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Role of Digitalized Sustainable manufacturing in SME'S: A Bibliometric analysis

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Abstract

The evolution of digital manufacturing is inherently linked with Computer Integrated Manufacturing (CIM) since 1980. CIM triggers the partial or fully automation in the industrial sector. Due to the global competitiveness and mandatory requirement of triple bottom line sustainability approach, the industries are on the verge of adapting digitalized sustainable manufacturing. The Digital manufacturing encompasses the whole integration throughout product life cycle and process, real-time monitoring of entire system, adaption of new innovative technologies in the context of sustainability. Nevertheless, DM is not restricted to a specific area, it includes all the tools and technologies for the quality improvement, customization, and efficient production strategies. The I4.0 technologies are vital elements of the Digital manufacturing paving the way to the sustainability. DM is the culmination of all information and communication technologies with high-speed computation capability, real-time data analysis by AI technology and finally cluster of all innovative technologies. Mostly all large-scale industrial sectors are adapting the digital technologies for existence survival in the international market. But the scenario of SME'S is contradictory, as they are perplexed in financial return, and ambiguous about the impact of these technologies on the accomplishment of overall sustainability. Especially, the adaption of innovative technologies in context of overall sustainability will cause a huge economic burden on the SME'S due to lack of funds and resources, and They must be reinforced by the government legislations and full back support from all corners. However, the past academic research was focused on the economic benefits of the digitalization and seldom efforts on providing insights about the integration of digitalization with triple bottom line sustainability. In addition, they envisioned the profitable aspects of the digital technologies in large scale manufacturing sector. These research gaps had been explored in the current study. The paper aims to conduct a bibliometric analysis on the past research developments in the digitalized sustainable manufacturing enhanced by the visualization software VOS in SME'S for providing a clear insight into the strategies, impediments, and ongoing trend in the small-scale sector.

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Keywords: *Digital manufacturing, Sustainability, Digitalized sustainable manufacturing, Innovation.*

1. Introduction

The world is transforming to digitalization era in which most of the daily activities are highly dependent on innovative digital and computer technologies. These contemporary technologies had profound applications in socio-economic, environmental, sustainability and to foster productivity and efficiency of a given system. Due to the uncontrolled population growth, industrialization, and urbanization the resource consumption, pollution and emissions drastically increases. The present generations are exploiting the resources without considering needs of the future generations. These current scenarios can be mitigated only through the sustainable development. The concept of sustainable development is well defined in the Brundtland report in 1987 "*The human ability to ensure that the current development meets the needs of the present without compromising the ability of future generations to meet their own needs"*. The sustainability developments rely on three pillars- Social, Economic and Environmental. Implementation of sustainability in the Industrial sector is challenging and cumbersome[1]. The Industry 4.0 encompasses numerous

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digital technologies like Internet Of Things (IOT), Cyber Physical Systems (CPS), Artificial Intelligence, Cloud Computing, Big Data Analytics etc. The adaption of these technologies in a traditional environment is hindered by numerous impediments. The key impediments are Organizational, Environmental, Technological, Economical, Societal and institutional where the Organizational dominates among them[1]. Despite of the individual contributions by digital technologies, their inter correlation and combination will foster the sustainability[2],[3][4][5]. The inter-relationship between Artificial Intelligence and Blockchain Technology and it's combined adaption had a progressive effect on sustainability supply chain in manufacturing industry[2]. Magdalena Rusch had depicted the significance of the combination of digital technologies in enhancing the sustainability[6][7]. The digitalization promotes the optimum decision making in an ambiguous environment of construction industry[8][9]. The small and medium scale enterprises (SME) are struggling after the COVID-19 pandemic for meeting global competitiveness in the context of overall sustainability[10][11][12]. The role of AI in fostering the sustainable development and it's hurdles in the implementations is clearly figured out by Xiaoqian Lu[10],[13][14]. In the article by Chiyin Chen, he contended that digital technologies incorporated in the supply chain will accelerate the sustainable development[15]. The social sustainability entails the safe working conditions, good living conditions, human rights, and inclusion of disabled persons. Despite of the benefits of achieving social sustainability, the implementation of digital technologies is hindered by various rigorous barriers[15][16][17][9].The cumulative contribution of all digital technologies and it's inter-relation had not been clearly depicted in the recent studies. For enduring socio-economic development, the role of digital technologies plays a vital role in industry[18]. An extensive literature review had been conducted on the role of digitalization in ensuring sustainability in energy sector[7]. The status quo of the recent literature envisaged the individual contributions to each pillar of sustainability by the adaption of specific digital technologies.

This study aims for the state of art of digitalized sustainable manufacturing and its inherent relationships by conducting bibliometric analysis on the recent articles collected in 2012-2022 and visualization network by VOS. The bibliometric analysis is an efficient and proven tool for providing insights into a specific matter and handling large amounts of unstructured data in rigorous manner. It involves quantitative and qualitative interpretation of bulk amount of data. It encapsulates the following main techniques: 1) Performance analysis, 2) Science Mapping and 3) Enrichment techniques[19]. The performance analysis is the contribution of the research constituents (Publication and citation related matrices) and science mapping is the inter relation between the research constituents (Citation analysis, Co-authorship analysis, Bibliographic coupling)[19]. The enrichment techniques constitute network metrices, Visualization and Clustering. The paper is structured as Methodology, Results and Discussion and References.

2. **Research Methodology**

In this article, a rigorous literature review is conducted on the articles downloaded from the Web of Science databases. The collected articles had undergone through numerous inclusive and exclusive criteria, eventually led to the appropriate articles for analysis. The steps are described in detail below.

2.1. Identifying the scope of study.

The transition to the digitalized era with overall sustainability is a challenging and complicated task with enormous sum of impediments[7][12][20]. The concept of digitalized sustainable manufacturing is burgeoning in the industrial sector, and related academic research is flourishing. The study evaluates the state of art by conducting bibliometric analysis and visualization by VOSviewer. The current paper explores the performance analysis of the research constituents and it's inter-relation by citation analysis, co-citation analysis, co-author analysis, bibliographic coupling with enrichment techniques.

2.2. Data Collection and Analysis.

The publication research was conducted using the Web of Science Core Collection, a database from Clarivate Analytics. It allows the users to depict multidisciplinary areas in single interface and encompasses huge amount of data. The research had been conducted on the selected search strings, which encapsulates all concepts of the digitalized sustainability. The Figure 1 illustrates the research methodology.

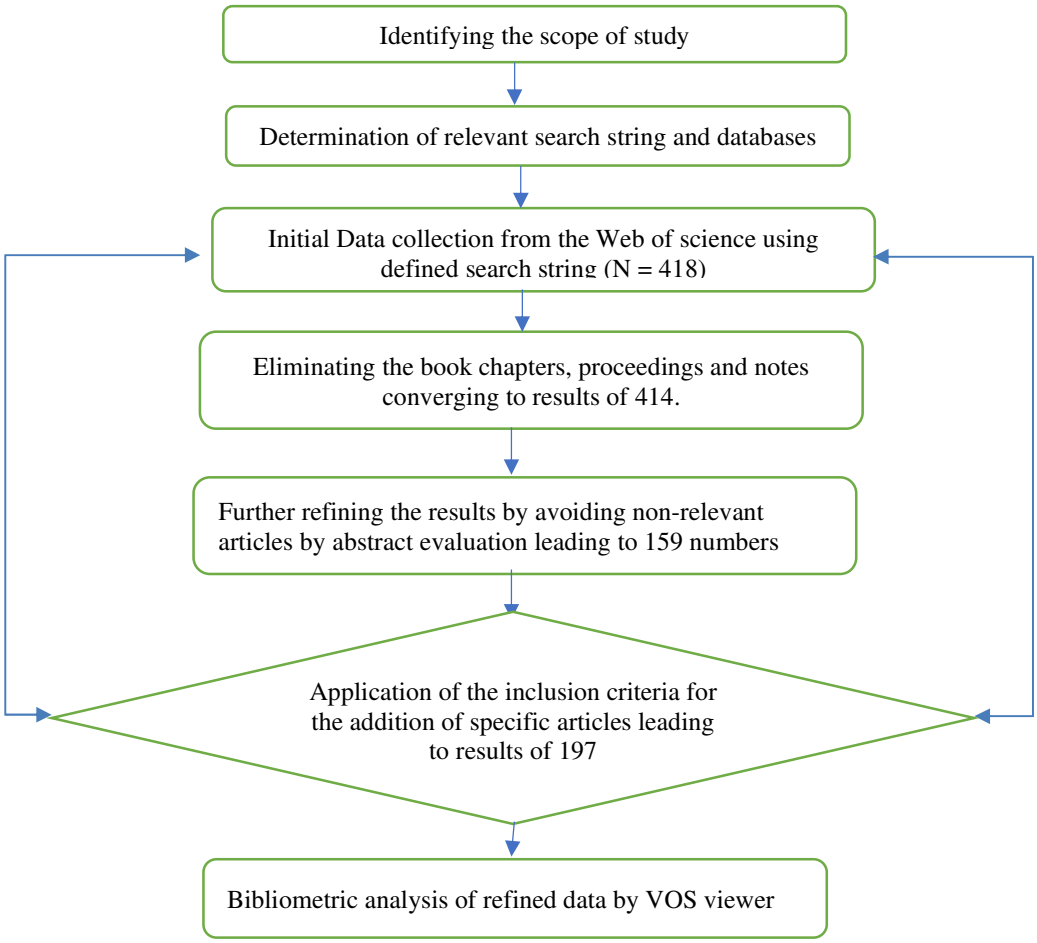


Figure 1: Methodology

3. Result and Discussion

3.1. Bibliometric Data.

The data had been extracted using the Search String: (((ALL= (BARRIERS OR OBSTACLES OR CHALLENGES OR "CRITICAL FACTORS")) AND ALL=("sustainable manufacturing" OR "sustainable development" OR Sustainability)) AND ALL=("digital manufacturing" OR "Digital technologies" OR Digitalization)) NOT ALL=("Industry 4.0" OR "Industry technologies"). The results obtained was 418. Refining the results by applying the exclusion criteria: Book chapters and Proceeding papers and results converge to 414. Further refining by the using the Exclusion criteria: Non relevant publications and articles lead to 159. The inclusion of additional relevant articles leads to the results of 197. The document distribution of the collected databases revealed the Article type with 158 numbers preceded by other types and is shown in the Table 1. The categorization according to the Web of Science shows the maximum number of articles belong to Environmental Sciences followed by Green Sustainable Science Technology with 109 numbers preceded by other categories which is elucidated in Figure 2.

Table 1 Distribution of documents

Sl No	Document Type	Total Numbers	Percentage (%)

1	Article	158	80
2	Review Articles	34	17
3	Early Access	13	6.6
4	Editorial Materials	4	2.03

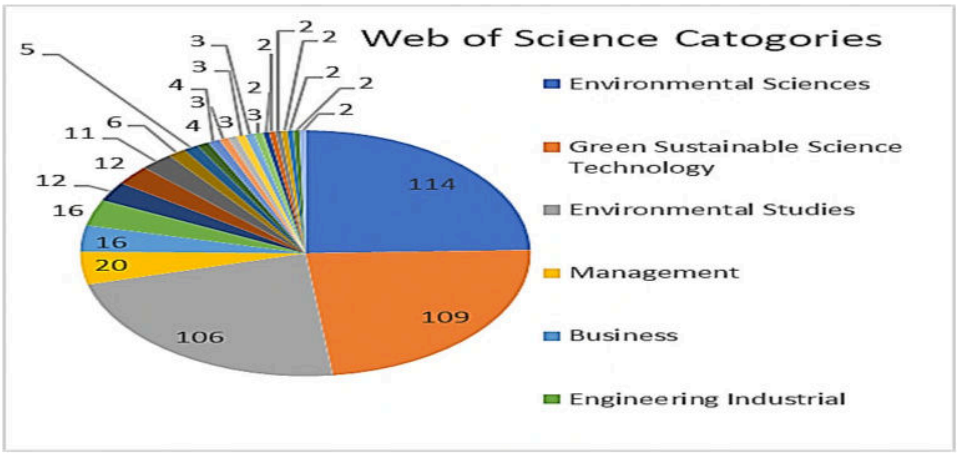


Figure 2 Web of Science Categories

3.2 Performance Analysis.

The contributions of research constituents are illustrated in the performance analysis. The performance of the publishers, authors, sources, or Journals are imperative for the coherent analysis of the extracted data. The total number of publications per year and cumulated amount is illustrated in the Figure 3 with time span from 2002 to 2022.



Figure 3 Total number of publications

The graph elucidate that the publication trend exponentially grows after 2017 progressing with positive trend onwards. This positive trend deciphers the imperativeness of digital sustainability in the industrial sector. Among the publishers

the MDPI and Elsevier and Taylor & Francis holds the huge and relevant published articles in the field. MDPI leads with 105 publications in the digitalized sustainability followed by Elsevier with 34 with huge divergences. The citation of the published article is a quantitative measurement of the topic's compliance with the emerging trend of digitalized sustainable manufacturing. The citation graph spectacles dreadful increase of academic research on digitalized sustainability from 2019 to present, which is a positive sign in the industrial sector engrossing on the implementation of digitalized sustainability concepts. In ranking of the publications w.r.t the citations, "Direct digital manufacturing: definition, evolution, and sustainability implications" by Chen et al ranked first with 212 citations The graph elucidate that the publication trend exponentially grows after 2017 progressing with positive trend onwards. This positive trend decipher the imperativeness of digital sustainability in which is a positive sign in the industrial sector engrossing on the implementation of digitalized sustainability concepts. In which is a positive sign in the industrial sector engrossing on the implementation of digitalized sustainability concepts. In ranking of the publications w.r.t the citations, "Direct digital manufacturing: definition, evolution, and sustainability implications" by Chen et al ranked first with 212 citations followed by "Industry 5.0-A Human-Centric Solution" by Nahavendi et al. The article by Chen was published in Journal of Cleaner Production having an average citations per year of 26.5. Both papers attributed the imperativeness of digitalized sustainability implementation in the industrial sector and profound knowledge on hurdles and its related strategies [21][22]. The study by Nahavendi et al provides clear insights on the transition to digitalization on the context of sustainable manufacturing[22]. The article "Reviewing Literature on Digitalization, Business Model Innovation, and Sustainable Industry: Past Achievements and Future Promises" elucidate the key barriers and formulate a framework linking the digitalization and sustainability for fostering productivity [24].

3.3 Science Mapping

The science mapping or Bibliographic mapping portrayed the inter-relationship between the research constituents [19]. The mapping encompasses citation analysis, co-citation analysis, co-author analysis, bibliographic coupling with enrichment techniques. This delineated the intellectual and structural relationship between publications, authors, co-authors, keywords, and journals. In co-citation analysis thematic clusters are built upon the cited publications. The co-citation enables to sort out the most influential publication. The co-citation analysis of references had been done with fraction counting method resulting 15442 references. The minimum number of citations is limited as 5 and 66 references meet the threshold value with highest total link strength 13. The analysis visualized through network diagram with 6 clusters as shown in Figure 4. The Cluster 1 with 19 items, Cluster 2 with 17 items, Cluster 3 with 12 items, Cluster 4 with 10 items, and Cluster 5 with 8 items.

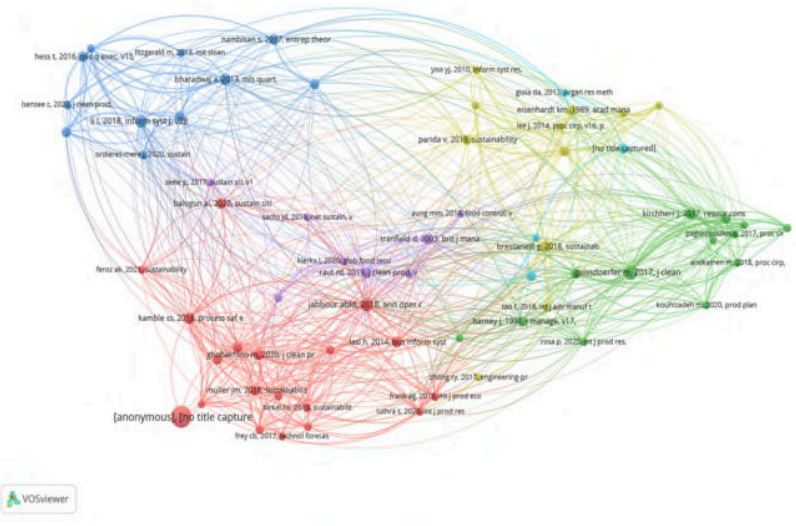


Figure 4 **Cluster Visualization**

The article "Circular economy, the transition of an incumbent focal firm: How to successfully reconcile environmental and economic

sustainability?" by Gandolfo et al was the most influential one with total link strength of 13, which articulated strategies for implementing the CE principles in conjunction with digital manufacturing in a tissue manufacturing company at Europe for achievement of the overall sustainability. The keyword co-occurrence is an efficient analysis for knowledge mapping. In analysis each node represented the keyword and link represents the co-occurrence between them. The total weight of the link represents the number of times the keywords is cited in the articles. In the study minimum number of occurrences of keyword is selected as 5, which resulted in 71 numbers from 1243 keywords. The keyword Sustainability is the highest with total link strength of 345 and occurrences of 75 preceded by digitalization with 56 occurrences having total link strength of 246. The keywords encompass Cluster 1(26 items), Cluster 2(15 items), Cluster 3(13 items), Cluster 4(9 items) and Cluster 5(8 items). Each cluster shows a thematic distinction between them. The Table 2 represents the top cited articles in the digitalized sustainable manufacturing.

Table 2 Top ten cited articles.

S. No	Title	Authors	Source Title	Total Citations	Average Per Year
1	Direct digital manufacturing: definition, evolution, and sustainability implications	Chen, Danfang et al	Journal of Cleaner Production	212	26.5
2	Industry 5.0-A Human-Centric Solution	Nahavandi, Saeid	Sustainability	130	32.5
3	Reviewing Literature on Digitalization, Business Model Innovation, and Sustainable Industry: Past Achievements and Future Promises	Parida et al	Sustainability	126	31.5
4	Consumption in the Circular Economy: A Literature Review	Camacho-Otero et al	Sustainability	97	19.4
5	Challenges for the cyber-physical manufacturing enterprises of the future	Panetto, et al	Annual Reviews in Control	96	24
6	A survey of smart product-service systems: Key aspects, challenges and future perspectives	Zheng, et al	Advanced Engineering Informatics	94	23.5
7	Sustainable supply chain management in the digitalisation era: The impact of Automated Guided Vehicles	Bechtsis, et al	Journal of Cleaner Production	83	13.83
8	Digital Economy as a Factor in the Technological Development of the Mineral Sector	Litvinenko, V. S.	Natural Resources Research	66	16.5
9	A framework for food supply chain digitalization: lessons from Thailand	Kittipanya-ngam, et al	Production Planning & Control	63	15.75
10	Assessing the Potentials of Digitalization as a Tool for Climate Change Adaptation and Sustainable Development in Urban Centres	Balogun et al	Sustainable Cities and Society	56	18.67

The sustainability is the keyword with highest occurrence weight (75) and linked with digitalization, digital transformation, Industry, management, and transformation This clearly stipulates the transition of traditional manufacturing into sustainable mode by rectifying all hurdles. By analysing the top listed co-occurrence keywords-Sustainability, Digitalization, Management, Challenges and framework, the phase change is in a predictable manner

with all perplexities. However, the achievement of fully digitalized sustainable manufacturing is a challenging and cumbersome task [21]. The geographical distribution of the article will depict the contribution of each country on the research domain. The 197 articles in this study were from 66 countries with 24 countries contributing more than 5 documents. In the contribution England ranks first with 33 documents followed by Italy, USA, and Germany. The developed countries are in the front foot as they have surplus funds and supports from agencies.

4. Conclusion

This paper demonstrates the current state of art of the digitalized sustainable manufacturing aspects in the Industrial sector especially SME'S by using the principles of bibliometric analysis. The study reveals that the transition to digitalization is a cumbersome and challenging task. The network analysis of the collected articles depicts that the major contributor is the developed country with surplus amount of funds and other supports. The research is narrowing down to the concept of digitalized sustainable manufacturing. Further industries are facing the impediments for this adaption mainly SME and other specific industries like piping spool fabrication Industry, mining industry etc. The SME are facing the financial risk of these transition and unaware of the impact. The key hurdles in the adaption of the digitalized sustainable concepts are lack of awareness in the area, unaware of the impact and consequences by the adaption, huge initial cost and completely encompassing with all perplexities and unawareness. The Industrial 4.0 technologies had the potential for the transition from traditional to digitalized sustainability paradigm. However, all Industrial 4.0 technologies will not provide specific contribution to sustainability development. The sustainability functions has to be formulated accordingly w.r.t the unique nature of the industry. The scenario in the developing countries is contradictory compared to those with developed countries, mainly due to lack of rigidness of change and management support. As the SME'S contributes a substantial proportion in the nation economy, the government and related bodies should formulate policies and strategies for monetary assistance. The future research should evaluate the specific contribution of each Industry 4.0 technologies to sustainability and integrate with business strategies of the organizations. This strategy and policies will be unique and collectively promote the overall sustainability of the companies.

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