hand, "Business model innovation", "Industrial economies", "IoT", and "data acquisition" were motor themes. "Smart manufacturing"-related research was a niche theme. The results revealed that only five themes were emerging before the pandemic outbreak (Figure 5).

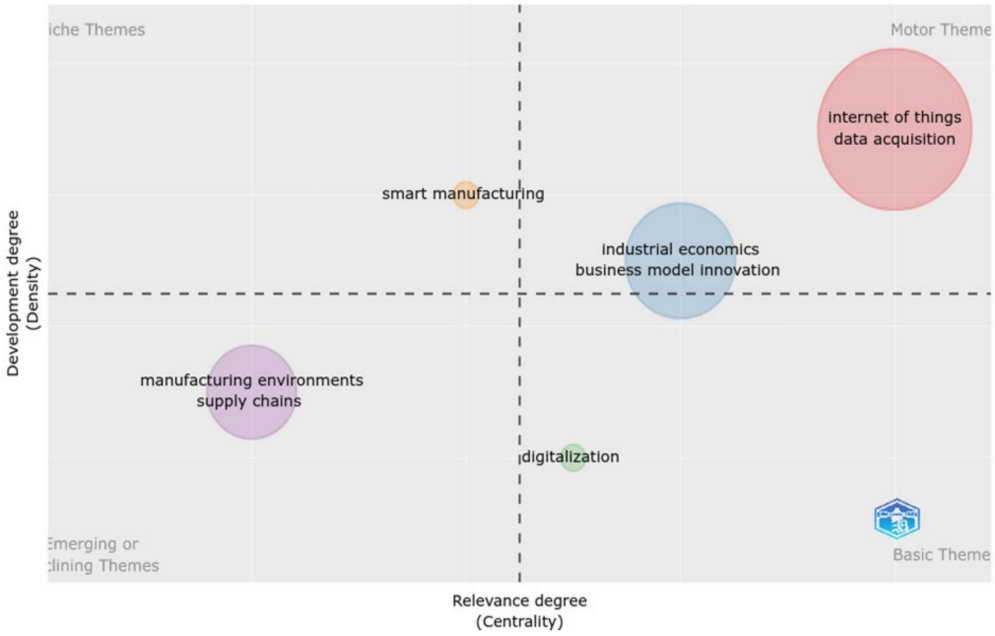

Figure 5. Pre-pandemic Thematic Evolution.

4.2. Pandemic-Period Thematic Evolution (2019–2022)

The COVID-19 pandemic outbreak has severely affected the SME sector [27]. Consequently, the research also evolved into twelve themes. Among those, "Smart manufacturing", "flow control", "data analytics", and "technology transfer" of SMEs have emerged as motor themes. "IoT"-related research, which was a motor theme during the pre-pandemic time, became a basic theme, which means comparatively they were of strong centrality but weak low-density and were, hence, transversal in nature. Similarly, several transversal words such as "implementation process", "sustainable development", "ERP", "Supply chain integration", "Life cycle assessment", "information dissemination", and "manufacturing industries" evolved during this period. "Assessment method" and "Europe" were emerging themes. To the authors' surprise, several niche themes have developed during this period, such as "Investment", "cost"-related research, "agile manufacturing", and "lean production system"-related research, along with "hardware and software" and "automotive industry". Hence, we concluded to classify the articles into two groups as pre-pandemic and pandemic period research and further review all the available manuscripts to differentiate the characteristics of research in this domain. The final document selection process is presented as a PRISMA flowchart (Figure 6), and the review results are presented in the next section.

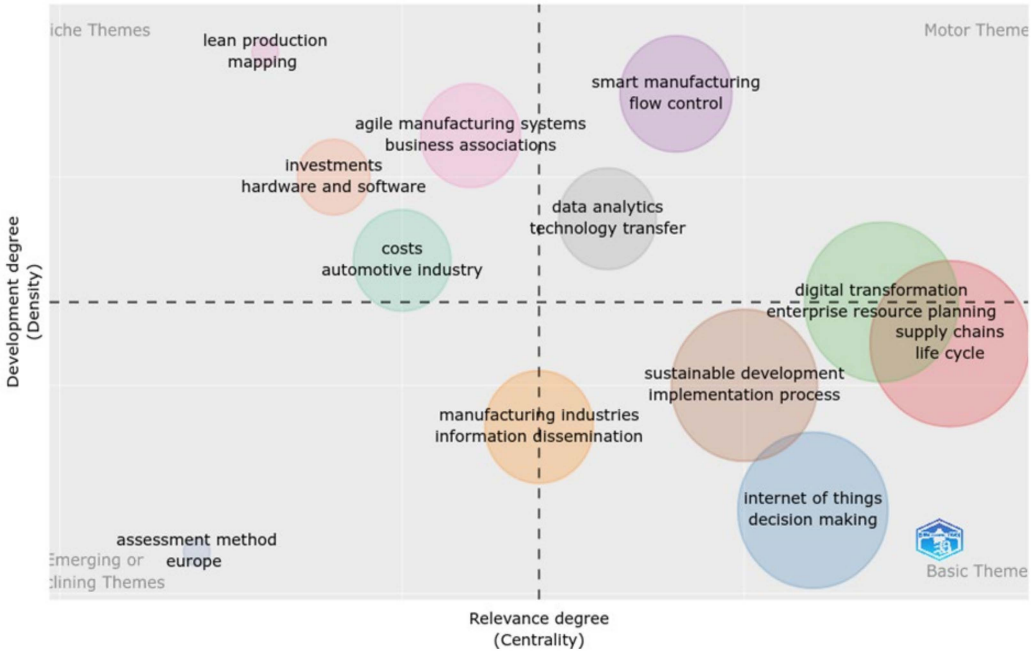

Figure 6. Pandemic period thematic evolution.

5. PRISMA 2020 and Systematic Review

The PRISMA flow diagram of article selection is depicted in Figure 7.

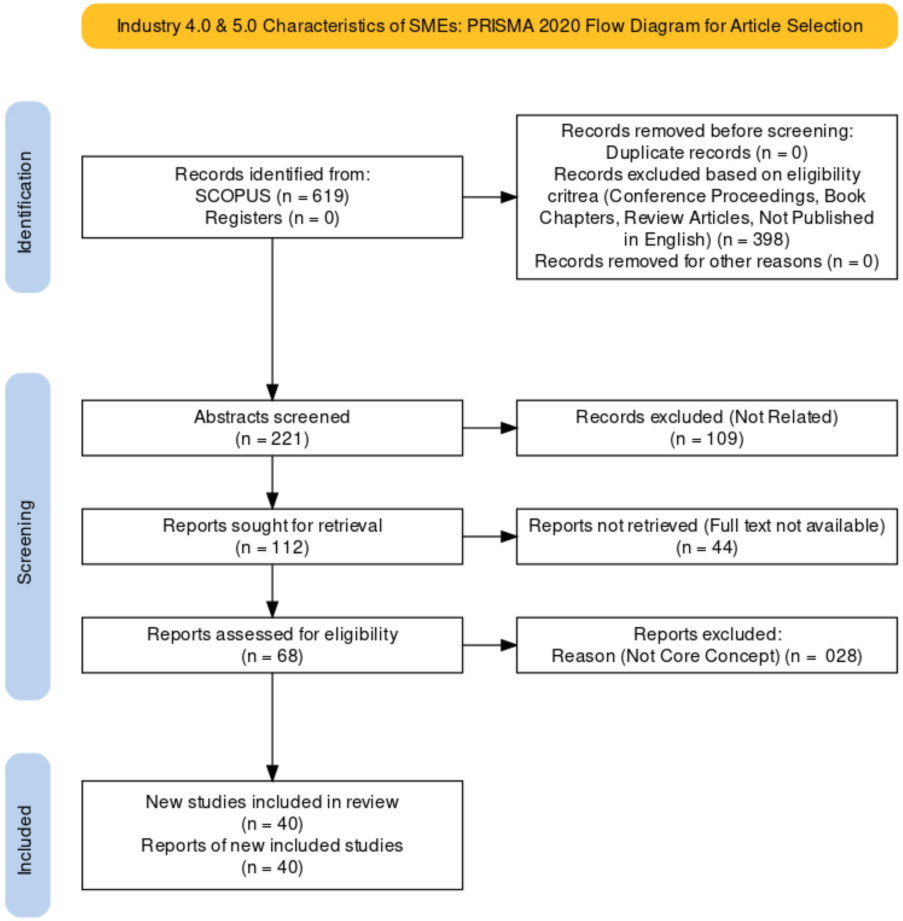

Figure 7. PRISMA 2020 of Article Selection.

5.1. Pre-Pandemic Research

Earlier studies on Industry 4.0 readiness of SMEs revealed mixed results of benefits [28]. Ganzarain and Errasti [29] developed a maturity model with three stages and five levels and found that only a very few SMEs adopted Industry 4.0 technologies. The studies were based on the theory of digital twins. Stark et al. [30] also revealed that digitalization and Industry 4.0 technologies such as cyber-physical production systems are not widely adopted in the SME sectors [31,32]. Later, Moeuf et al. [33] summarized the characteristics of Industry 4.0 adoption in SMEs and revealed that the adoption is more cost-driven than the business model transformation. Thus, SMEs can be classified based on their Industry 4.0 adoption into (a) "Craft manufacturers", (b) "Preliminary stage planners", (c) "Industry 4.0 Users", and (d) "full-scale adopters" [34]. However, such adoption is not just limited to internal motivation. Müller et al. [34], in their multiple case study, found that the "Industry 4.0" adoption is also due to external pressure such as type of business, inter-company connectivity and market trends. Hence, developing absorptive capacity [35] or partnering with IT specialist companies can ease the "Industry 4.0" adoption of SMEs [36]. Conversely, the characteristics of Industry 4.0 adoption in SMEs are comparatively simpler than that of MNCs (Multinational Company). This is evident from a precise quantity study conducted with 270 SMEs in Thailand [37]. The study characterized (a) "smart factory", (b) "big data", and (c) "IoT" as the "Industry 4.0" attributes to overcome the technology-related issues and found that these three have a positive impact on SME business performance. To the reviewer's surprise, even though Industry 4.0 adoption is technology adoption at its core, its benefits and challenges went unnoticed from the socio-economic perspectives in early studies. One significant study that focused on implementing the Industrial Internet of Things (IIoT) and included the socio-economic perspective was from Kiel et al. [38]. The authors in their study adopted the "Triple Bottom Line" approach [39] and extended it into six dimensions, namely "Economic", "ecological", "social" and "technical integration", "data and information", and "public context" and found that opportunities outweighed the challenges. In another similar study, Moeuf et al. [40] focused on identifying the risks and success factors for Industry 4.0 adoption in SMEs and found that the short hierarchical structure and awareness about the importance of data were the crucial factors that could influence success; on the other hand, the short life cycle and high risk of obsolescence of current technology along with lack of expertise, short-term strategic business models, and employees' fear of the increase in surveillance remained as the major risk factors. Studies [12] also used the multi-criteria decision-making techniques such as DEMATEL and found that the "fear of failure" of I4.0 technology is the major challenge of I4.0 adoption by SMEs, which is similar to that of risk of obsolescence [40]. A much broader approach of the complex IIOT requirements for the adoption of Industry 4.0 by SMEs was conceptualized as the "innovation ecosystem" [41]. This finding is different from the earlier traditional model, where the business associations had more control over the power structure. The study also revealed the changes in the "innovation ecosystem" during the three phases of the life cycle stages of Industry 4.0 adoption, namely birth, expansion, and leadership phases. As per the model, the higher the phase, the more complex the platform and its integrators. This research makes it evident that the concept of "one model fit for all" will not be suitable for assessing the I4.0 adoption by different industries. For example, Industry 4.0 adoption in a country may be at different levels for the food-processing industry and automotive industry. Hence, a precise scale for assessing the readiness level for each industry/sector is the need of the hour. There are also comparative studies that conferred the relationship between Industry 4.0 adoption and competitive advantage [42]. Another important realization in this time period was the heterogeneous nature of Industry 4.0 adoption. The enablers and barriers of Industry 4.0 are not limited to technology and its relevant knowledge of managers/entrepreneurs. Further, it also includes the availability of loans, workforce, and the labor market structure [43].

From the above literature, it is evident that the highly influential articles related to Industry 4.0 readiness of SMEs during the pre-pandemic period focused on the:

(a) stages of adoption models, maturity models, life cycle, and growth models.
(b) adoption of specific technologies such as cyber-physical production systems.
(c) industry 4.0 characteristics of SMEs.
(d) need for a broader perspective such as the influence of external forces such as market demand, industry structure, labor market structure, banking, and financial services for assessing the enablers and barriers of industry 4.0 adoption.
(e) growing complexity and changing structure of the business environment.

5.2. Pandemic Period Research

This research adopted two global factors to classify the research into pre-pandemic research. Even though WHO declared the COVID-19 outbreak as a pandemic on 11th March 2020, the global economic slowdown began well early in 2019. Multiple reasons such as "Brexit", "US–China trade war", and "high liquidity" were quoted as reasons for the economic slowdown in 2019. Hence, this research uses 2019 as the year for dividing pre-pandemic and pandemic period research. However, the submission date of the articles and data collection timespan were carefully reviewed to identify and classify the research conducted in pre-pandemic and pandemic periods.

Beyond the economic benefits of adopting Industry 4.0 technology, the social and environmental dimensions of sustainability became a major area of study in this domain. However, the economic benefits such as error-free production and effective logistics outweigh social factors such as reduction in labor hours and environmental factors such as lower environmental impact [44]. Another growing interest is the implementation of artificial intelligence in the manufacturing process of SMEs [45,46]. Cimini et al. [47] conducted an operations-specific Industry 4.0 adoption and found that effective adoption needs a lean organizational structure that creates new job profiles of non-technical competencies. Dutta et al. [48] adopted the five-step Industry 4.0 adoption model [49] and found that the SME sector in India is at the initial stages of "defining" and "awareness creation". Another study conducted in the Czech Republic also revealed similar results of low adoption level of Industry 4.0 technologies by SMEs [50]. The central role of human resources, such as operator's safety and health, which is the core of Industry 5.0, is also discussed [51], and urban production was proposed as a solution to overcome the shortage [52]. Garzoni et al. [53] proposed and tested a four-level approach ("digital awareness", "enquirement", "collaboration", and "transformation") of Italian SMEs' engagement in the adoption of Industry 4.0 technologies. Ever since the economic slowdown, market uncertainty has become a major factor of concern for Industry 4.0 adoption [54]. Another important concept discussed was the applicability of cost-effective single-board computers as a core agent for dynamic value stream mapping [55].

The next major area of study in this domain is transparency. Because transparency has always been a challenging factor in improving trust and cooperation throughout the supply chain. Therefore, the adoption of blockchain technology in Industry 4.0 is the solution to overcome the challenge and to increase transparency [56]. Additionally, Cotrino et al. [57] proposed a conceptual platform called "Industry 4.0 HUB", which can be used as a web platform for supporting the Industry 4.0 adoption of SMEs. Such a Hub can reduce the risk of the knowledge gap and foster the Industry 4.0 adoption of SMEs.

The third major area of study is focused around the COVID-19 pandemic and resilience. The impact of the COVID-19 pandemic on the SME sector was analyzed in the Malaysian furniture sector, and supply chain disruption along with financial management became crucial areas of concern, which is driving the industry towards Industry 4.0 adoption [27]. Additionally, the urgent need for digital reorganization for COVID-19 recovery was asserted through a precise quantitative study with 2622 Italian SMEs involved in the manufacturing sector [58]. The study results revealed that openness and adoption of Industry 4.0 technologies had a positive and significant direct impact on the perceived production recovery of SMEs. On the other hand, in the prevailing pandemic situation, there is a need for predictive maintenance in companies that have already implemented Industry 4.0

technologies. In another study, Chen et al. [59] proposed an "Artificial intelligence-based", "human-centric" "decision support framework", which could achieve 82% accuracy. On the other hand, the pressure and related level of Industry 4.0 adoption was also studied. For example, the pressure for the digitalization of Hungarian SMEs due to the pandemic is well-documented [60]. The findings revealed that the results of present implementations are not visible, and it was recommended that the government extend the support for the transformation of SMEs towards Industry 4.0. Similarly, Ponis and Lada [61] studied the digital transformation of the fashion industry in Greece and found that there is a lag in the transformation, which further needs a clear roadmap to meet the post-pandemic era.

The fourth major area of study in the current pandemic situation also led to the comparative study of the usefulness of Industry 4.0 for all types of SMEs. The study by Jang et al. [62] revealed that the performance may vary based on human resources and industry type. Thus, the COVID-19 pandemic situation has led the researchers to re-examine the Industry 4.0 technology, its adaptability and usability on a large scale, and the need for extended support from government organizations to accelerate the adoption of Industry 4.0 technologies by SMEs in the post-pandemic era.

The fifth major area of study is the role of open innovation in Industry 4.0 adoption of SMEs. Open innovation can influence Industry 4.0 adoption of SMEs through inbound supply chain [45] and can accelerate value development and collaborative learning [63]. This domain has gained less attention during the pre-pandemic research and gaining attention from researchers in the pandemic period.

From the above literature, it is evident that the highly influential articles related to Industry 4.0 readiness of SMEs during the pandemic period focused on:

(a) Human-centric approaches for the adoption of Industry 4.0 by SMEs.
(b) Adoption/acceptance models are based on various conceptual levels.
(c) Cost-effective solutions for SMEs' Industry 4.0 adoption.
(d) COVID-19 impact, resilience, and SMEs' Industry 4.0 adoption.
(e) Artificial intelligence and predictive maintenance.
(f) The emerging role of open innovation in Industry 4.0 adoption of SMEs.

5.3. Evolution of Industry 5.0 and Its Role in SME Transformation

The concept of Industry 5.0 emerged and supplemented Industry 4.0 since 2015 [6], and bibliometric analysis of the research corpus in the SCOPUS database was already conducted [64]. According to the European Union, Industry 5.0 is a supplement to industry 4.0 with an emphasis on the human-centric, sustainable resilience of the industries [6]. Though the concept is clear, the keyword "Industry 5.0" is not widely adopted in SME-related academic research. Our systematic review revealed that since the pandemic period, the research focus has already shifted from a machine-centric approach towards more human-centric and sustainable resilience of the SME sectors such as environmental impact [44], creation of new job profiles [47], operators' health and safety [51], and urban production [52]. However, the keyword "Industry 5.0" is not widely used by the authors.

6. Discussion: The Pandemic as the Trigger of Open Innovation

This research adopted a novel mix of scientometrics and citation-based systematic review to study the characteristics of industry 4.0 and industry 5.0 in SME research. Generic keyword search in the SCOPUS database with (("Industry 4.0" OR "Industry 5.0") AND ("SME")) revealed 619 documents in the SCOPUS database. This research further filtered the documents to only articles published in journals, excluding conference proceedings, book chapters, and commentaries. The final articles used in the scientometric analysis and systematic review were 221. The descriptive analysis of document details, annual scientific production, Top 5 Sources of Industry 4.0 and 5.0 SME Research in Zone 1 (Bradford's Law), and Word Dynamics (Keyword Plus Growth Rate) was discussed in Section 3. Further, the year 2018 was used as a cutting point to identify the thematic evolution of Industry 4.0 and Industry 5.0 SME research in pre-pandemic and pandemic periods. The results

revealed that several basic, motor, and niche themes have evolved since 2019 (refer to Figures 5 and 6). Further, all 221 articles were reviewed, and the relevant top 20 most cited articles in both time periods were reviewed and presented in Section 5.

The major findings of this systematic review concluded that there is a conceptual shift among "Industry 4.0 and SMEs" researchers during the pandemic period. Thus, the conceptual framework (Figure 8) was developed based on the findings of the review. Even though there are enough theories to establish the influence of external pressure, external and internal barriers, characteristics, vision, and roadmap of SMEs in their Industry 4.0 adoption, the theories on the role of open innovation in transformation of SMEs is relatively new. Open innovation [65] is the business management process in which an entity expands its business opportunities through accessing innovative successful ideas available in the information rich market, harnessing, and using the most appropriate innovation inputs across the process, and also providing knowledge throughout its supply chain for external use of innovation [66–68]. Irrespective of the socio-demographic factors, it was found that the present external pressure of pandemic has triggered the adoption of open innovation in SMEs [69–71] and such innovation adoption completely mediates the relationship between the sustainable supply chain management practices and sustainable firm performance of SMEs [72]. Thus, the influence of open innovation in competitiveness and sustainable growth of different types of sectors such as high-tech SMEs (HTSMEs) [73], the manufacturing sector [74], the service sector [72], and low-tech SMEs (LTSMEs) [75] has gained attention since the pandemic. Additionally, the role of a process-based approach in innovating the business model itself through business model innovation [13,76] has also been studied. However, since this is an emerging theory, different perspectives in measuring the adoption of open innovation exists [77] since adoption of Industry 4.0 technologies and open innovation of SMEs can even be achieved through adoption of e-commerce [78]. However, such adoption needs government intervention and support through "open innovation" policies [79–81]. There are also the possibilities of exploitation in the supply chain [82], thus the need for balancing between the exploitation and exploration was also discussed. Another important need addressed during this pandemic period is the role of universities in open innovation adoption of SMEs [83]. Thus, the inbound open innovation of SMEs can be through the openly available innovations in the market [65], social media [84], inbound and outbound supply chain [85], and through the universities.

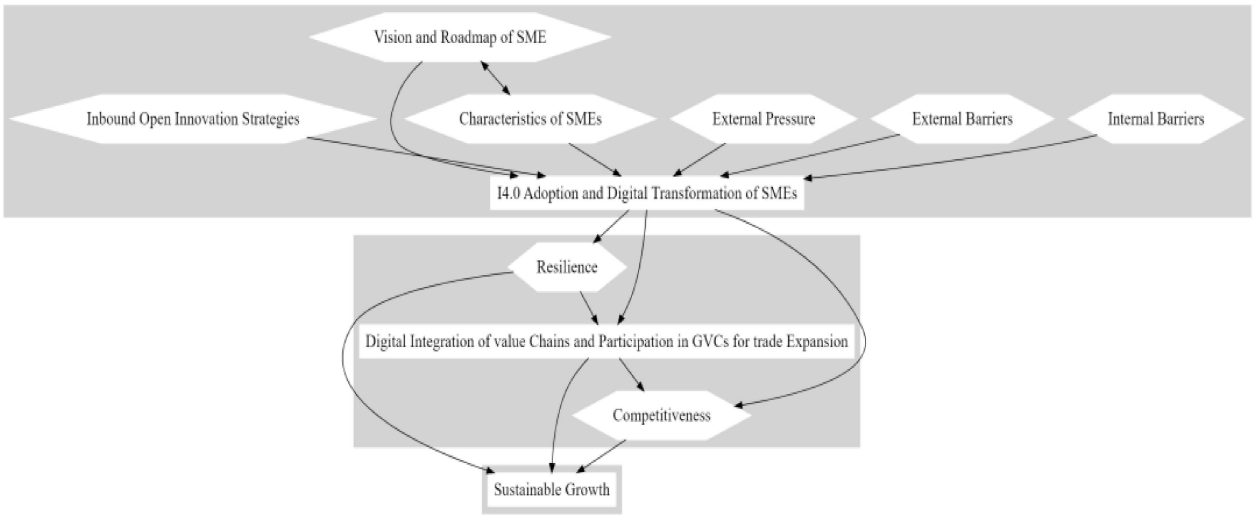

Figure 8. Conceptual framework (based on the findings of review).

7. Conclusions

7.1. Theoretical Implication

This scientometrics and systematic review and its findings cumulated the research performed pre-pandemic and during the pandemic period on Industry 4.0 adoption of

SMEs and elucidated the research shift from technology adoption to open innovation adoption during the pandemic period. Theoretically, this is valuable information for researchers, academicians, and industry experts involved in studying the factors influencing the Industry 4.0 and Industry 5.0 adoptions of SMEs.

7.2. Practical Implication

The model developed (Figure 8) through the systematic review when further tested with inbound open innovation strategies to assess the resilience, digital integration of value chains, and participation in global value chain of SMEs for trade expansion and its causal relationship towards the competitiveness and sustainable growth can reveal more insights on Industry 4.0 adoption and digital transformation of SMEs.

7.3. Limits and Future Research Topic

Although numerous studies have analyzed the Industry 4.0 adoption and implementation, only limited studies suggested the need for a roadmap, and consideration of characteristics of SMEs, internal motivation, and barriers. Thus, there is a need for an integrated framework and a more precise industry-specific research approach for SMEs.

Further, the concept of "Industry 5.0", which is a complementary to "Industry 4.0" with emphasis on human-centric, sustainable resilience of the industries, is already studied by academicians around the world. However, the keyword "Industry 5.0" is not widely adopted. Hence, a universal approach of adopting the keyword "Industry 5.0" is needed to streamline the research in this domain. However, it is too early to clearly define the characteristics of "Industry 5.0 for SMEs" because the research is in its infancy stage. The research findings are limited to articles published in the SCOPUS database. However, the research findings achieved the objectives of this study. Further research with articles published in multiple databases such as Web of Science may reveal more insights in this research domain.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/joitmc8030152/s1, Table S1: PRISMA 2020 Main Checklist; Table S2: PRIMSA Abstract Checklist.

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