FinTech

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Review

Blockchain Technology for Supply Chain Management: A Comprehensive Review

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Abstract: Firms are eager to adopt new technologies, such as Artificial Intelligence (A.I.), Cloud Computing, Big Data, etc., as they witness successful business applications. As one of the disruptive technologies, Blockchain technology (BCT) has been drawing attention stemming from cryptocurrency proliferation (e.g., Bitcoin and Ethereum), for which Blockchain serves as the backbone. However, the public is haunted by the bewilderment between cryptocurrencies and BCT. Furthermore, the burgeoning of Metaverse and *non-fungible tokens* (NFT) has raised BCT to another notch. This study conducts a holistic literature review on BCT features, implementations, and business implications. In particular, by reviewing and analyzing 2265 up-to-date articles that reveal BCT's applications across various fields, this Blockchain-centered study reveals the research status and delineates future research directions. It is shown that, among various characteristics of BCT, *traceability* is the main characteristic fueling BCT's application in supply chain management (SCM). We further find that the BCT-related research has been extremely growing in SCM, healthcare, and government, while declining in the areas of banking and cyber security. Geographically, the top countries with BCT-related publications are China, U.S., and India. Finally, it is emphasized that BCT-related research in environmental sciences and agriculture have potential to be explored.

Keywords: Blockchain technology; Industry 4.0; Supply chain management; Text mining; Metaverse; NFT; Hashgraph; BaaS

Citation: Chang, A.(.; El-Rayes, N.; Shi, J. Blockchain Technology for Supply Chain Management: A Comprehensive Review. *FinTech* **2022**, *1*, 191–205. https://doi.org/10.3390/fintech1020015

Academic Editor: Shyan-Ming Yuan

Received: 7 March 2022
Accepted: 30 May 2022
Published: 6 June 2022

1. Introduction

Blockchain is a decentralized digital ledger where data is stored in blocks secured using cryptographic principles. BCT's main components are node (server), transaction, block (set of transactions), ledger (where the transactions are recorded), and hash (algorithmic function) [1]. Blockchain is an internet-based technology that is valued for its ability to validate publicly, record, and distribute transactions in immutable, encrypted ledgers (see Figure 1). As the backbone technology of Bitcoin, Blockchain technology (BCT) was put under the spotlight in 2017, especially after the Bitcoin price skyrocketed to its first peak in December 2017 at almost $20,000. In 2018, the Blockchain spending grew by 110%, and the financial sector alone contributed $552 million to Blockchain projects. As a result, the Blockchain market grew dramatically from only a million in 2012 to almost 4.3 billion in 2018 [2]. In addition to its financial application, people have started to explore Blockchain's potential in other fields, such as supply chain, government systems, etc., and immense efforts have been made.

Many big names of consumer goods and food companies are testing Blockchain technology for its salient advantage of traceability and transparency. Walmart teamed up with Nestle, Dole, Unilever, and Tyson to test "farm to table" tracing by Blockchain, and the tracing time of a bag of mango is reduced from one week to 2.2 s by Blockchain-enabled system. Carrefour is testing Blockchain in organic foods and expects the sales of organic products to increase by $5 billion by 2022 for its revolutionized information system. The global market of Blockchain in foods and agricultural products was $41.9 million in 2018 and is projected to be $195.3 million by 2023 and $1.4 billion by 2028.

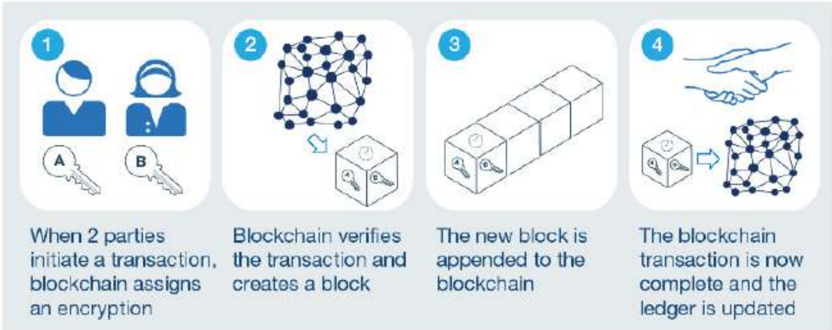


Figure 1. How the transaction works with Blockchain [3].

Regardless of the growing effort into Blockchain implementation globally [4], the public seems confused between Bitcoin and Blockchain [5]. The analysis of Google Search reveals a strong positive correlation (with a correlation coefficient 0.8371) between "Blockchain" and "Bitcoin Price"(see Figure 2), which implies that the Bitcoin price dominates the public attention on Blockchain. When the Bitcoin price rises, the public attention on Blockchain grows accordingly. This observation can be further justified by the change in Blockchain investment funding in 2018 and 2019. After a price peak in December 2017 to almost $20,000, Bitcoin declined by 83.5% to $3,214 in December 2018. Coincidentally, Blockchain investment dropped about 30% in 2019 compared to 2018.

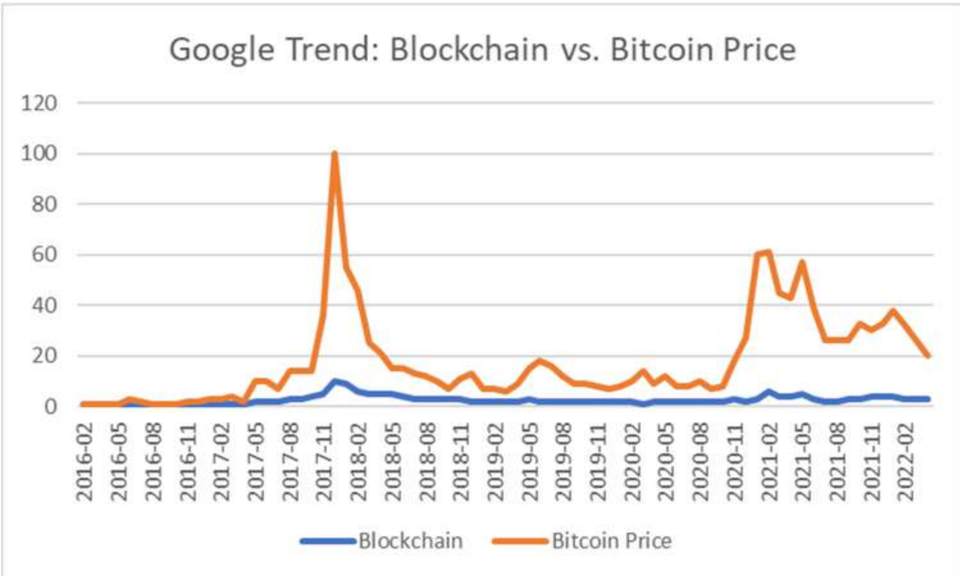


Figure 2. Google Trend: "Blockchain" vs. "Bitcoin Price".

Besides, there is rising anxiety in the industry with technology adoption. In the US, the struggles of brick-and-mortar retailers (e.g., Macy's, J.C. Penny, Toys R US, etc.), cable TV service (e.g., Direct TV, Dish, etc.), traditional news media (e.g., local newspapers, etc.), and many others are creating a consensus of FOMO—fear of missing out—with technology adoption. Therefore, the advent of Blockchain immediately drew public attention, and companies flocked to embrace the technology without hesitation. Given the irrational pulse for technology adoption combined with the bewilderment of Bitcoin and Blockchain, there emerged many unsuccessful Blockchain projects, and the failure rate is reported to be 92% [6]. This study thus attempts to combat such irrationality by systematically reviewing the existing literature to characterize the blockchain technology and summarize its applications. Specifically, this study attempts to answer the following research questions:

(1) What are the BCT functionalities and features;
(2) What are the prevailing and potential applications of BCT;
(3) Identify the business benefits and impact of BCT in SCM.

Adopting a seven-step framework of literature review, this study extracts 2291 papers from the Scopus database from 2016 to February 2022 and finds that the BCT is mainly applied in the fields of (1) healthcare; (2) supply chain management; (3) sustainable supply chain; (4) circular supply chain; (5) real estate; (6) automotive; (7) finance; (8) accounting/auditing; (9) agriculture; and (10) education. Additionally, the characteristics of BCT are summarized as follows: (1) anonymity; (2) audibility and traceability; (3) autonomy; (4) contract automation; (5) decentralization; (6) immutable; (7) irreversible; (8) open-source; (9) ownership and uniqueness; (10) provenance; (11) security; and (12) smart execution. Among those characteristics, traceability is the strongest one that fuels the application of BCT to supply chain management. By comparing research topics, several fields are growing, including supply chain management, healthcare, and government, while the others are declining, including banking and cyber security. SCM, BCT, and Environmental Sciences-related research (i.e., BCT for Sustainable SCM, BCT for Circular SCM) or Agriculture-related research (i.e., BCT for Agribusiness, BCT for Food SCM) are potential areas to explore due to the shortage under these areas. The top countries with publications related to Blockchain are (1) China, (2) U.S., (3) India, (4) U.K., and (5) Germany.

Additionally, the characteristics of BCT bring some restrictions by nature, for example, confidentiality issues. Although some confidentiality techniques are applied, a certain level of privacy is inevitably compromised due to the nature of BCT. For example, the distributed ledger allows all users to view the history of activities; even though users are anonymous, privacy information would still leak somehow [7]. Secondly, the immutability issue. Although the immutability feature of BCT ensures data integrity, it also brings some restrictions to business applications. For instance, if BCT is applied to transaction processing, information immutability would cause problems processing product returns and refunds. Thirdly, scalability issues. The current BCT is energy-consuming and requires repetitive work to broadcast the transaction information across the entire Blockchain. Therefore, when the number of users grows, the system will encounter scalability issues. Fourthly, regulation issue. Regulatory sectors struggle to develop an effective system to regulate Blockchain technology and related systems. Fifthly, legacy system integration with BCT is another significant challenge.

Lastly is the information authenticity issue. The advantages of immutability and security guarantee that once information is created, verified, and added to the Blockchain, it is secured from tampering and revision. However, it does not necessarily mean that the information carried in the Blockchain is 100% true. Information manipulation might still emerge in the data entry phase. After all, a blockchain can be considered an information interface or a machine that passively accepts information input by humans without an auditing mechanism. In other words, the conventional system requires information auditing at numerous checkpoints (e.g., money transfer between banks, cargo shipment between ports of entry, etc.). In contrast, the Blockchain system replaces those checkpoints with enhanced security and immutability while still susceptible to data manipulation when the information is first entered into the system. Therefore, to ensure a successful implementation of BCT, a business may consider: (1) using the Internet of Things (IoT) for tracking components and goods, (2) recording transaction data, (3) standardizing and aligning data from various sources, and (4) involving predictive and prescriptive analytics; cf. [8,9].

The remainder of the paper is organized as follows; Section 2 describes the methodology adopted in the study. Section 3 covers the literature review across various related areas. The results are presented in Section 4. Section 5 encompasses discussion and limitations. Section 6 points out future research avenues. Finally, the conclusion is given in Section 7.

2. Methodology

Following [10], this work adopts the seven-step process to conduct a comprehensive review of literature retrieved from the Scopus database, one of the largest sources of peer-reviewed publications [11]. First, we looked through all the BCT papers between 1990 and 2022 and collected all the studies with the term "Supply Chain Management" and "BlockChain Technology", which are 2291 studies. Second, we filter by four criteria to include only the papers written in "English," where the publication status is "Final." The publication is an "Article" or "Conference Paper" and classified under at least one of the six areas of interest, which are: "Business, Management, and Accounting", "Computer Science", "Social Sciences", "Decision Sciences", "Economics, Econometrics, and Finance", "Environmental Sciences." Then, we developed descriptive statistics to understand the status of the literature. Third, we used the abstracts, titles, and keywords from 2265 publications (the outcome of step 2). After removing the stop words, and some trivial terms (i.e., article, abstract, report, etc.), the dataset was composed of 9553 unique terms. We included only the terms that appear 10 times or more, which are 250 terms, as any terms that appear less than 10 times in 2265 abstracts would be insignificant. The 250 terms that fulfilled the threshold were used to develop a network analysis to visualize the connection between the terms, the frequency of occurrence, and the top clusters among which the terms belong. Along with that, google trends analysis was run in parallel to determine the pattern of the occurrence of BCT, Bitcoin, and Metaverse since the year 2015 across the different regions. Figure 3 illustrates the four iterations and the methodology steps followed in the literature review process.

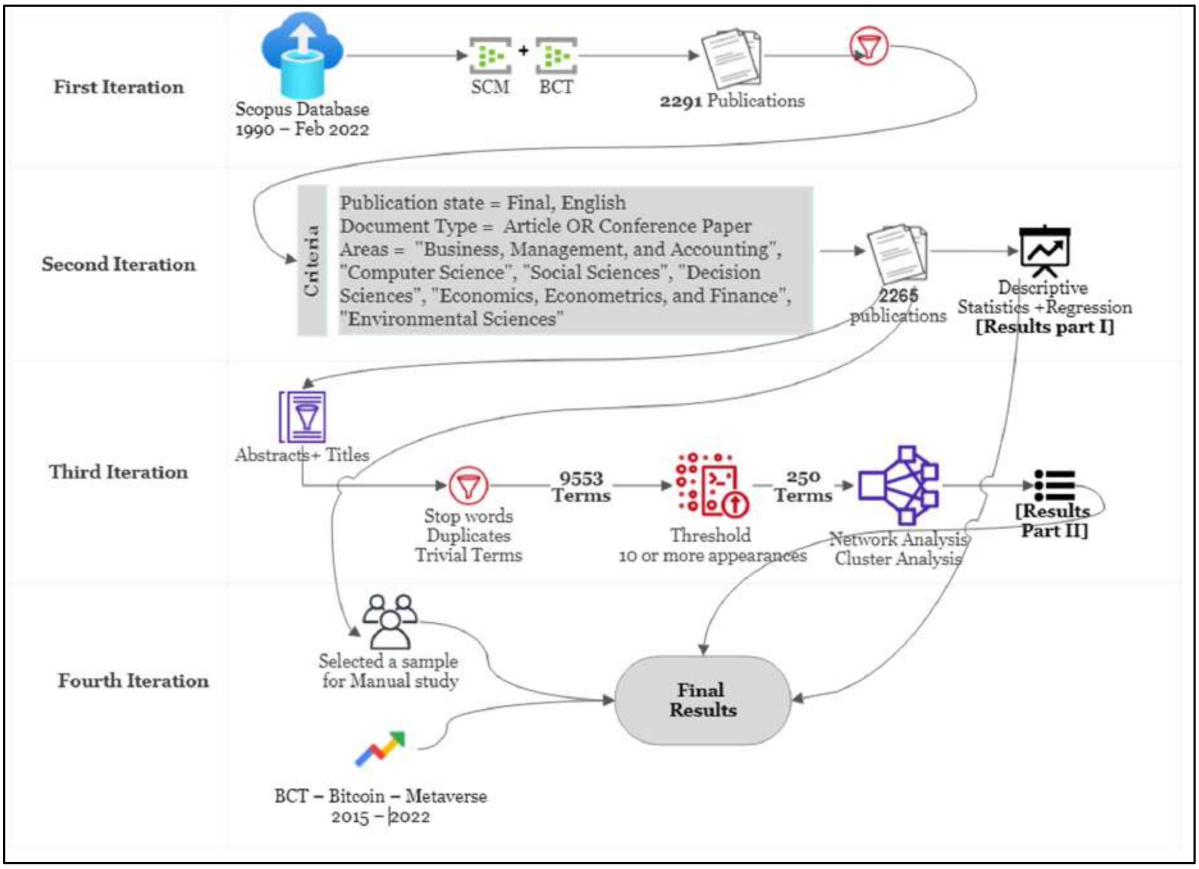


Figure 3. Methodology iterations.

3. Literature Review and Analysis

3.1. Blockchain Technology

Blockchain is a disruptive information technology [12,13] and a validation [14] of a shared digital ledger (either public or private) of all digital events across the participating agents [15,16] and a new information flow and computing technology [17,18]. BCT has a wide range of characteristics, some of which are Anonymity [13,16], Auditability [13,19], Autonomy [16,20], Contract Automation [16], Decentralized/non-localization [15,16,19–21], Immutable [13,19,20], Irreversible, Open-source [16,20], Ownership and Uniqueness [13,16,20], Provenance [16,17,22], Security [13,19–21], and Smart execution [13,19]. The return of Blockchain-related initiatives in a certain country is affected to a great extent with the level of data restriction set in that given country, in addition to the strength of the research related to blockchain.

Blockchains have become pervasive in various areas, including but not limited to, healthcare, SCM [16,19,23–32], sustainable supply chain [13,21], circular supply chain [20], real estate, government, automotive industries, finance [26,33], auditing accounting [34], agriculture [18,35–37], education [38], and many more [24]. Blockchains can make any institution or industry that requires record-keeping more efficient, transparent, and secure [2]. Furthermore, [39] examines the implications of BCT on value creation in the healthcare sector based on investigating 33 companies. An annual global survey for more than 1400 senior leaders revealed in the year 2020 that 39% of the respondents had brought Blockchain into production [40]. In 2018, blockchain spending grew by 110%, and the financial sector alone contributed $552 million to Blockchain projects. As a result, the Blockchain market grew dramatically from only a million in 2012 to almost 4.3 billion in 2018 [3].

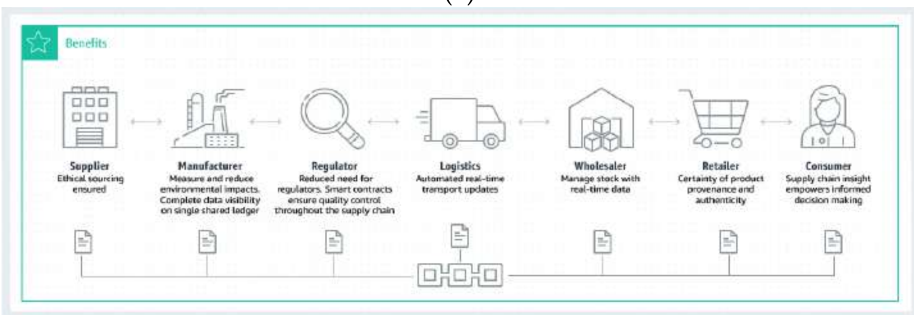
3.2. Blockchain Technology and Supply Chain Management

BCT disruptively changes the way traditional SCM runs [17,18], while [21] concludes that technology is one of the main critical and dominant barriers for Blockchain in SCM that would pose a threat specifically to industries with anxiety toward technology adoption. To illustrate the struggles of brick-and-mortar retailers (e.g., Macy's, J.C. Penny, Toys R US, etc.), cable T.V. service (e.g., Direct TV, Dish, etc.), traditional news media (e.g., local newspapers, etc.), and many others are creating a consensus of FOMO—fear of missing out—with technology adoption. Therefore, the advent of the Blockchain immediately drew public attention, and companies flocked to embrace the technology without hesitation. However, given the irrational pulse for technology adoption combined with the bewilderment of Bitcoin and Blockchain, many unsuccessful Blockchain projects emerged, and the failure rate is reported to be 92% [6].

IoT and smart contracts are the leading technologies in using BCT for SCM [31]. The electric power industry is ahead in the integration of BCT because of the advanced usage of smart contracts [22]. Furthermore, BCT has a strong potential for fostering sustainable SCM [41]. Ref. [20] developed a framework for designing circular blockchain platforms. Trust, social influence, and effort expectancy are three facilitating conditions for BCT adoption [22]. There are 53 applications for BCT toward SCM [29]. Ref. [30] identifies five strengths of Blockchain application from the operations management perspective, including visibility, aggregation, validation, automation, and resilience. On the other hand, BCT has a dark side; their study indicates five corresponding weaknesses: lack of privacy, lack of standardization, garbage in, garbage out, black box effect, and inefficiency [30].

Typically, a traditional supply chain consists of suppliers, manufacturers, logistics companies, wholesalers, and retailers that work together to deliver products to end consumers; see Figure 4a. However, as supply chains expand, they become more complex. Consequently, traditional supply chains lack traceability and transparency, which becomes an industry-wide challenge causing painful inefficiency with delays, errors, and increased costs. To address this issue, supply chain participants need a unified view of data while still verifying transactions independently and privately, e.g., production, shipment, delivery, and sales. Figure 4b illustrates how BCT reshapes the interoperability among those participants via transparent information sharing. For example, Amazon Managed Blockchain can provide the end-to-end visibility that today's supply chains need to track and trace their entire production process with increased automation efficiency.

(**a**)



(**b**)

Figure 4. (**a**) Blockchain challenges (Source: AWS [42]). (**b**) Blockchain benefits (Source: AWS [43]).

BCT can maximize the performance of the supply chain if the organizations put into consideration (1) using the Internet of Things (IoT) for tracking components and goods, (2) recording transaction data, (3) standardizing and aligning data from various sources, and (4) involving predictive and prescriptive analytics; cf. [8]. Ref. [28] presentsthe critical success factors and requirements for a business to implement BCT for traceability, and [41] evaluates the implementation of BCT through analytics models.

3.3. Blockchain Technology and Metaverse

Nowadays, the burgeoning Metaverse and NFT elevates BCT to a new era. In particular, Facebook rebranded itself as *Metaverse* in Oct. 2021 by creating an internet that is hyper-realistic and more immersive. In the virtual Metaverse world, individuals can socialize, interact, and conduct business, where digital NFT presents its entities. The virtual ecosystem heavily relies on Blockchain technology to enable *peer-to-peer* (P2P) exchanges and transactions and share decision making [42–45]. Figure 5 depicts the word clouds of Blockchain and Metaverse.

Figure 5. Blockchain and Metaverse: word cloud (source: Dreamstime.com, accessed on 1 January 2022).

A metaverse is a network of 3D virtual worlds focused on social connection. Futurism and science fiction often describe it as a hypothetical iteration of the Internet as a single, universal virtual world facilitated by *virtual reality* (VR) and *augmented reality* (AR) headsets.

The blood of Metaverse is the one so-called *non-fungible token* (NFT). An NFT is a non-interchangeable unit of data stored on a blockchain, a form of digital ledger. NFT data units may be associated with digital files such as photos, videos, and audio. NFTs inherently differ from blockchain cryptocurrencies, such as Bitcoin, as each token is uniquely identifiable and non-fungible. NFT ledgers claim to provide a public certificate of authenticity or proof of ownership, but the legal rights conveyed by an NFT can be uncertain. NFTs do not restrict the sharing or copying of the underlying digital files and do not prevent the creation of NFTs with identical associated files. An NFT is a unit of data stored on a blockchain, and it can be sold and traded. The NFT can be associated with a particular digital or physical asset (such as a file or a physical object) and a license to use the asset for a specified purpose. An NFT (and, if applicable, the associated license to use, copy or display the underlying asset) can be traded and sold on digital markets. However, the extralegal nature of NFT trading usually results in an informal exchange of ownership over the asset that has no legal basis for enforcement, often conferring little more than use as a status symbol.

It is commonly perceived that 2021 is entitled the "Year of NFT". To illustrate the revolution and evolution of the NFT market, Figure 6 provides a snapshot of the history up to April 2022. Clearly, NFT has been recently growing extraordinarily, especially since January 2021.

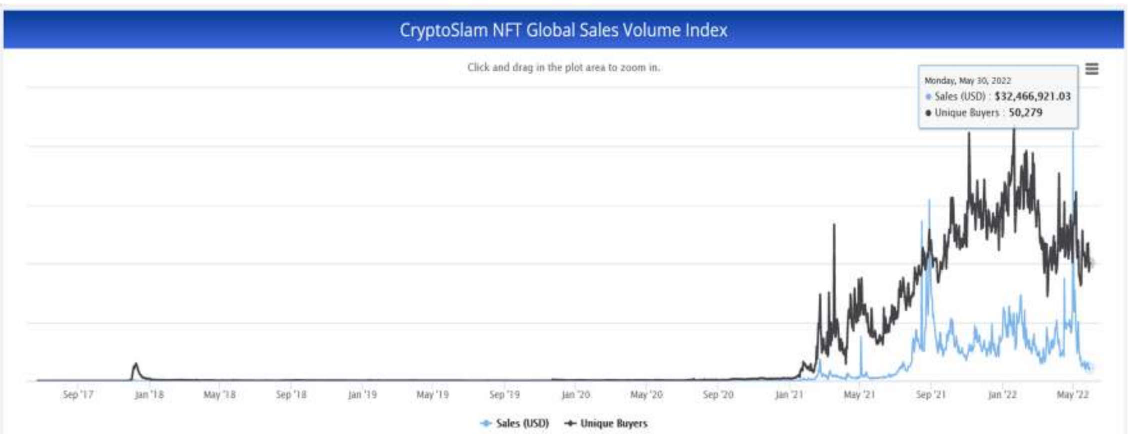
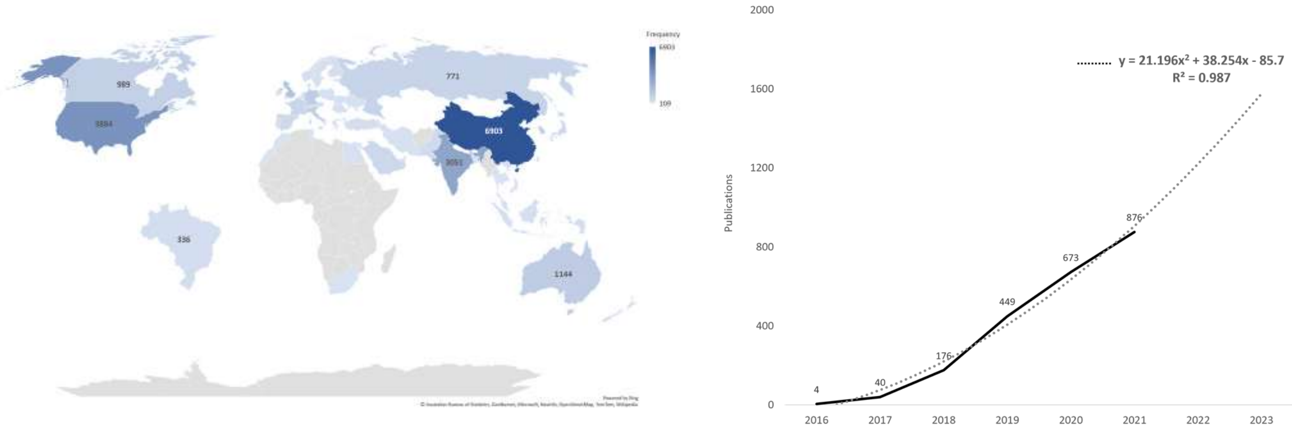


Figure 6. NFT global sale volume index [46].

4. Results

4.1. Blockchain between 1990–2022

The research studies on BCT have been proliferating exponentially [32]. Blockchain was mentioned 27,723 times on the Scopus database until February 2022. The first publication on that database goes back to 1990, lecture notes on secret error-correcting codes presented at a conference in 1988 [47], followed by the security of cipher block chaining [33]. Between 1990–2013, there were one to two publications a year on the Scopus database. In the year 2018, that jumped to 3 k publications. That number doubled in 2019, and in 2021, the frequency of publications reached 8629. Over the years, there are six areas under which the publications exceeded 2 k: computer science, engineering, mathematics, decision sciences, business/management/accounting, and social sciences. The top countries with publications related to Blockchain are China, U.S., India, U.K., and Germany (cf. Figure 7a). Based on the publications related to BCT applications, the main areas of industries are Banking, Cyber Security, Government, Health, and SCM. For example, Banking and Cyber Security are related to the main context of cash flow (e.g., Supply Chain Finance) and information flow (e.g., Information System), respectively, in a supply chain network. In terms of the reviewed literature, India has the highest number of publications across all industries except the Cyber Security Industry, where the U.S. is ranked first. The U.S. and China fluctuate between the second and third positions across the remaining selected industries.



(**a**) (**b**)

Figure 7. (**a**) Blockchain publications by country (1990–2022). Countries with more than 100 publications. (**b**) Publication frequency pattern and prediction for the year 2022–2023.

Many governments are also trying to exploit BCT in the national system to improve administrative efficiency, and there have been at least 20 countries either adopting or researching BCT. For instance, Tunisia and Senegal issued blockchain-backed cryptocurrencies in 2015 and 2016, respectively. The Government of Estonia digitalizes national services via Blockchain, including information on health, tax, etc. The U.K.'s National Archives is testing to put national documents onto the Blockchain-backed information system. Singapore's government is experimenting with a Blockchain-backed distributed ledger to enable cross-border financial transactions. It is also trying to exploit Blockchain smart contracts to facilitate insurance filing and consolidation. Based on our most recently collected data, there are 2291 publications in the Scopus database on "Blockchain" and "Supply chain" between the years 2016 and February 2022 (see Figure 7b). Following a polynomial trendline with an order of 2, the frequency of publications is predicted to be around 1200 by the end of the year 2022 and approaching 1500 by the end of the year 2023. There are no publications before the year 2016 with both terms.

4.2. Top Countries with Interests in BCT, Bitcoin, and Metaverse

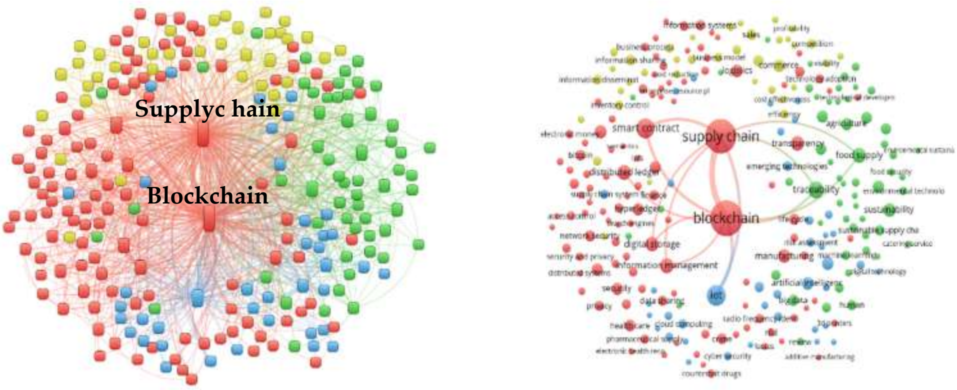
Figure 8a–c reflects the country's interest index between 2015 and 2022 across BCT, Bitcoin, and Metaverse. The top five countries with a high-interest index for BCT are Brazil, Italy, Germany, France, and Russia (cf. Figure 8a). While Australia, New Zealand, Ireland, Canada, and South Africa are the top five countries with a high-interest index for Bitcoin price (cf. Figure 8b). Finally, Turkey, Indonesia, France, South Korea, and Thailand are the top five countries with a high-interest index score for Metaverse (cf. Figure 8c).

(**a**) (**b**) (**c**)

Figure 8. Google Trend Interest Index over the countries. (**a**) Blockchain; (**b**) Bitcoin; (**c**) Metaverse.

4.3. Network Analysis (BCT and SCM)

Based on the most recently collected data, there are 2291 publications in the Scopus database on "Blockchain" and "Supply chain" from 2016 to February 2022 (see Figure 7b). The publications in English are 2265, which are the ones for further evaluation and review. The publications are assigned to one or many of 25 subject areas. Overall, 88% of the publications are under eight subject areas. After stemming, the total unique terms in all the abstracts, keywords, and index keywords are 9553 terms. Approximately 250 terms were repeated ten times or more. Figure 9 shows the network diagram for the terms and their clusters. There are four clusters of keywords with a cluster size of 35 nodes or more. The abstract view in Figure 8a shows the connection and overlap between clusters of the two centroids (Blockchain and Supply Chain). Publications that include BCT and SCM are 107 publications between 2010 and February 2022.



(**a**) (**b**)

Figure 9. Blockchain and SCM. (**a**) Abstract view. (**b**) Detailed view.

There are four main clusters red, yellow, green, and blue (see Figure 9a,b). The links connecting the nodes reflect the level of interaction between the nodes. The diagram shows the main terms under each cluster and the links to the words that appeared more than 130 times. The largest cluster is the red cluster, and it has a theme related to finance-related applications and healthcare. The green cluster is related to using Blockchain for supply chain-related to agribusiness, circular economy, and a sustainable supply chain. The blue cluster has a theme related to the other Industry 4.0 tied with Blockchain and the other three groups. The yellow cluster has abstracts about e-commerce and information dissemination and sharing. Overall, information management, digital storage, and smart contract are almost equal strengths within the supply chain and Blockchain networks. At the same time, the distributed ledger is strongly tied to Blockchain. Traceability is the only feature strongly connected to Blockchain and the supply chain. In contrast, there is an absence or low occurrence for the rest of the features (i.e., transparency, security, efficiency, confidentiality, and immutability). Table 1 shows the number of occurrences and links of Blockchain features across 2265 abstracts.

Table 1. Blockchain features and frequency of connections (sorted by links).

Blockchain Features	Links	Occurrences	Total Link Strength
Traceability	201	210	1329
Security	132	79	789
Transparency	126	126	527
Efficiency	88	32	216
Confidentiality	0	0	0
Immutability	0	0	0

4.4. Blockchain Application Areas

BCT has a wide range of applications, to list a few, logistics field [21,42], food supply chain and cold chain [21,29], circular supply chain [20], healthcare, manufacturing [29], retail [47,48], and transportation [48]. Some of the famous recent Blockchain solutions under SCM are vaccine distribution, food traceability, supply chain transparency, trade lens container logistics, trusted supplier management [49], recycling [19], and waste and emissions control [14].

Figure 10 shows the breakdown of SCM and BCT research by area. SCM is ranked third concerning the frequency of publications, after the health industry and the government sector. SCM, healthcare, and government areas are consistently growing in recent years (2018–2021), while the others (i.e., banking and cyber security) are declining. Overall, 60% of the publications under SCM and BCT are classified under Computer Science, Engineering, and Business. Business, Management, and Accounting represent 12% of the publications. SCM, BCT, and Environmental Sciences-related research (i.e., BCT for Sustainable SCM, BCT for Circular SCM) or Agriculture-related research (i.e., BCT for Agribusiness, BCT for Food SCM) are potential areas to explore due to the shortage under these areas (See Figure 11).

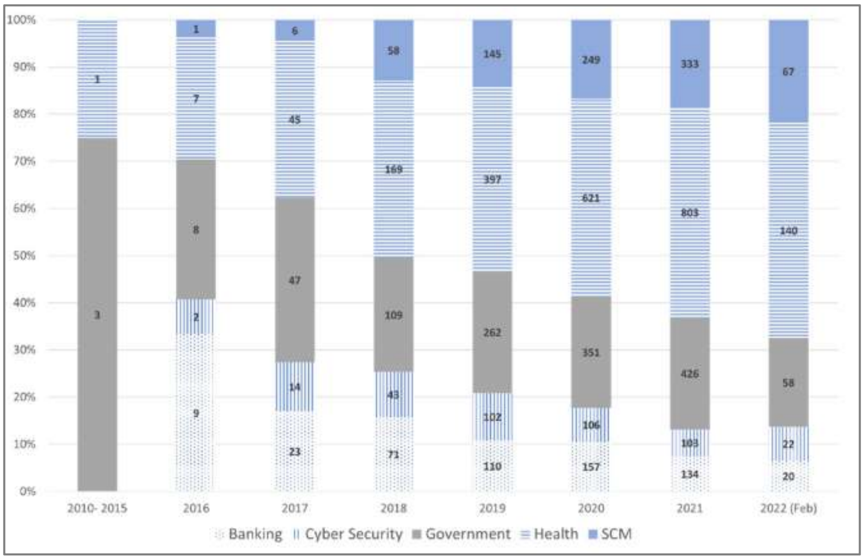


Figure 10. Blockchain publications across areas over the years.

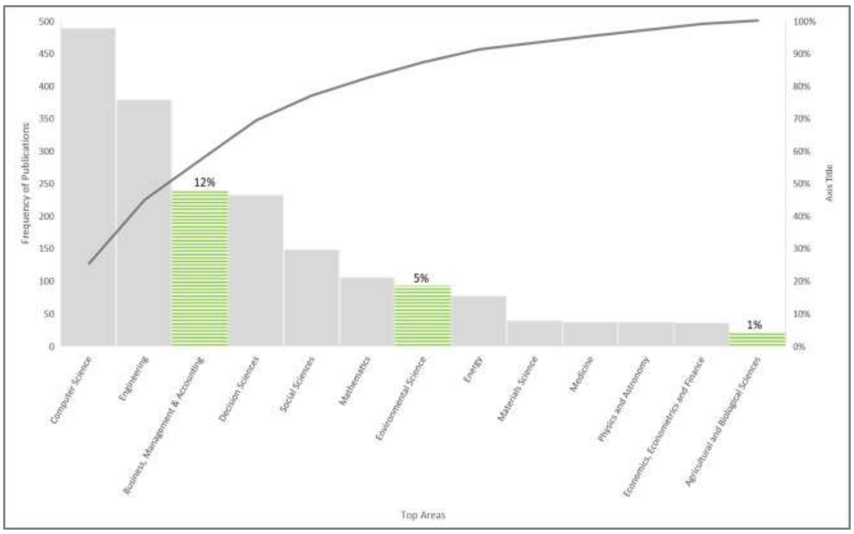


Figure 11. Blockchain publications across areas within the research regime of SCM (2010–2022).

5. Discussion and Limitations

SCM and BCT publications are still less than half the publications under Health Industry and BCT between 2010 and 2022. Therefore, considering more significant adoption of BCT in the SCM context reflects the need for more scholarly research along this line.

Based on the collected data, the U.S. is ranked first in the frequency of publications under BCT and Cyber Security, ranked second under Banking, and the health industry ranked third under SCM area and Government-related applications. India is ranked first in all the selected areas under study, except for Cyber Security. China is ranked second under SCM and Government applications, third under the health area, and fourth under banking and Cyber Security areas.

We have manually reviewed more than 100 publications, including BCT and SCM, thorough studies besides the text mining analysis. The abstracts of these publications include four main clusters with terms that appeared 130 times or more. The most significant two clusters have a theme related to finance-related applications and healthcare, followed by a cluster related to using Blockchain for supply chain-related to agribusiness, circular economy, and a sustainable supply chain.

Numerically, based on 2265 abstracts, traceability is the central feature strongly tied to blockchain and the supply chain. In contrast, there is a complete absence of two features: confidentiality and immutability.

We acknowledge that there exist multiple limitations to this review study. First, one of the main challenges faced while working on that study was the fast pace and changes related to BCT. That imposes a threat on many researchers investigating or performing a literature review on any of the Industry 4.0 technologies due to the accelerated speed of technology's revolution and evolution in addition to the increasing overlap across the various fields among which the technology may serve. In addition, the analysis and results are based on one database only (i.e., Scopus DB). The decision of exclusion and inclusion of abstracts by area was based on a consensus decision by the authors to exclude the research that may not have any connections/ties with the business areas and that may impact the applicability of the results in some areas like engineering, physical sciences, and life sciences.

6. Future Research Opportunities: Next Generation Blockchain

There is no doubt that the future will be more decentralized and data-driven, and BCT is one of the disruptive technologies that remarkably enables that. Furthermore, if effectively applied, BCT can guarantee the correctness of the information accessed by users without tampering. That significantly resolves the problem of information asymmetry [37] and strengthens trust among users. Although BCT has solid ties and possesses a deep root within the FinTech regime, the term "Blockchain" was not one of the top 20 keywords listed between 2011–2021 but was ranked first by 25 scholars involved in the study related to providing their opinion on future research directions [20].

Blockchain has been ever-expanding its potential applications in more and more areas. The evolutionary transformation of BCT can be delineated in Table 2 from Blockchain 1.0 to Blockchain 4.0. This table summarizes the evolution across time based on two BCT-related references [50,51].

In what follows, we proceed to discuss several potential research topics. BCT, along with IoT, has a promising combination. For example, [52] proposed a pallet pooling system based on BCT and IoT (BIoT). They found that the suggested system positively impacts the overall quality of the pooling, increases end-user trust and satisfaction level, facilitates traceability, and minimizes errors. Moreover, this integration leverages cyber security by minimizing system vulnerabilities [53].

Table 2. Evolutionary transformation of Blockchain technology.

	BCT 1.0 Bitcoin—"The Mother of All Blockchain."	**BCT 2.0 Ethereum**	**BCT 3.0 Hyperledger**	**BCT 4.0 Industry 4.0**
Based on	Distributed Ledger Technology, proof of work [50]	Smart contracts, proof of work consensus mechanisms [51]	Smart contract + decentralized Apps (dApps), proof of stack, proof of authority [51]	BCT + A.I. Proof of integrity [51]
Speed	7 transactions/sec.	30 transactions/sec.	Thousands of transactions/sec.	1 Million Transaction/sec.
Pros	• Trusted. • Reliable. • Efficient. • Independent. • Secure.	• Immense application for crowdsourcing. • Reduce verification and execution costs. • Fraud prevention. • Increased Transparency. • Increased efficiency.	• Higher versatility and modularity. • Built-in verification mechanism. • More efficient, scalable, and interoperability than the previous generation. • Enhanced speed. • No single controlling authority. • Eliminate dependency on miners for verification and authentication.	• Enable smooth integration of different platforms. • Highly scalable. • Automated Verification (Sharding) • Most efficient compared to previous generations.
Cons	• Limited Functionality. • Inability to support smart contracts. • No scalability.	• Difficult to write. • Errors may lead to adverse effects. • Poor scalability.	• Complicated. • More bugs and updates due to the decentralized nature.	• To be determined after progressing with applying it.
Cost Level	$$$$$$	$$$$	$$	$
Well-known Applications	Financial Applications.	Electronic voting, trading, and real estate.	Business platform.	Business-usable platform. Industry 4.0

Metaverse and NFT are expected to elevate BCT applications across various industries from different spectrums. Furthermore, as the supply chain is typically complex with multiple supply chains connected and intertwined, blockchains serving different supply chains can relate. Therefore, interoperability and chain–chain communication can be a potential research stream, given that it has been raised as a potential challenge in practice.

Blockchain as a Service (BaaS) has been streamlined as a potential trend that will drive the evolution and revolution of technology in the coming years. For example, IBM provides its Hyperledger Fabric blockchain service to several large-scale and medium-scale companies. In addition, there have been several successful business use cases such as Food Trust, World Wire, etc. As a type of SaaS, BaaS will be seen more and more in the new era of business. In this case, BaaS-related research is another tread in the spotlight.

Hashgraph is another decentralized distributed ledger-based technology to address the data storage challenge. Hashgraph is expected to be the next generation BCT because of its fast speed, fairness, and security. For example, Hashgraph may handle up to half a million transactions per second, while BCT can handle hundreds of thousands of transactions per second [54]. However, there are only 34 publications on the SCOPUS database and Blockchain. Researchers in China and India developed half of the publications for hashgraph and Blockchain. Only seven of these publications were published by researchers in the U.S.

Finally, the holistic review is targeted to inspire research communities across the globe to investigate and explore the open opportunities and areas discussed in this paper. To widen the implementation of BCT across SCM, it is critical to examine the impact of the next-generation technologies, such as Web 3.0, Industry 4.0, and Society 5.0. For example, would hashgraph replace BCT or go alongside it? Is BCT getting more efficient than hashgraph in specific industries? Are businesses ready to go to the next generation distributed ledger if BCT is not fully utilized? Many new research questions will arise with the inclusion of BCT into more SCM applications in the upcoming years.

7. Conclusions

This study performed a holistic and in-depth literature review on BCT for SCM. In particular, we investigated the broad range of potential applications and adoptions where BCT serves as a disruptive superior solution in providing truthful and authentic information compared to its peer technologies. For its salient features, BCT has been embraced widely as a disruptive, decentralized, and internet-based technology for ensuring (1) accountability, (2) efficiency, (3) traceability, (4) transparency, (5) reliability, and (6) security. Indeed, the advantages of transparency, traceability, security, and efficiency lure businesses to explore and experiment with the potential of BCT. As a result, its adoption in SCM has been witnessed with many successful business applications.

In contrast, confidentiality, immutability, and scalability are the main challenges discussed across various studies. Based on the 2265 abstracts studied, there is an absence or low occurrence for many BCT features (i.e., transparency, security, efficiency, confidentiality, and immutability). In addition to BCT's financial application, researchers are exploring Blockchain's potential in other fields, such as supply chains, government systems, etc., and immense efforts have been made to date. As a result, SCM is ranked third regarding the frequency of publications, after the health industry and the government sector. Publications covering both SCM and BCT first appeared together in 2016 on the Scopus database, and 88% of these publications are under eight subject areas. Finally, 12% of the publications related to SCM and BCT are under the business/management/accounting field, followed by 5% under the environmental sciences area and 1% under agricultural and biological sciences. There are strong ties between BCT and IoT, and that is aligned with the recent research pointing out the future era of (BIoT) [38,55].

Author Contributions: A.C.: Developing the main idea and concepts, reviewing articles and collecting data, drafting the manuscript, writing and editing; N.E.-R.: enriching the study, reviewing articles and analyzing the reviewing with data, editing and proofread; J.S.: developing the main idea, reviewing articles, framing and drafting the manuscript, enriching and polishing the study. All authors have read and agreed to the published version of the manuscript.

Funding: The United States Department of Agriculture (USDA) grant (Award No. AM21TMATRD-00C003).

Institutional Review Board Statement: Not available.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Not available.

Acknowledgments: This research is supported in part by the Leir Research Institute (LRI), the Hurlburt Chair and Leir Chair Endowments at NJIT, and the United States Department of Agriculture (USDA) grant (Award No. AM21TMATRD00C003).

Conflicts of Interest: The authors declare no conflict of interest.

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