The development of blockchain technology in manufacturing: A bibliometric analysis

Huma Sikandar[*]*, Nohman Khan*[**]*, Muhammad Imran Qureshi*[***]*, Sabeen Bhatti*[****]

Received 03 May 2023 – Accepted 28 June 2023

Abstract

Many manufacturing organizations have adapted their governance systems, strategies, business models, and strategic processes in the "New Normal" and technologies like Blockchains have irreversibly transformed how people live and work. Despite extensive scholarly research, analysing emerging trends in Blockchain research remains critical. Unfortunately, the use of bibliometric analysis to study Blockchain has been limited, with little understanding of how its various research areas are progressing. Bibliometric analysis, a useful method for examining the development of research, has not been widely used in the context of blockchain. The progression of its numerous research areas is also yet unknown. This study seeks to fill these gaps by employing bibliometric analysis to assess scientific progress and research focus on Blockchains in manufacturing. We used Vos Viewer to conduct this bibliometric analysis to evaluate 265 papers published from 2017 to 2022 using co-authorship and co-occurrence of keywords analysis. We have identified the most productive authors, institutions, countries, and top research fields, highlighting the essential advancements in the Blockchain field. The findings demonstrate how keywords related to Blockchain have changed over time and describe the research hotspots. The originality of this research lies in its application of bibliometric analysis to examine the development and emerging trends in Blockchain research within the manufacturing domain while offering novel insights into the productivity of authors, institutions,

[*] Ph.D. Student. Universiti Teknologi Malaysia. huma.sikandar@gmail.com

[**] Ph.D in Management from UniKL Business School Universiti Kuala Lumpur, Malaysia. nohman.khan@s.unikl.edu.my

[***] Ph.D. in Operations Management from Universiti Teknologi Malaysia. M.Qureshi@tees.ac.uk

[****] Associate Fellow. Teesside University. s.bhatti@tees.ac.uk

Corporate Governance and Research & Development Studies, n. 2-2023
(ISSN 2704-8462-ISSNe 2723-9098, Doi: 10.3280/cgrds2-2023oa15802)

and countries, as well as identifying research hotspots and future research directions. This study contributes to the inadequate body of literature on bibliometric analysis in Blockchain research and provides useful guidance for researchers and practitioners in the field.

Keywords: Blockchains, blockchain technology, bibliometric analysis, VOS viewer.

Sommario

Molte organizzazioni manifatturiere hanno adattato i loro sistemi di governance, strategie, modelli di business e processi strategici nel "New Normal", laddove tecnologie come la Blockchain hanno trasformato irreversibilmente il modo in cui le persone vivono e lavorano. Nonostante l'ampia ricerca accademica, l'analisi delle tendenze emergenti nella ricerca sulle Blockchain rimane fondamentale. Sfortunatamente, l'uso dell'analisi bibliometrica per studiare le Blockchain è stato limitato, con poca comprensione di come stanno progredendo le varie aree di ricerca. L'analisi bibliometrica, un metodo utile per esaminare lo sviluppo della ricerca, non è stata ampiamente utilizzata nel contesto della blockchain. Anche la progressione delle sue numerose aree di ricerca è ancora sconosciuta.

Questo studio cerca di colmare tali lacune impiegando l'analisi bibliometrica per valutare il progresso scientifico e l'attenzione della ricerca sulle Blockchain nella produzione. Abbiamo utilizzato Vos Viewer per condurre questa analisi bibliometrica, valutando 265 articoli pubblicati dal 2017 al 2022 eed utilizzando la co-paternità e la co-occorrenza dell'analisi delle parole chiave. Abbiamo identificato gli autori, le istituzioni, i paesi e i principali campi di ricerca più produttivi, evidenziando i progressi essenziali nel campo della Blockchain. I risultati dimostrano come le parole chiave relative alle Blockchain siano cambiate nel tempo e descrivano i punti caldi della ricerca.

L'originalità di questa ricerca risiede nell'applicazione dell'analisi bibliometrica per esaminare lo sviluppo e le tendenze emergenti nella ricerca Blockchain all'interno del settore manifatturiero, offrendo al contempo nuovi approfondimenti sulla produttività di autori, istituzioni e paesi, oltre a identificare la ricerca hotspot e direzioni di ricerca future. Questo studio contribuisce all'inadeguatezza della letteratura sull'analisi bibliometrica nella ricerca Blockchain e fornisce una guida utile per ricercatori e professionisti del settore.

Parole chiave: Blockchains, blockchain technology, bibliometric analysis, VOS viewer.

1. Introduction

Technology-driven practices are embedded within the organizations in the new normal (Carroll and Conboy, 2020; Singh *et al*., 2022) as the pandemic created a transformative environment in which individuals and

companies rapidly adopted digitalization (Bag *et al*., 2021). Blockchain technology is the most recent 'disruptive innovation' that has piqued the interest of academicians and scholars. Bitcoin is the first and the most well-known blockchain application. According to Adam Hayes, 2022 Blockchain is "a decentralised ledger" that secures, verifies, and transparently maintains all transactions done on top of a peer-to-peer network (Hayes, 2022). The primary advantage of Blockchain over traditional technology is that it enables two parties to perform secure Internet transactions without the need for a third party. The technique is simple yet powerful, consisting of a chain of information blocks, each of which is validated by a distributed network of nodes. The blockchains are classified into three categories in order to conceptualise the rapid development of blockchain technologies that is blockchain 1.0, blockchain 2.0, and blockchain 3.0 (Raja Santhi & Muthuswamy, 2022; Swan, 2015; Zhang & Jacobsen, 2018). Blockchain 1.0 is the currency in the same way as digital payment and cryptocurrencies are. Smart contracts are at the heart of Blockchain 2.0. Blockchain 3.0 has potential in areas other than financial, such as government, health, science, arts, and culture. However, according to the previously stated principle, contemporary blockchain applications are still in the 1.0 and 2.0 stages. Research conducted recently has looked into the potential of blockchain to help citizens reclaim control over their personal information (Mainelli, 2017), make the insurance business more transparent (Disparte, 2017), manage supply chains (Tönnissen & Teuteberg, 2020; Queiroz, Fosso Wamba, 2019), manage employee benefits (Ying *et al*., 2018) transform electronic health records (Mayer *et al*., 2020) (Epiphaniou *et al*., 2019; Madir, 2020; Yeung, 2021) and manufacturing processes (Ghimire *et al*., 2022; Kurpjuweit *et al*., 2021; Agarwal, 2018).

Blockchains are used in sectors that value openness, automation, and a verifiable ledger. Healthcare, finance, energy, government, and manufacturing are just a few of the areas that potentially benefit from Blockchains (Ghimire *et al*., 2022). Due to the distinctive breakthroughs in decentralisation and security, the recent development of blockchain technology offers a potentially practical solution. Blockchains are classified into three types: public, private, and federated or consortium (Raja Santhi & Muthuswamy, 2022). The public Blockchain allows you to view, write, and check the blockchain. It is completely decentralised. In contrast, only one individual or organisation is authorised to write to a private Blockchain. It lacks essential decentralisation properties. Finally, the federated Blockchain allows for the management of several organisations. It has a group of organisations or people who make decisions mutually for the network's best interests.

A blockchain is "a database architecture which enables the keeping and sharing of records in a distributed and decentralized way, while ensuring its

integrity through the use of consensus-based validation protocols and cryptographic signatures" (Benos *et al*., 2017, p.1). The resulting blockchain is saved on each node, constituting a distributed database network, rather than on a single server. Blockchain offers inherent security, record immutability, transaction transparency, digital information authenticity, data ownership, and the ability to replace trust in intermediary organisations with trust in cryptographic consensus (Beck *et al*., 2016; Christidis, Devetsikiotis, 2016). In the context of supply chains, blockchain is projected to act as a seamless peer-to-peer network infrastructure in which each supply chain participant would have access to a reliable source of data in the form of distributed copies of blockchain transactions (Kurpjuweit *et al*., 2021). To summarise, the key features of blockchain are depicted in Fig. 1.

Figure 1. Features/benefits of Blockchains

While Bitcoin and other financial blockchain applications get the most attention, organisations in the industrial manufacturing industry are also developing novel commercial solutions based on the technology. Manufacturers are discreetly experimenting with blockchain applications that are changing the way businesses communicate. Simply said, blockchain technology could transform the way manufacturers create, design, build, and scale their goods. It is paving the way for a future with increased trust, streamlined processes, transformed pricing, and more security. Blockchains in manufacturing are more subtle than blockchains in finance.

As manufacturers around the world become more interconnected, the

importance of blockchains is growing in the manufacturing sector as well. Now, more than ever before, manufacturers face the challenge of securely sharing data within and outside factory walls. Manufacturing is the transformation of raw materials or parts into finished products through a variety of tools, machinery, chemical processing and labour. The primary four departments of the manufacturing industry include engineering, IT and finance, operations, and marketing (Raja Santhi & Muthuswamy, 2022). Manufacturing, production planning, maintenance, quality control, supply chain, logistics, packing, and dispatch are all examples of operations. Several applications for blockchains have been identified in manufacturing and supply chain management (Kurpjuweit *et al*., 2021; Wamba & Queiroz, 2020; Zhao, 2020). Blockchain can enhance transparency and trust at every stage of the industrial value chain. It is, basically, a decentralised ledger that allows two parties to trade value without the need for a third party.

Ever since the industrial revolution, we have seen remarkable progress in technologies that make up the tangible manufacturing process. Machines communicate with one another, and they are controlled by software that trades data at incomprehensible rates on the cloud and can be sometimes vulnerable to outside sources. In such a scenario the manufacturing sector needs to protect sensitive personal data. Manufacturers are increasingly focusing on integrating blockchain technology into their manufacturing processes as a result of concerns like data protection. Data is the most valuable resource on the planet right now (Kessler, 2019). The core of blockchain in the manufacturing industry is classifying and safeguarding data ownership and legality. The real challenge of ensuring product visibility at every stage remains unaddressed, even though many large enterprises have long moved away from conventional methods of tracking their products, such as Excel sheets, emails and physical ledgers in favour of IT-based technology infrastructure (Klapita, 2021; Jiménez & Muñoz, 2006). Furthermore, because conventional manufacturing processes are centralised database management technologies, they are vulnerable to manipulation and security threats.

Manufacturers have become much more aware of blockchain technology's potential usage in their processes, but in practicality, it is still a few years away. A private blockchain is an appealing alternative for industrial applications due to data privacy and the flexibility to select network participants. Blockchain can manufacture better, more intelligent, and increasingly secure supply chains, tracking an item's voyage consistently.

In the past few years, the rapid development of Blockchain technology has created numerous research gaps and directions for the scientific community(Abbas *et al*., n.d.). As a result, a significant amount of research has been conducted in the field of Blockchain (Sharma *et al*., 2018; Xia *et al*., 2017;

Cruz *et al*., 2018). Over a thousand scientific publications have recently been published and indexed in the Web of Science, not to mention other similar databases (Dabbagh *et al*., 2019). Given the increasing quantity of research papers in the field of Blockchain, there is a need for research studies that examine the present state of knowledge in this area. To meet this demand, a bibliometric analysis of the current literature on blockchains and their applications in the manufacturing sector is carried out in order to examine past research trends and emerging topics in the literature for future research, as well as identify top authors, countries, journals, and institutions. Few review articles have been published to explain the recent developments and challenges in blockchains (Karafiloski & Mishev, 2017; Meng *et al*., 2018; Khan & Salah, 2018; Tama *et al*., 2017; Frizzo-Barker *et al*., 2020; Andoni *et al*., 2019) and few bibliometric analysis have been conducted (Niknejad *et al*., 2021; Guo *et al*., 2021; Duan & Guo, 2021; Luo *et al*., 2021; Musigmann *et al*., 2020; Hakim & Bahari, 2021). However, to the best of the author's knowledge, no bibliometric analysis of the state-of-the-art in blockchain in the manufacturing area has yet been published in which Scopus or any similar database has been used as a literature database. As a result, to keep making continuous development in this area, a thorough bibliometric analysis of recent scientific papers in the Blockchain in manufacturing sector is required, with the goal of providing useful information to the Blockchain research community.

The primary goal of this study is to gather, describe, and analyse the blockchain research publications in the manufacturing industry that have been indexed by Scopus. To accomplish this, we conducted a bibliometric analysis of the Blockchain literature to offer some useful insights to current researchers and practitioners in the field. This study aims to answer the following research questions to provide significant insights to existing scholars and practitioners in the field of blockchain research in the manufacturing industry:

1. What are the annual publication trends and prior research patterns in the manufacturing industry's blockchain research?
2. Who are the most productive authors, which publications are the most prominent, and which nations have made substantial contributions to blockchain research in manufacturing?
3. Which research articles on blockchain in manufacturing have acquired a high number of citations, suggesting their impact and significance?
4. What are the most popular publication venues for disseminating research on blockchains in the manufacturing sector?
5. What are the well-established and emerging keywords in blockchain research?

To answer the research questions mentioned above, this study gathered,

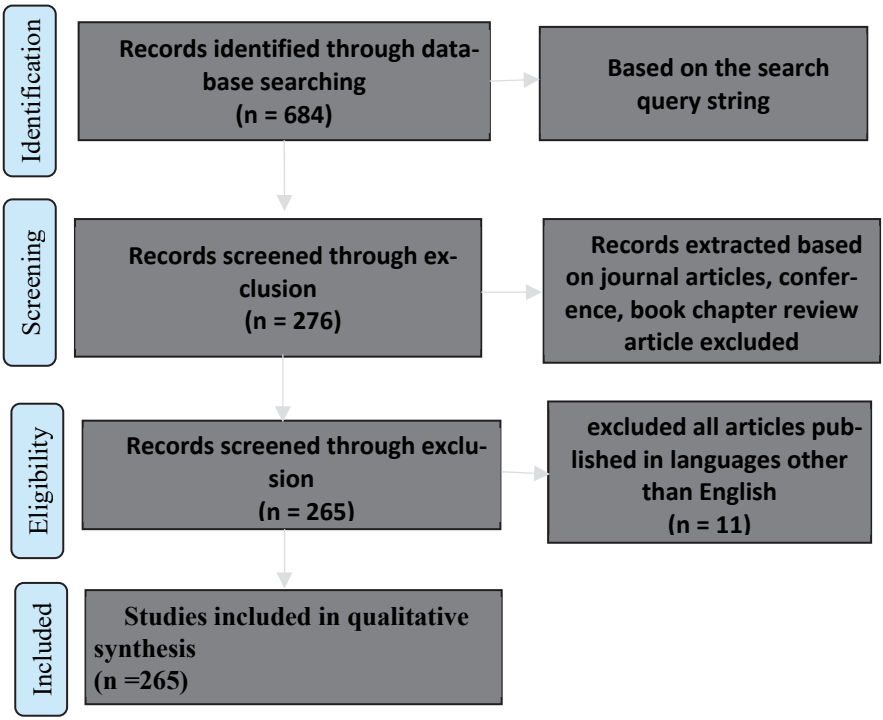
described, and examined blockchain research publications that are listed in the Scopus index. The analysis's findings offer important new perspectives on yearly publication patterns, significant contributors, significant articles, and changing keywords and publication venues in blockchain research for the manufacturing sector. These results act as a conduit for knowledge that can guide current work in the field of blockchain in manufacturing as well as future study and practice.

The rest of this paper is structured as follows. Section II explains the research methods used in this study. Section III gives the detailed findings from the bibliometric analysis. Section IV wraps up this research and describes future work.

2. Methodology

We conducted a bibliometric study on scholarly research on blockchain technology in the domain of manufacturing. Bibliometrics is a quantitative method for visualising and synthesising a body of knowledge on a certain topic (Sikandar *et al*., 2022). The bibliometric analysis in this study was performed with VOS viewer software. Our search period included the years 2017 to 2022. The search was performed on 18th May 2022. The overall procedure of selecting and rejecting the pertinent articles is described using the preferred reporting items for systematic reviews and meta-analyses (PRISMA) statement template. The PRISMA statement aids researchers in enhancing the reporting of review articles (Sikandar & Abdul Kohar, 2021). The articles were then assessed for relevance to our study using the inclusion criteria. The terms blockchain and manufacturing were used as primary terms in the title and abstract of the article to be considered in the analysis. In this study, we only included academic peer-reviewed journal publications, excluding conference papers, book chapters, and review articles, as well as those articles that were not available in English. The records originally identified through the search query were 684. The total number of articles on which the bibliometric analysis was performed was 265. The inclusion and exclusion criteria of the articles are mentioned in Fig. 2.

Figure 2. Search Flow Chart based on PRISMA

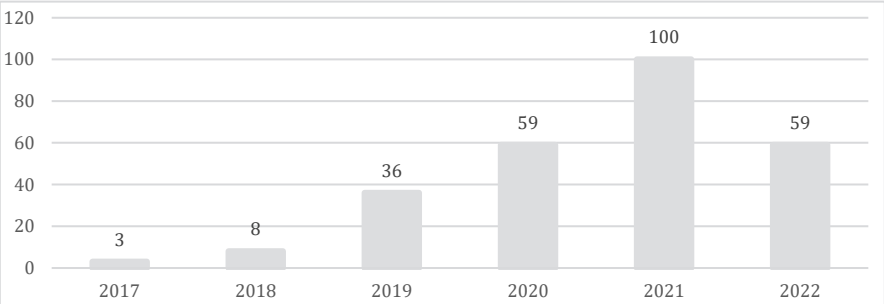


3. Results

3.1. Publication Trend

Fig. 3 depicts the publication growth of articles published in the blockchains in the manufacturing sector. The growth of articles has essentially increased from 2017 to 22. Although the year 2022 is still going on, the number of articles published has already reached the entire number of articles published in 2020. The year 2021 has the most published articles. However, given the current trend in the year 2022, the total number of published papers in the field is expected to exceed the total number of published articles in the year 2021. Because of the increased interest of academics and practitioners in blockchains, this pattern is likely to persist in the future.

Figure 3. Publication Trends in Blockchains research in the manufacturing sector



3.2. Top journals and authors

The top journal that published research articles on blockchains in the manufacturing sector has been identified. IEEE Access, with 16 published articles and 336 citations, appears to be the leading journal with the most publications. It was followed by the International Journal of Production Research and Sustainability Switzerland, which each published 10 articles with 177 and 206 citations.

Table 1. Top journal in blockchains research

Source	Documents	Citations	Publisher
IEEE Access	16	336	IEEE
International Journal of Production Research	10	177	Taylor & Francis
Sustainability Switzerland	10	206	Multidisciplinary Digital Publishing Institute (MDPI)
IEEE Internet of Things Journal	8	143	IEEE
IEEE Transactions on Industrial Informatics	8	190	IEEE
Sensors	7	20	Multidisciplinary Digital Publishing Institute (MDPI)
International Journal of Production Economics	6	24	Elsevier
Journal of Manufacturing Systems	6	59	Elsevier
Technological Forecasting and Social Change	5	19	Elsevier
Annals of Operations Research	4	23	Springer Nature

Table 2 lists the top 10 authors who have contributed to the blockchains literature in the manufacturing sector. The top author in the said field is Raja Jayaraman from UAE followed by Zhi Li from China and Mohammed Omar from UAE. The complete details of the top 10 authors including their h index, total publications, current affiliations and total citations are listed in Table 2.

Table 2. Top 10 most productive authors

Rank	Author	TP	Scopus Author ID	h-index	Current affiliation	Country	Year of 1st Publication	Total citations
1	Jayaraman, R.	5	14520494400	21	Khalifa University of Science and Technology, Abu Dhabi	United Arab Emirates	2020	99
2	Li, Z.	5	57189370824	24	Guangdong University of Technology, Guangzhou	China	2018	383
3	Omar, M.	5	23101060500	27	Khalifa University of Science and Technology, Abu Dhabi	United Arab Emirates	2020	99
4	Salah, K.	5	35617663600	37	Khalifa University of Science and Technology, Abu Dhabi	United Arab Emirates	2020	99
5	Byun, Y.C.	4	8897891700	16	Jeju National University, Jeju	South Korea	2021	64
6	Huang, G.Q.	4	7403425048	58	The University of Hong Kong, Pokfulam	Hong Kong	2018	363
7	Leng, J.	4	57188970257	24	Guangdong University of Technology, Guangzhou	China	2019	218
8	Shahbazi, Z.	4	57212241946	7	Jeju National University, Jeju	South Korea	2021	64
9	Singh, S.K.	4	57211843264	11	Seoul National University of Science and Technology (SNUST), Seoul	South Korea	2020	89
10	Tao, F.	4	12141248300	64	Beihang University, Beijing	China	2019	88

3.3. Top cited articles

We found the top ten most cited articles in blockchain research through our study. Table 3 lists the top ten most cited articles.

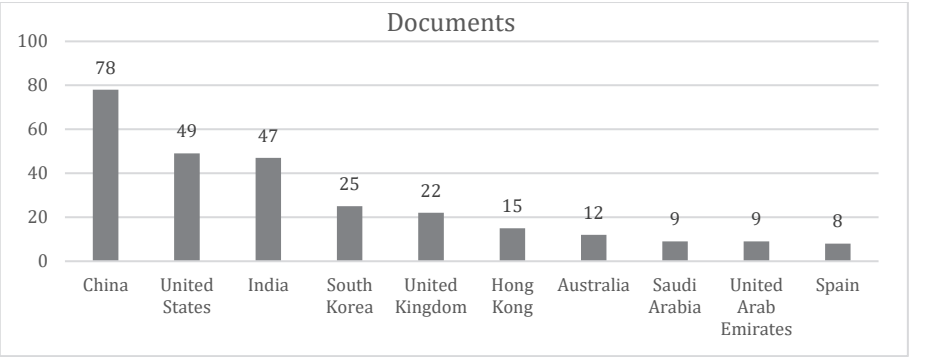
Table 3. Top cited articles in blockchains area in the manufacturing domain

Rank	Authors	Title	Year	Source Title	Citations
1	Lin C., He D., Huang X., Choo K.-K.R., Vasilakos A.V.	BSeIn: A blockchain-based secure mutual authentication with a fine-grained access control system for industry 4.0	2018	Journal of Network and Computer Applications	199
2	Zhao G., Liu S., Lopez C., Lu H., Elgueta S., Chen H., Boshkoska B.M.	Blockchain technology in agri-food value chain management: A synthesis of applications, challenges and future research directions	2019	Computers in Industry	167
3	Li Z., Barenji A.V., Huang G.Q.	Toward a blockchain cloud manufacturing system as a peer-to-peer distributed network platform	2018	Robotics and Computer-Integrated Manufacturing	156
4	Li Z., Wang W.M., Liu G., Liu L., He J., Huang G.Q.	Toward open manufacturing, a cross-enterprises knowledge and services exchange framework based on blockchain and edge computing	2018	Industrial Management and Data Systems	154
5	Tang C.S., Veelenturf L.P.	The strategic role of logistics in the industry 4.0 era	2019	Transportation Research Part E: Logistics and Transportation Review	139
6	Dutta P., Choi T.-M., Somani S., Butala R.	Blockchain technology in supply chain operations: Applications, challenges and research opportunities	2020	Transportation Research Part E: Logistics and Transportation Review	129
7	Mandolla C., Petruzzelli A.M., Percoco G., Urbinati A.	Building a digital twin for additive manufacturing through the exploitation of blockchain: A case analysis of the aircraft industry	2019	Computers in Industry	114
8	Fraga-Lamas P., Fernández-Caramés T.M.	A Review on Blockchain Technologies for an Advanced and Cyber-Resilient Automotive Industry	2019	IEEE Access	112
9	Olsen T.L., Tomlin B.	Industry 4.0: Opportunities and Challenges for operations management	2020	Manufacturing and Service Operations Management	111
10	Lee J., Azamfar M., Singh J.	A blockchain enabled Cyber-Physical System architecture for Industry 4.0 manufacturing systems	2019	Manufacturing Letters	107

3.4. Leading countries

It has been discovered that China is the leading country in terms of blockchain research publications in the manufacturing sector, with 78 publications. It is followed by the United States, which has 49 publications on the topic, and India, which has 47 publications in the field. Fig. 4 shows the top 10 countries that published the most articles in the stated field.

Figure 4. Most productive countries in blockchain research in manufacturing



4. Bibliometric Analysis

A bibliometric map depicts items and their links. For instance, the number of publications two scholars co-authored together (in the case of co-authorship links) or the number of publications where two terms occur together may be indicators of the strength of a link (in the case of co-occurrence links). A network, precisely, is a collection of items and the links connecting those items. The links attribute displays the number of co-authorships links a certain researcher has with other researchers in the case of co-authorship of authors and certain countries with each other in the case of co-authorship of countries. The total link strength (TLS) attribute represents the total strength of a researcher's co-authorship links with other researchers (Jan van Eck & Waltman, 2021).

4.1. Co-Authorship Analysis of Countries

Co-authorship analysis was conducted to determine the collaboration among authors from different geographical regions. The minimum number

of countries for the co-authorship of countries analysis was set at 5, implying that only documents with a minimum of three published documents per country should be chosen. Consequently, thirty countries out of eighty-three matched the criteria.

We discovered that China had the most publications (n=80) and citations (n=1615), as well as the highest connections with countries, with 19 linkages and a total link strength of 54, based on co-authorship analyses. The United States came in second, with 18 links, a total link strength of 40, and 50 published papers with 1357 citations. India ranked third in the collaborative research in blockchains, with 17 links, a total link strength of 34, 48 total published publications and 556 citations. Table 4 lists all 33 nations, together with their link strength, the number of documents, and total citations, and Fig. 6 displays a screenshot from the VOS viewer illustrating the relationships between the countries. The close proximity of the two countries in the figure denotes their close relationship.

Figure 5. Bibliometric map of co-authorship analysis of countries, available online at URL: https://bit.ly/38cOU88

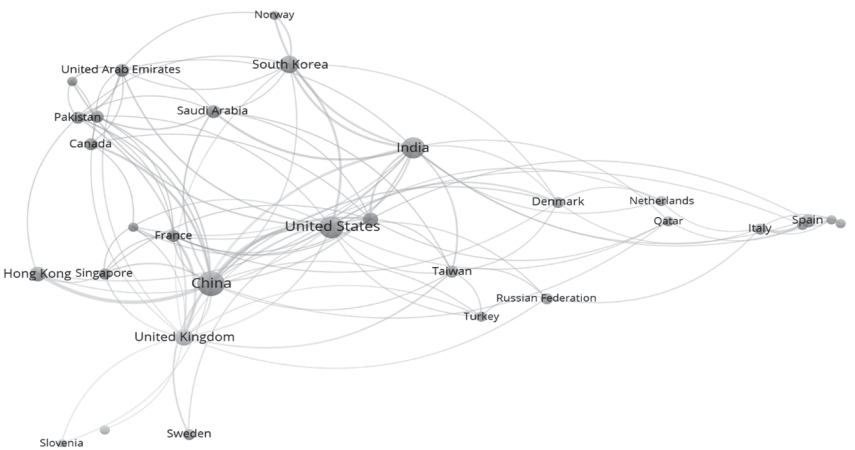


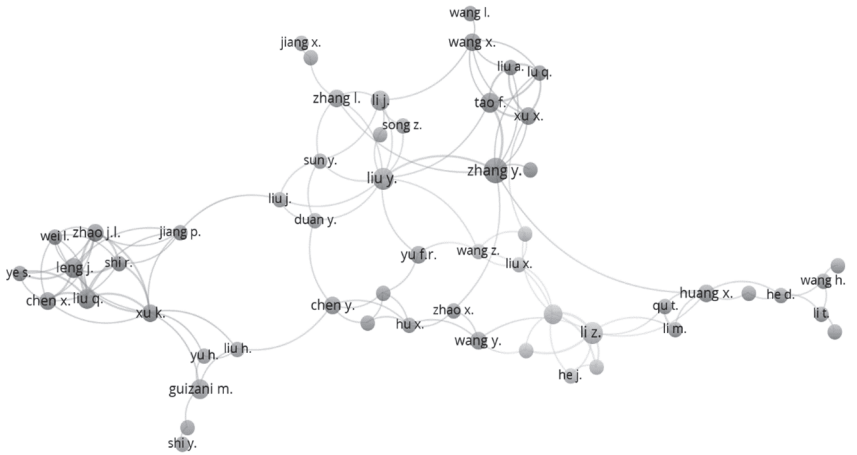
Table 4. Results of country-based co-authorship analysis as per their total link strength (TLS)

Countries	Links	TLS	Documents	Citations
China	19	54	80	1615
United States	18	40	50	1357
India	17	34	48	556
United Kingdom	16	28	22	435
Australia	12	19	12	210
France	10	17	7	21
South Korea	9	16	25	354
Hong Kong	5	14	15	707
Pakistan	10	14	7	81
Saudi Arabia	8	13	9	82
United Arab Emirates	10	13	9	123
Taiwan	9	11	7	58
Denmark	8	10	6	63
Malaysia	6	9	7	44
Canada	5	8	7	164
Italy	7	8	6	146
Morocco	7	8	3	8
Singapore	6	7	6	64
Spain	6	7	8	165
Ireland	6	6	4	35
Kuwait	4	6	3	42
Norway	3	6	3	12
Portugal	5	5	3	10
Qatar	5	5	4	75
Russian Federation	5	5	5	26
Turkey	5	5	4	44
Greece	4	4	3	16
Netherlands	4	4	4	197
Sweden	2	3	6	235
Slovenia	2	2	3	174
Hungary	1	1	3	157

4.2. Co-Authorship (Authors)

A co-authorship analysis of authors is carried out to determine the authors who contributed to the field's advancement through collaboration. The main research method for studying research collaboration (RC) is co-authorship analysis (Chen *et al*., 2019). The connections in the co-authorship analysis represent the overall number of co-authorship linkages with other researchers. The total link strength (TLS) gauges the quality of a researcher's collaborations with other researchers (Van Eck & Waltman, 2018).

Figure 6. Bibliometric map showing Co-authorship analysis of authors in network visualisation mode, available online at URL: https://bit.ly/3yNcYJz



In the Vos viewer, to perform the co-authorship analysis the minimum number of authors for co-authorship analysis was set to 2 and the minimum number of citations for an author was set to 0. Out of 857 authors, only 105 met the criteria. 56 of the 105 authors were closely linked, forming seven clusters (as displayed in Fig. 6). This demonstrates how these 56 authors are well connected and how they have enriched the literature through collaborative research work.

As a result of the co-authorship analysis, we found out that Leng J. has the highest overall link strength (TLS=17) with 4 published documents and 203 citations, followed by Liu Q. (TLS=17, documents=4 and citations=203), and Xu K. (TLS=14, documents=3 and citations=226). Table 5 shows the linkages, TLS, documents, and citations for the top 10 writers according to their TLS. It's worth mentioning that Li Z. has the most citations (n=371), whereas Zhang Y. has the most published documents (n=7).

Table 5. Results of Co-authorship analysis of Authors based on Total Link Strength (TLS)

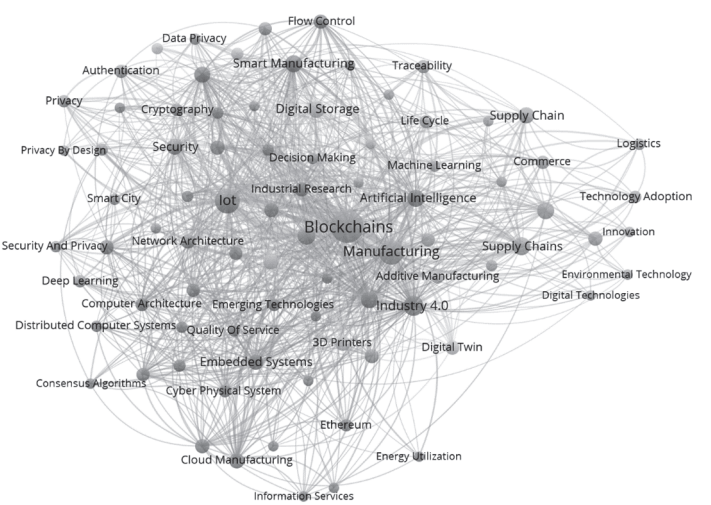
Label	Links	TLS	Documents	Citations
Leng J.	8	17	4	203
Liu Q.	8	17	4	203
Xu K.	10	14	3	226
Zhao J.L.	8	14	3	203
Li Z.	8	12	5	371
Liu Y.	11	12	5	45
Zhang Y.	9	12	7	136
Shi R.	7	11	2	163
Tao F.	6	11	4	81
Huang G.Q.	7	10	4	353

4.3. Co-occurrence keywords

Co-occurrence is the term used to describe how frequently a keyword appears in a document. The total link strength (TLS) reflects the frequency with which a term appears in a document. The size of nodes can represent keyword frequency: the larger the node, the more frequently the keyword appears. The thickness of the line between two keywords is related to their proximity and depicts their strong association (Eck & Waltman, 2020)(Sikandar *et al*., 2021). The minimum number of keyword occurrences was set to 5 when importing Scopus data into the VOS viewer for keyword analysis, yielding 106 keywords out of 2140. Simply put, only 106 terms had at least 5 occurrences, resulting in 7 different keyword clusters. We found 84 keywords out of 2120 (creating 5 clusters) that met the requirement of being present in five articles per document after merging the related keywords and deleting the irrelevant ones.

We identified the well-established and emerging topics in blockchains through the co-occurrence of keywords analysis. Some of the most frequently used keywords are blockchains, internet of things (IoT), manufacturing, industry 4.0, smart contracts, smart manufacturing, supply chains, artificial intelligence, manufacturing industry, digital storage, security, industrial IoT, embedded systems, information management, cloud manufacturing, network architecture and supply chain management. Table 6 presents the keywords with top occurrences along with their links, TLS, number of occurrences and their average publication year.

Figure 7. Bibliometric map of co-occurrence of keywords analysis in network visualisation mode; available at URL: https://bit.ly/3wAEqsn



In contrast, some of the keywords with the least number of occurrences in the given dataset are Digital Technologies, Energy Utilization, Environmental Technology, Innovation, Complex Networks, Quality Control, Machine Learning, Performance, Logistics, Manufacturing Resource, Privacy By Design, Cyber Security, Efficiency, Technology Adoption, Enabling Technologies, Service Oriented Architecture (SOA), Consensus Algorithms, Edge Computing, Information Services, Product Design and Economic And Social Effects of blockchains. We may conclude from this study that more research is needed in the aforementioned domains to obtain a better knowledge of the concept and to expand the literature. Fig. 8 illustrates developing blockchain themes in yellow to emphasise how recently they have been researched in the literature. These are the research hotspots and areas where future research is required. Table 7 presents the research hotspots of blockchains research in manufacturing.

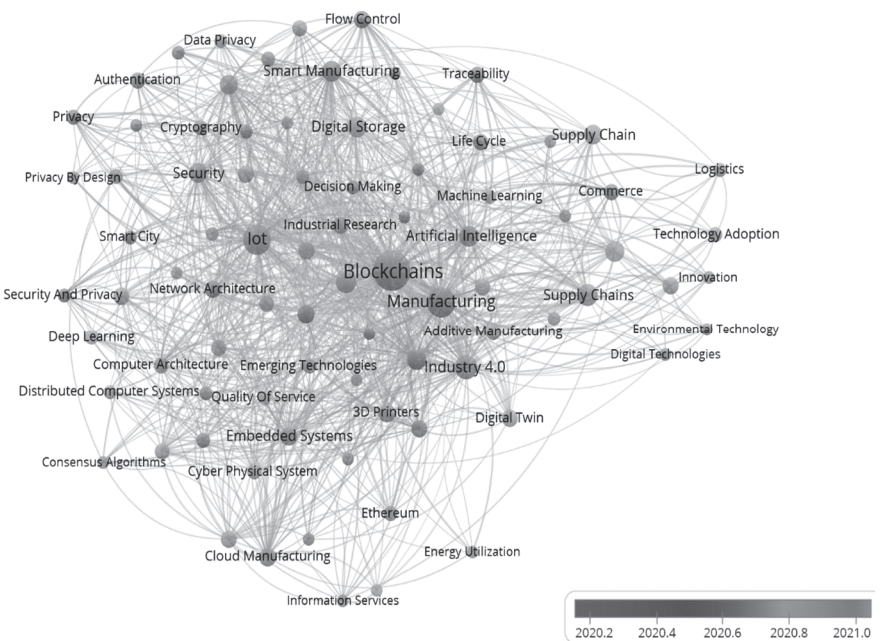
Table 6. Top studies keywords based on their Total link strength (TLS)

Keywords	links	TLS	Occurrences	Avg. pub. year
Blockchains	83	1039	230	2020.639
IoT	78	484	90	2020.889
Manufacturing	80	475	86	2020.605
Industry 4.0	73	272	47	2020.66
Smart Contracts	59	179	32	2020.688
Smart Manufacturing	54	169	26	2020.962
Supply Chains	48	156	33	2020.697
Artificial Intelligence	55	153	26	2020.962
Manufacturing Industry	64	153	26	2020.423
Digital Storage	52	149	27	2020.815
Security	55	143	23	2021.13
Industrial IoT	51	141	22	2021
Embedded Systems	57	138	19	2020.316
Information Management	53	132	19	2020.526
Cloud Manufacturing	42	127	17	2020.353
Network Architecture	55	122	16	2020.375
Supply Chain Management	43	122	26	2020.808
Industrial Research	51	113	16	2020.875
Flow Control	40	109	15	2020.6
Supply Chain	40	106	23	2020.826
3D Printers	50	105	17	2020.294
Computer Aided Manufacturing	38	102	15	2020.2
Computer Architecture	46	102	12	2021
Manufacturing Process	47	102	15	2020.533
Peer To Peer Networks	42	100	13	2020.077
Security Of Data	43	93	16	2020.25
Distributed Ledger	44	92	15	2021.4
Cloud Computing	40	89	11	2020.909
Network Security	44	88	16	2019.938
Big Data	44	84	12	2020.917

Table 7. Emerging keywords/Research Hotspots

Keywords	links	TLS	Occurrences	Avg. pub. year
Digital Technologies	16	22	6	2020.667
Energy Utilization	17	25	5	2021
Environmental Technology	15	26	6	2020.667
Innovation	15	26	5	2021
Complex Networks	23	29	5	2020.8
Quality Control	19	29	6	2020.5
Machine Learning	23	30	7	2020.714
Performance	25	30	6	2021.333
Logistics	14	31	7	2020.286
Manufacturing Resource	22	32	5	2020.6
Privacy By Design	23	33	6	2021
Cyber Security	25	35	5	2020.4
Efficiency	27	35	5	2021.4
Technology Adoption	16	35	10	2019.7
Enabling Technologies	24	37	5	2020.6
Service Oriented Architecture (SOA)	23	37	5	2020.8
Consensus Algorithms	22	38	6	2021
Edge Computing	23	39	7	2020.571
Information Services	21	39	6	2021
Product Design	24	39	6	2020.5
Economic And Social Effects	28	40	6	2021
Industrial Revolutions	26	42	6	2020.5

Figure 8. Bibliometric map of co-occurrence of keywords analysis in overlay visualisation mode



5. Discussion and Conclusion

Manufacturing has long been regarded as a conservative business. However, when technology such as artificial intelligence, machine learning and blockchains gain acceptance, the factory of the future will appear drastically different. As blockchain technology evolves, manufacturers will be able to overcome some of the barriers that have prevented the mainstream adoption of other next-generation technologies and creative business models. Consequently, more efficient industrial processes will be developed and embraced as the industry's new standard, necessitating data exchange and collaboration across complex networks of businesses and machinery. By eliminating the need for human validation at each step, a blockchain technique would increase standards, trust, and project delivery speed. This would have a knock-on effect on product availability and production schedules.

This study has analysed the previous literature and attempted to analyse the top trends in blockchains in the manufacturing sector. We have analysed the publication growth along with top journals, leading countries, and the top-cited articles in the said field. While conducting bibliometric analysis, through co-authorship analysis we have determined the countries and authors involved in collaborative research with the authors of other countries. Our findings suggest that China is the top country involved in collaborative research followed by the US and India. Through the co-occurrence of keywords, we determined the well-established and emerging topics in blockchain research. This research identifies areas that have received less attention, highlighting potential gaps in the literature. Future scholars can help fill these gaps and advance the knowledge base in the field of blockchains in manufacturing by focusing on these underexplored areas.

6. Implications for Theory and Practice

This research adds to our understanding of how blockchain technology could affect the conservative manufacturing industry by enabling the adoption of next-generation technologies and creative business models. Blockchain can revolutionise the manufacturing sector by breaking down barriers and promoting more efficient industrial processes. This study enhances the theoretical understanding of these processes and sheds light on the consequences of blockchain adoption in manufacturing.

This study provides valuable managerial insights for manufacturing practitioners. The findings highlight the potential benefits of implementing Blockchain technology in manufacturing operations, such as improved

efficiency, trust, and production schedules. This data can help organisations considering Blockchain adoption guide their decision-making processes and strategic planning efforts.

Additionally, an examination of co-authorship patterns and collaborative research in Blockchain in the manufacturing sector identifies key countries and authors involved in international research collaborations. This managerial insight enables practitioners and researchers to identify potential collaboration and knowledge exchange opportunities in the field. Furthermore, the study identifies research gaps and emerging topics through keyword co-occurrence analysis in Blockchain research in manufacturing. This information is a valuable resource for future scholars, directing their attention to areas that have received less attention and assisting in the filling of gaps in the existing literature.

7. Limitations

Although we tried to provide a thorough analysis of the previous research in the field of blockchains in the manufacturing domain, our research is constrained by several factors. To begin, our study focused solely on the use of blockchains in the manufacturing sector, neglecting the rest of the industries where blockchains may be beneficial. Secondly, we looked at research that was written in English. As a result, important literature research published in different languages may have been overlooked. Future research might broaden the scope of the search to include more relevant studies, therefore adding to the body of knowledge. thirdly, due to the paucity of research on the topic, we have chosen journal and conference publications that may or may not have undergone comprehensive peer review. Third, we solely used Scopus to collect and analyse data; while Scopus is a vast database which published a diverse range of articles every year, there's a chance we overlooked some potential publications. Different databases might be used to compare the results in future studies.

References

Abbas A.F., Qureshi N.A., Khan N., Chandio R., Ali J. (2022). The Blockchain Technologies in Healthcare: Prospects, Obstacles, and Future Recommendations; Lessons Learned from Digitalization. *International Journal of Online & Biomedical Engineering*, 18(9). DOI: 10.3991/ijoe.v18i09.32253

Agarwal S. (2018). Blockchain Technology in Supply Chain and Logistics. *MIT Sloan Management Review*, 23 (Doctoral dissertation, Massachusetts Institute of Technology).

Andoni M., Robu V., Flynn D., Abram S., Geach D., Jenkins D., McCallum P., Peacock A. (2019). Blockchain technology in the energy sector: A systematic review of challenges and opportunities. In *Renewable and Sustainable Energy Reviews*, 100: 143-174. DOI: 10.1016/j.rser.2018.10.014

Beck R., Stenum Czepluch J., Lollike N., Malone S. (2016). Blockchain - The gateway to trust-free cryptographic transactions. *24th European Conference on Information Systems, ECIS 2016*.

Benos E., Garratt R., Gurrola-Perez P. (2017). The Economics of Distributed Ledger Technology for Securities Settlement. *SSRN Electronic Journal*. DOI: 10.2139/ssrn.3023779

Chen K., Zhang Y., Fu X. (2019). International research collaboration: An emerging domain of innovation studies? *Research Policy*, 48(1): 149–168. DOI: 10.1016/j.respol.2018.08.005

Christidis K., Devetsikiotis M. (2016). Blockchains and Smart Contracts for the Internet of Things. In *IEEE Access*. DOI: 10.1109/ACCESS.2016.2566339

Cruz J.P., Kaji Y., Yanai N. (2018). RBAC-SC: Role-based access control using smart contract. *IEEE Access*. DOI: 10.1109/ACCESS.2018.2812844

Dabbagh M., Sookhak M., Safa N.S. (2019). The evolution of blockchain: A bibliometric study. *IEEE Access*. DOI: 10.1109/ACCESS.2019.2895646

Disparte D. (2017). Blockchain could make the insurance industry much more transparent. *Harvard Business Review*, 2.

Duan R., Guo L. (2021). Application of blockchain for internet of things: a bibliometric analysis. *Mathematical Problems in Engineering*, 1-16. DOI: 10.1155/2021/5547530

Epiphaniou G., Daly H., Al-Khateeb H. (2019). Blockchain and Healthcare. In: Jahankhani H., Kendzierskyj S., Jamal A., Epiphaniou G., Al-Khateeb H. (eds.) *Blockchain and Clinical Trial. Advanced Sciences and Technologies for Security Applications*. Springer, Cham.

Frizzo-Barker J., Chow-White P.A., Adams P.R., Mentanko J., Ha D., Green S. (2020). Blockchain as a disruptive technology for business: A systematic review. *International Journal of Information Management*. 51: 102029. DOI: 10.1016/j.ijinfomgt.2019.10.014

Ghimire T., Joshi A., Sen S., Kapruan C., Chadha U., Selvaraj S.K. (2022). Blockchain in additive manufacturing processes: Recent trends & its future possibilities. *Materials Today: Proceedings*, 50: 2170-2180. DOI: 10.1016/j.matpr.2021.09.444

Guo Y.M., Huang Z.L., Guo J., Guo X.R., Li H., Liu M.Y., Ezzeddine S., Nkeli M.J. (2021). A bibliometric analysis and visualization of blockchain. *Future Generation Computer Systems*, 116: 316-332. DOI: 10.1016/j.future.2020.10.023

Hakim T., Bahari M. (2021). Blockchain Technology Research in Business, Management and Accounting Field: A Bibliometric Analysis. *International Conference on Research and Innovation in Information Systems, ICRIIS*. DOI: 10.1109/ICRIIS53035.2021.9616980

Hayes A. (2022). *Blockchain Definition: What You Need to Know*. Blockchain Definition: What You Need to Know.

Jiménez L., Muñoz R. (2006). Integration of supply chain management and logistics: development of an electronic data interchange for SAP servers. *Computer Aided Chemical Engineering*. DOI: 10.1016/S1570-7946(06)80375-5

Kamble S.S., Gunasekaran A., Sharma R. (2020). Modeling the blockchain enabled traceability in agriculture supply chain. *International Journal of Information Management*, 52: 101967. DOI: 10.1016/j.ijinfomgt.2019.05.023

Karafiloski E., Mishev A. (2017). Blockchain solutions for big data challenges: A literature review. *17th IEEE International Conference on Smart Technologies, EUROCON 2017 - Conference Proceedings*. DOI: 10.1109/EUROCON.2017.8011213

Kessler J. (2019). Data protection in the wake of the gdpr: California's solution for protecting "the world's most valuable resource". In *Southern California Law Review*, 93(1): 99–128.

Khan M.A., Salah K. (2018). IoT security: Review, blockchain solutions, and open challenges. *Future Generation Computer Systems*, 82: 395-411. DOI: 10.1016/j.future. 2017.11.022

Klapita V. (2021). Implementation of electronic data interchange as a method of communication between customers and transport company. *Transportation Research Procedia*, 53: 174-179. DOI: 10.1016/j.trpro.2021.02.023

Kurpjuweit S., Schmidt C.G., Klöckner M., Wagner S.M. (2021). Blockchain in Additive Manufacturing and its Impact on Supply Chains. *Journal of Business Logistics*, 42(1): 46-70. DOI: 10.1111/jbl.12231

Luo J., Hu Y., Bai Y. (2021). Bibliometric Analysis of the Blockchain Scientific Evolution: 2014-2020. *IEEE Access*, 9: 120227-120246. DOI: 10.1109/ ACCESS.2021.3092192

Madir J. (2020). Blockchain opportunities in healthcare. In *HealthTech*, 193-217. DOI: 10.4337/9781839104909.00019

Mainelli M. (2017). Blockchain Could Help Us Reclaim Control of Our Personal Data. *Harvard Business Review*, 2-5.

Mayer A.H., da Costa C.A., Righi R. (2020). Electronic health records in a Blockchain: A systematic review. *Health Informatics Journal*, 26(2): 1273-1288. DOI: 10.1177/1460458219866350

Meng W., Tischhauser E.W., Wang Q., Wang Y., Han J. (2018). When intrusion detection meets blockchain technology: A review. *IEEE Access*, 6: 10179-10188. DOI: 10.1109/ACCESS.2018.2799854

Musigmann B., Von Der Gracht H., Hartmann E. (2020). Blockchain Technology in Logistics and Supply Chain Management - A Bibliometric Literature Review from 2016 to January 2020. *IEEE Transactions on Engineering Management*, 67(4): 988-1007. DOI: 10.1109/TEM.2020.2980733

Niknejad N., Ismail W., Bahari M., Hendradi R., Salleh A.Z. (2021). Mapping the research trends on blockchain technology in food and agriculture industry: A bibliometric analysis. In *Environmental Technology and Innovation*, 21: 101272. DOI: 10.1016/j.eti.2020.101272

Queiroz M.M., Fosso Wamba S. (2019). Blockchain adoption challenges in supply chain: An empirical investigation of the main drivers in India and the USA. *International Journal of Information Management*, 46: 70-82. DOI: 10.1016/j.ijinfomgt.2018.11.021

Raja Santhi A., Muthuswamy P. (2022). Influence of Blockchain Technology in Manufacturing Supply Chain and Logistics. *Logistics*, 6(1): 15. DOI: 10.3390/logistics6010015

Sharma P.K., Chen M.Y., Park J. H. (2018). A Software Defined Fog Node Based Distributed Blockchain Cloud Architecture for IoT. *IEEE Access*. DOI: 10.1109/ACCESS.2017.2757955

Sikandar H., Abbas A.F., Khan N., Qureshi M.I. (2022). Digital Technologies in Healthcare: A Systematic Review and Bibliometric Analysis. *International Journal of Online and Biomedical Engineering*, 18(8): 34–48. DOI: 10.3991/ijoe.v18i08.31961

Sikandar H., Abdul Kohar U.H. (2021). A systematic literature review of open innovation in small and medium enterprises in the past decade. In *Foresight,* 24(6): 742-756. DOI: 10.1108/FS-01-2021-0030

Sikandar H., Vaicondam Y., Khan N., Qureshi M.I., Ullah A. (2021). Scientific Mapping of Industry 4.0 Research: A Bibliometric Analysis. *International Journal of Interactive Mobile Technologies*, 15(18): 129-147. DOI: 10.3991/ijim.v15i18.25535

Swan M. (2015). *Blockchain: Buleprint for a new Economy*. O'Reily Media.

Tama B.A., Kweka B.J., Park Y., Rhee K.H. (2017). A critical review of blockchain and its current applications. *ICECOS 2017 - Proceeding of 2017 International Conference on Electrical Engineering and Computer Science: Sustaining the Cultural Heritage Toward the Smart Environment for Better Future*. DOI: 10.1109/ICECOS.2017.8167115

Tönnissen S., Teuteberg F. (2020). Analysing the impact of blockchain-technology for operations and supply chain management: An explanatory model drawn from multiple case studies. *International Journal of Information Management*, 52. DOI: 10.1016/j.ijinfomgt.2019.05.009

Van Eck N.J., Waltman L. (2018). VOSviewer Manual: Manual for VOSviewer version 1.6.7. *Univeristeit Leiden*, *February*, 51.

Wamba S.F., Queiroz M.M. (2020). Blockchain in the operations and supply chain management: Benefits, challenges and future research opportunities. In *International Journal of Information Management*, 52. DOI: 10.1016/j.ijinfomgt.2019.102064

Xia Q., Sifah E.B., Asamoah K.O., Gao J., Du X., Guizani M. (2017). MeDShare: Trust-Less Medical Data Sharing among Cloud Service Providers via Blockchain. *IEEE Access*, 5: 14757-14767. DOI: 10.1109/ACCESS.2017.2730843

Yeung K. (2021). The Health Care Sector's Experience of Blockchain: A Cross-disciplinary Investigation of Its Real Transformative Potential. *Journal of Medical Internet Research*, 23(12). DOI: 10.2196/24109

Ying W., Jia S., Du W. (2018). Digital enablement of blockchain: Evidence from HNA group. *International Journal of Information Management*, 39: 1–4. DOI: 10.1016/j.ijinfomgt.2017.10.004

Zhang K., Jacobsen H.A. (2018). Towards dependable, scalable, and pervasive distributed ledgers with blockchains. *Proceedings - International Conference on Distributed Computing Systems*. DOI: 10.1109/ICDCS.2018.00134

Zhao M. (2020). Blockchain Technology Improves Supply Chain: A Literature Review. *Academic Journal of Computing & Information Science*, 3(4): 73–85.