Blockchain from the Information Systems Perspective: Literature Review, Synthesis, and Directions for Future Research

Abstract

This paper profiled blockchain studies in information systems (IS) journals from 2016 to 2022. Drawing on the 443 selected articles from 77 IS journals, we proposed a classification scheme from the IS perspective. Current blockchain articles are highly skewed, focusing on research agendas and system design. We proposed a theoretical framework by summarizing the current status of the blockchain literature and highlighting 15 future research questions for the IS research community. We are optimistic that the proposed framework and future research questions can guide blockchain research and advance its scale and impact.

Keywords: Blockchain literature review, Information systems, Research framework, Systematic literature review.

1 Introduction

Specific blockchain-based applications, such as cryptocurrencies and non-fungible tokens, have attracted widespread public attention because of their fluctuating value, which creates opportunities for speculative activities [1, 2]. However, blockchain, as their underlying technology, has attracted less public attention than such speculative activities.

Blockchain should mean more than speculative gain or loss [3]. A blockchain is a distributed ledger shared among participants. It stores the chronology of immutable and distributed transactions [4-6]. In 2008, the blockchain concept was first actualized by Bitcoin [7], the first decentralized digital currency or cryptocurrency [8].

Blockchain offers two distinctive qualities that set it apart from other technologies: immutability and decentralization [9]. Practitioners across sectors and industries have attempted to incorporate blockchain into their business processes that require these qualities [4, 10, 11]. For example, in the supply chain field, blockchain has been adopted to keep track of diamond transactions, which used to be recorded on paper [12]. The insurance industry has used blockchain-based smart contracts to automate regulatory reporting [13]. Some practitioners even believe that blockchain technology can revolutionize current industrial ecosystems and trigger widespread economic change [4, 7, 14].

Concurrent with the attention to blockchain applications from various industries, academic researchers have also investigated blockchain-related issues [15]. However, scholarly attention to blockchain technology has relied on technical perspectives, such as computer science and software engineering [e.g., 16, 17, 18]. Investigating blockchain-related issues from these perspectives is essential to advancing blockchain development. However, given that these perspectives mainly focus on the development of software or systems without substantially emphasizing societal concepts (e.g., change management, strategy, impact of information technology [IT]) [19, 20], they may not provide direct insights or implications for organizations and managers.

Information systems (IS) research could fill this gap by focusing on the relationship between organizations and IS and how IS can generate value [21]. Therefore, IS researchers should not wait on the sidelines but rather take the initiative and contribute to the development of blockchain technology. However, although the number of blockchain studies in the IS discipline has significantly increased in recent years, this research field remains largely unknown to potential researchers. Therefore, it is necessary to conduct a systematic review of blockchain studies in the IS literature and develop a research agenda to guide future studies. Previous reviews of the blockchain literature have focused on a specific application area or ways of assimilating blockchain. Therefore, these review papers do not provide a holistic view of the status of blockchain studies in the IS discipline.

This paper presents such a holistic analysis and provides a glimpse of a research agenda for blockchain technology from an IS perspective. Moreover, this study aims to make contributions grounded in a systematic literature review. By identifying underdeveloped areas in blockchain studies in the IS discipline, we propose a research framework highlighting current gaps in the literature. This framework will guide future academic studies to generate more practical implications. Last, we highlight potential future avenues by proposing 15 future research questions on blockchain-related issues.

The remainder of this paper is organized as follows. Section 2 provides the background on blockchain and related work. Section 3 presents the research method. Section 4 presents the descriptive statistics for the identified studies. Section 5 summarizes the current development of blockchain studies in the IS discipline. Section 6 discusses future research directions for blockchain studies. Last, Section 7 concludes our study.

2 Background and Related Work

2.1 Characteristics of Blockchain

Blockchain is an append-only shared ledger storing a highly immutable chronology of transactions [4, 5]. In the general case of blockchain-based applications, every participant needs to store an identical set of blocks to ensure that the information stored in the blocks is not altered [22]. Furthermore, no single party can control the data stored in blockchain applications or change the information stored in a blockchain. Therefore, blockchain-based applications generally provide two main valuable features (i.e., immutability and decentralization) [9].

Blockchain is decentralized. In other words, the operations and data storage of blockchain-based applications do not depend on any single party but on all of the participants in the blockchain network [7]. No single trusted party is needed to conduct any transaction, and no single party can get control of the data and operations of the blockchain, given that no single party can gain control more than 50% of the parties in the blockchain network [23]. In the case of Bitcoin, the operation and proof-of-work mechanism are conducted on the computers in the network [6, 24]. The decentralized design of blockchain eliminates the risk of system downtime caused by the failure of a single, central point.

Blockchain is designed to be immutable [4, 25, 26] (i.e., its architectural design only allows appending the new block in the blockchain but not altering the information stored or deleting any data from the blockchain). Every participant holds a full copy of the blockchain, and the authenticity of data stored in every blockchain is verified through a consensus algorithm. Therefore, the alteration of blockchain data on less than 50% of the nodes will be detected and corrected [7].

Generally, there are three types of blockchain: public blockchain, consortium, and private blockchain. These differ in terms of consensus determination, read permission, immutability, efficiency, centralization, and consensus mechanism [27, 28]. Anyone can participate in a public blockchain, and all participants are responsible for storing and validating the transactions. Therefore, a public blockchain is the most decentralized, immutable, and inefficient among the three types because of the number of participants. A public blockchain is also called a permissionless blockchain because anyone can join [29]. Bitcoin is an example of a public blockchain.

Because only specific, selected nodes are responsible for data storage and validation in a consortium, a consortium blockchain is less decentralized, resistant to changes, and more inefficient than a public blockchain because of the lower number of nodes involved [27]. Last, because a private blockchain is controlled by one organization, it is the most centralized, mutable, and efficient among the three blockchain types [29]. Therefore, both private blockchains and consortiums are called permissioned blockchains.

2.2 How a Blockchain Works

A blockchain contains a series of blocks linked together in chronological order and stores many transactions [30]. Beyond the transactions, each blockchain also comprises a block header containing vital information, such as software version, timestamp, the hash value of the previous block header, and a Merkle root [31]. The hash value of the preceding block header serves as the identifier for a focal block to identify the preceding block (i.e., the linkage between blocks) and the Merkle root serves as the summary of all transactions stored in the focal block [32].

In the general case, every time new transactions are created in the blockchain network, the other nodes participating in the network are responsible for validating the new transactions [26]. In the case of Bitcoin, Bitcoin miners validate the transactions and compete to solve a mathematical challenge by grouping transactions into a block. The Bitcoin miner who has successfully solved the mathematical challenge will be granted the chance to append the new block to the blockchain and get the reward. The new block will then be broadcast to the whole Bitcoin network, and other nodes will reverify the transactions in the new blockchain [31]. In other words, the nodes participating in the blockchain network are responsible for validating the transactions. Different blockchain platforms use different consensus mechanisms to determine the roles of network participants and who will be the block creators [33]. For example, instead of letting the participating node compete in solving a mathematical challenge to create a block, a blockchain using proof of stake as the consensus mechanism will select a single blockchain creator based on preset criteria [31].

The transactions stored in a blockchain are immutable because of hashing, which refers to a mechanism that generates an irreversible, fixed-size, alphanumeric string transformed from a value [26]. Therefore, no one can retrieve the original value from a hash value. As mentioned previously, the header of every block stores a Merkle root summarizing the transactions stored in the focal block and the hash value of the preceding blockchain header [31]. Therefore, every time someone attempts to alter a transaction in a block, the Merkle root is also altered, resulting in a change in the hash value of the focal block's header. At the same time, the hash value of the focal block's header stored in the following block would fail to match the changes. As a result, the link between the focal block and the following block will be broken [34]. Furthermore, because the person who has changed the focal block's content has to gain enough control over the network (which is extremely unlikely) to change the hash value stored in the following block, changes in the focal blockchain will be rejected by other nodes in the blockchain network. As a result, the transactions stored in a blockchain are immutable [31].

Although blockchain is designed to be immutable, developers can still make changes to a blockchain through an action called forking, when necessary. A fork happens in a blockchain when two or more nodes append different valid blocks to the same preceding block [35]. For example, developers of blockchains may create forks when they want to make software updates on the blockchain. Forking is called a soft fork when the participants agree on updates. In this case, during the lag time of the updates, some nodes that have not been updated yet adhere to the old rules, and the updated nodes follow the new rules. In this way, a fork is created. However, the forked chain representing the old rules will become obsolete when all of the nodes have implemented the new rules given in the update [31].

In contrast, a hard fork occurs when the blockchain update is not agreed on. The objectors continue to use the old version, and the others append the newly forked chain, which follows the new rules. For example, in the case of Ethereum, after some users disagreed with the latest updates of Ethereum, Ethereum hard-forked into Ethereum Classic and Ethereum [35].

When the developers do not initiate the creation of forks, these are regarded as unintended forks. These occur most often in open participation blockchains where the participating nodes compete to create a new block. Bitcoin in particular deals with unintended forks by always recognizing the longest chain; unintended forked chains will thus eventually be rejected [31].

In sum, blockchain differs from other IS, such as relational database management systems, in terms of its immutability, decentralization, and distributiveness. As mentioned previously, because of the use of hashing and its structure, the data stored in a blockchain are more immutable than the data stored in a typical IS. Therefore, a blockchain can ensure data integrity once the correct data are stored in the blockchain [36].

In terms of decentralization and distributiveness, because a blockchain depends on a peer-to-peer network, it does not require a central authority or hierarchy [31]. As a result, no single party can take control of a blockchain as long as it is not possible to take over the majority of the nodes in a blockchain network. Moreover, in contrast to other types of IS, implementing blockchain-based systems does not need a trusted intermediary. This eliminates the possibility of a single point whose breakdown would affect the operation of the blockchain-based system [37].

2.3 Previous Systematic Literature Reviews of Blockchain

We have identified several narrative or systematic literature reviews of blockchain studies. Although these literature reviews have provided valuable insights, highlighting the gaps in the blockchain literature and opportunities for future blockchain research, there is still a need for a holistic and systematic literature review of blockchain studies from an IS perspective. First, most systematic literature reviews focus on applying blockchain to a particular purpose or industry [e.g., 38, 39]. However, these literature reviews may not be able to provide an overall picture of the blockchain literature to IS scholars that is relevant to their research interests. Second, some literature reviews focus on a particular topic (e.g., blockchain adoption [e.g., 40, 41]). However, overfocusing on a specific topic may hinder the further development of helpful ideas. For example, although a literature review on blockchain adoption may generate insights for IS researchers focusing on IS adoption, they may overlook how IS topics such as system design may inform the future development of blockchain adoption studies. Third, although some blockchain literature reviews and research agendas cover multiple IS topics related to blockchain, they either are too early or not based on a systematic literature review [e.g., 42, 43]. In Appendix A, we summarize the blockchain literature reviews that we have identified and list their limitations.

3 Research Methodology

3.1 Review Approach

To create our framework and highlight directions for future blockchain research, we conducted a systematic literature review based on the suggestions from Webster and Watson [44] and the practices of Steininger [45]. Table 1 outlines the research design of this study.

Table 1. Research Design of This Study

Steps	Descriptions
Journal Selection	We selected 115 IS journals for our literature search.
Article Identification	We identified 523 potentially relevant articles from the shortlisted journals using the keyword "blockchain." Then, we read the 523 articles[1] and eliminated the irrelevant ones, resulting in the final sample of 443 articles.
Review and Categorization	We used the following criteria to organize our review: (1) research paradigms, (2) methodologies, (3) theoretical frameworks, (4) interactions with other technologies, (5) blockchain-based innovations, (6) forms of blockchain, (7) application sectors, and (8) phases of blockchain innovations.
Analysis of Results	We analyzed and calculated the numbers of articles for categories and subcategories.
Presentation of Results and Agenda	We summarized the findings and gaps from the literature review. We then developed a research agenda based on the review.

3.2 Literature Search

This study involved a systematic literature review of blockchain studies in the IS discipline to explore how blockchain is covered in IS research. This review is not exhaustive but serves as a representative summary of blockchain studies conducted in the IS discipline. In this section, we justify this systematic literature review's search scope in terms of its process, sources, coverage, and techniques [46].

3.2.1 Process

We searched the literature using the sequential search process to ensure the search results' consistency, replicability, and transparency [47, 48]. The sequential search process is the dominant literature-searching strategy in the IS discipline [49].

3.2.2 Sources

We searched and retrieved the full-text articles from multiple bibliographic databases corresponding to each journal outlet instead of a fixed set of bibliographic databases. The reason we used this procedure is that many IS journals are not indexed in the common bibliographic databases, and some databases do not provide complete volumes and issues of the targeted IS journals even if they are indexed [46].

3.2.3 Coverage

We followed the approaches adopted by Dubé and Paré [48] and Wareham, Zheng and Straub [47] and searched for relevant articles in a list of mainstream IS journals [46], which contained 115 journals. Book chapters, dissertations, editorials, short surveys, letters, and reports were excluded from the search because we targeted works from peer-reviewed sources to ensure our review's quality [44, 50, 51]. Following the practice of Ng, Tan, Sun and Meng [51], we also excluded conference papers and reviews to reduce double counting because many were subsequently developed into journal papers that were already included in our sample [e.g., 52, 53].

[1]Two identified articles were retracted from a journal during our review process.

The list of 115 mainstream IS journals consisted of journals in the (1) Association for Information Systems Senior Scholar's Basket (henceforth "the Basket"), (2) "A star" or "A" rankings of the Australian Business Deans Council list under the subject category of IS (henceforth "ABDC List"), (3) "4 star," "4," "3," or "2" rankings of the United Kingdom's Chartered Association of Business Schools (CABS) Academic Journal Guide (henceforth "CABS List"), or (4) top two quartiles of SCImago Journal Rank (SJR) under the subject category of management information systems (henceforth "SJR List").

The Basket contains eight top and representative journals in the IS discipline [21, 54]. Therefore, systematic IS literature reviews typically rely on it [55, 56]. However, focusing on only the Basket may lead to ignoring of an essential body of relevant knowledge published in other IS outlets [57]. Therefore, following the suggestions from Bandara, Furtmueller, Gorbacheva, Miskon and Beekhuyzen [58], the journal list also includes international and country-specific IS journal ranking lists with journal citation reports updated regularly (i.e., the ABDC List, CABS List, and SJR List), which offer objective methods for evaluating the quality and representativeness of IS journals.

The SJR List is adopted because it is widely recognized as an effective indicator of the prestige and importance of journals in this discipline [59-62]. Some systematic literature reviews have used the top two quartiles in SJR as a proxy for the quality of publication outlets [e.g., 63]. The ABDC List and CABS List are highly regarded by the IS community and have been used in other systematic literature reviews in the IS discipline [50, 64, 65]. Because there is no universal definition of an IS study [66], it is a common practice to treat studies published in journals listed in the commonly accepted IS journal lists as IS studies [64, 67]. Although there could also be some IS studies on blockchain published in other journals, because the aim of this study is to provide a representative summary of the blockchain literature from the IS perspective for the consideration of the coverage against feasibility, we limited the search scope to the 115 mainstream IS journals.

3.2.4 Techniques

We searched for the keyword "*blockchain*" in the title, abstract, and keywords of papers through multiple online databases delivering the selected IS journals without specifying the start date of the literature search. Only the term "*blockchain*" was used as a keyword, rather than in combination with other related keywords, such as *"bitcoin,"* "*cryptocurrency,*" "*non-fungible token,*" and "*decentralized autonomous organization,*" which describe a series of blockchain-based applications. We did this for several reasons. First, most of the studies in this area use the term "*blockchain*" in their title, abstract, and keywords because blockchain is the core technology behind these applications [68]. Second, the research studies on these applications, which do not contain the term "blockchain" in their title, abstract, and keywords, tend to ignore the role of blockchain in the focal application. Therefore, these studies can hardly be regarded as blockchain studies. For example, although the study by Xie [69] investigated Bitcoin's trading activities, it conceptualized Bitcoin as an investment tool instead of a blockchain technology.

As of December 2022, 523 articles were initially retrieved from journals. Given that some studies' titles, abstracts, and keywords that contained the term "blockchain" may not be relevant to the blockchain, each retrieved article was reviewed carefully to determine if it focused on this topic. Eventually, 443 relevant articles were retained.

4 Descriptive Quantitative Analysis

4.1 Distribution by Publication Year

Figure 1 shows the distribution of articles according to publication year (2016–2022). It shows that the output of blockchain research has increased since 2016, and a total of 443 articles have been published in IS journals.

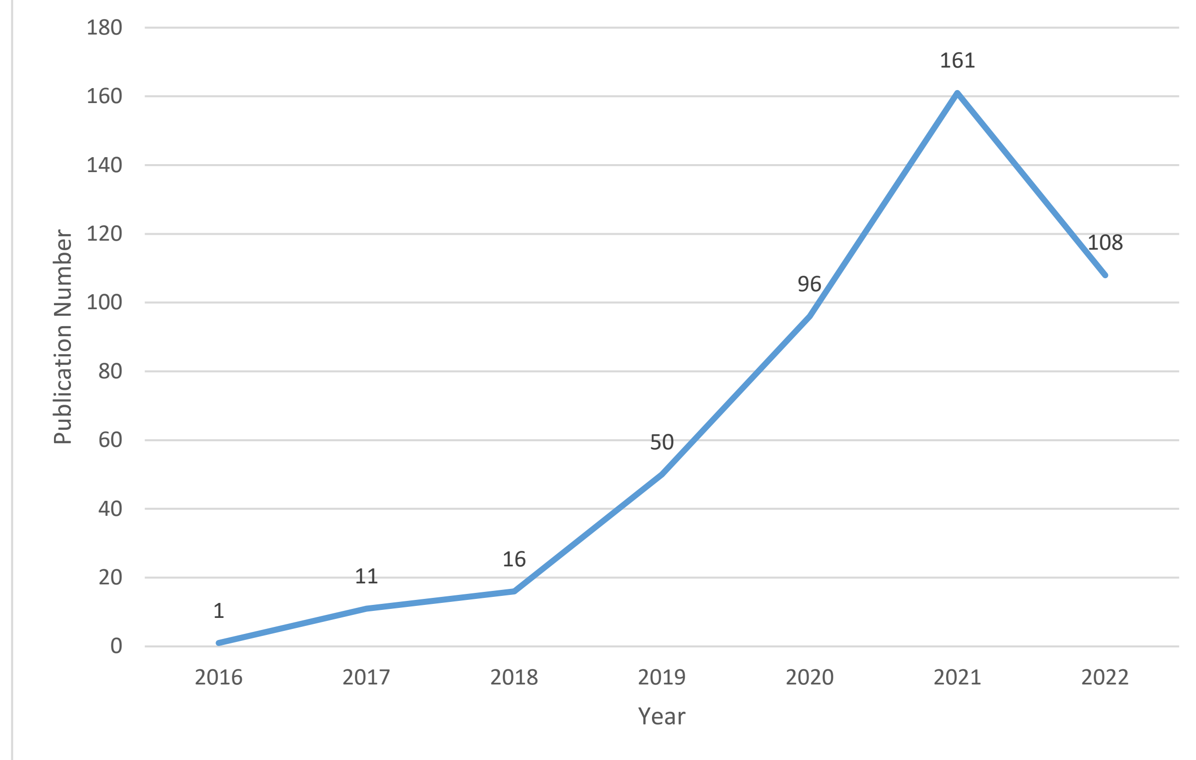

Figure 1. Distribution of Reviewed Journal Articles by Publication Year

4.2 Publication Sources

The 443 selected articles were distributed across 77 journals from the IS discipline. The IS journals that published at least three articles included *ACM Transactions on Management Information Systems* (3 articles), *Big Data and Cognitive Computing* (10), *Big Data Research* (5), *Business & Information Systems Engineering* (7), *Communications of the Association for Information Systems* (4), *Computers & Security* (53), *Computers in Human Behavior* (3), *Decision Support Systems* (9), *Electronic Commerce Research and Applications* (10), *Electronic Markets* (13), *Enterprise Information Systems* (13), *Expert Systems* (8), *Government Information Quarterly* (3), *Industrial Management & Data Systems* (11), *Information & Management* (13), *Information Processing & Management* (54), *Information Systems and e-Business Management* (9), *Information Systems Frontiers* (7), *Information Systems Management* (3), *Information Technology & People* (6), *Information Technology for Development* (7), *International Journal of Information Management* (30), *International Journal of Logistics Systems and Management* (4), *International Journal of Medical Informatics* (7), *Journal of Association for Information Systems* (4), *Journal of Computer Information Systems* (4), *Journal of Enterprise Information Management* (17), *Journal of Global Information Management* (4), *Journal of Information Systems* (8), *Journal of Information Technology* (3), *Journal of Management Information Systems* (7), *Journal of Systems and Software* (8), *Journal of the American Medical Informatics Association* (6), *Knowledge-Based Systems*

(5), *MIS Quarterly Executive* (8), *Records Management Journal* (7), *The Computer Journal* (12), and *Uncertain Supply Chain Management* (5).

4.3 Research Regions

Figure 2 shows the geographical scope of the research.[2] Fifty-three countries or regions were involved in blockchain studies under the IS scope. Among those countries and regions, mainland China ranked first, with 99 publications, followed by the United States (66 articles), India (35), Germany (29), Australia (22), Italy (18), the United Kingdom (18), Switzerland (10), Canada (9), Spain (9), Denmark (8), Malaysia (8), the United Arab Emirates (8), Ireland (7), Turkey (7), France (6), the Netherlands (6), Taiwan of China (6), Austria (5), Hong Kong of China (5), Pakistan (5), Qatar (5), Brazil (4), Korea (4), New Zealand (4), Belgium (3), Hungary (3), and Norway (3). The remaining 31 articles were produced by researchers from 28 other countries or regions.

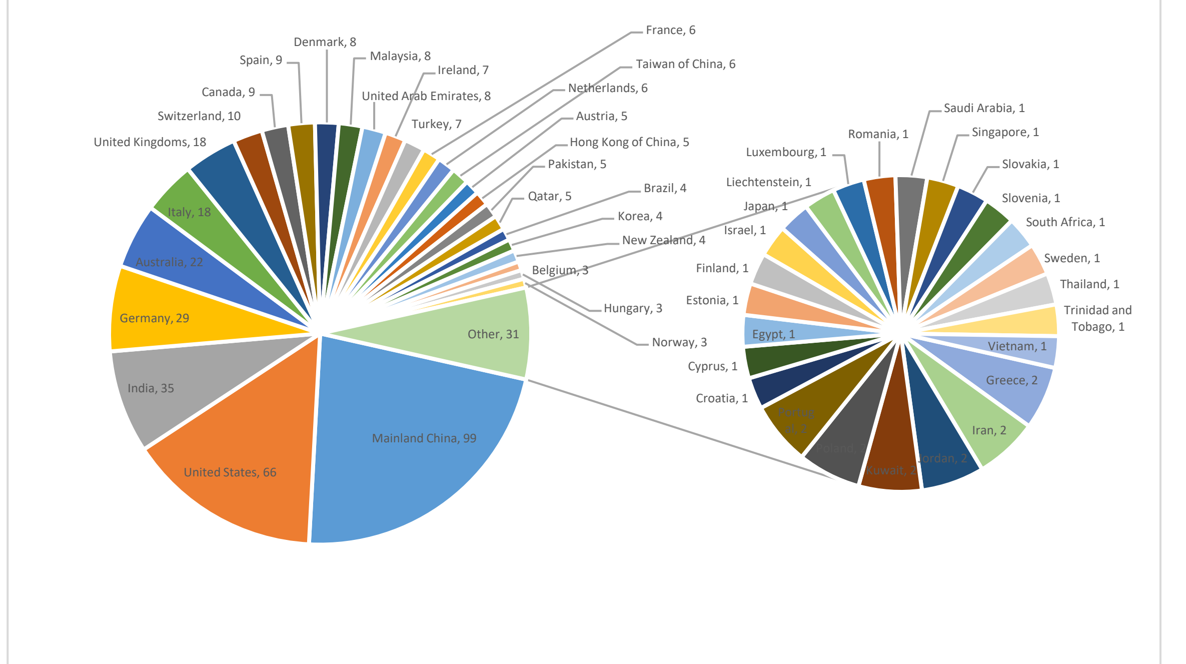

Figure 2. Geographical Scope of the 443 Articles Retrieved

[2] We used the country or region of the first affiliation of the work as a proxy of its geographic scope.

5 Literature Analysis

As stated, the main objectives of this literature review are to present a holistic analysis of the status of the blockchain literature in the IS discipline and to provide IS researchers with a research agenda to guide future blockchain studies. Specifically, we used the following criteria to organize our review: (1) research paradigms, (2) methodologies, (3) theoretical frameworks, (4) interactions with other technologies, (5) blockchain-based innovations, (6) forms of blockchain, (7) application sectors, and (8) phases of blockchain innovations.

The first dimension of our literature analysis, research paradigms, aims to highlight the underlying assumptions and perspectives that guide blockchain studies in the IS discipline. We can also identify research gaps by highlighting the research paradigms that attracted less attention from IS researchers. The second dimension, methodologies, aims to explore the methodologies that IS researchers use to answer their research questions. The third dimension attempts to identify the theoretical frameworks that IS researchers have used to explore blockchain-related issues. We also wish to understand whether blockchain studies are adequately guided by theoretical frameworks and to identify the emerging theoretical frameworks concerning blockchain. The fourth dimension aims to identify the current technologies that IS researchers have co-investigated with blockchain. In the fifth dimension, blockchain-based innovations, we classify the identified blockchain studies in the IS discipline according to the type of innovation in blockchain itself or the new IS enabled by blockchain. With the sixth and seventh dimensions, we classify blockchain studies in the IS disciplines according to the forms of blockchain and the industrial sector being studied, respectively. In the eighth dimension, we analyze the identified studies according to the type of research questions they answer. For example, some of the blockchain studies in the IS discipline attempt to design innovations related to blockchain, whereas some aim to identify the factors determining the adoption of blockchain-related innovations.

We carefully reviewed the identified articles to gain a better understanding of the status of blockchain research and future trends in the IS discipline. Given the interdisciplinary nature of IS and blockchain studies [21], article domain classification is diverse. Therefore, to classify the identified studies, we adopted the iterative inductive classification approach by Ngai and Gunasekaran [70] to extend the three-phase classification framework of Xiao, Califf, Sarker and Sarker [71].

5.1 Research Paradigm

First, we classified the articles according to their research paradigms: positivism, constructivism/interpretivism, criticalism, and pragmatism [72, 73]. These research paradigms offer researchers the opportunity to investigate IS phenomena from different perspectives. Table 2 depicts the distribution of articles according to their research paradigm.

Table 2. Research Paradigms of the Identified Studies

Research Paradigm	**Research Paradigm Description**	**Articles**
Positivism (**N** = 159; **Prop** = 35.9%)	These research studies focus on exploring objective reality through empirical observations by assuming the existence of objective reality.	[5, 28, 32, 36, 37, 40-43, 74-223]
Constructivism/interpretivism (**N** = 16; **Prop** = 3.6%)	These research studies focus on exploring socially constructed realities.	[3, 34, 224-237]
Criticalism (**N** = 3; **Prop** = 0.7%)	These research studies criticize the status quo and challenge social assumptions concerning the distribution of power, alienation, and domination.	[238-240]
Pragmatism (**N** = 265; **Prop** = 59.8%)	These research studies focus on developing and applying prescriptions for solving a problem or achieving a goal.	[30, 35, 38, 39, 52, 241-500]

N: Number of studies; **Prop:** Proportion.

5.1.1 Positivism

Positivism, the dominant paradigm of IS behavioral research studies [48], assumes the existence of objective reality, which is verifiable through empirical observations, such as the a priori fixed relationships between constructs [47, 501]. Therefore, IS research studies that adopt the research paradigm of positivism focus on discovering the objective reality through proposing and verifying testable research hypotheses [73].

We identified 159 IS studies that investigated blockchain-related issues from the perspective of positivism. For example, Liang, Kohli, Huang and Li [129] proposed a research model to investigate the factors driving the organizational adoption of blockchain technology in the finance and health care sector and validated the research model using survey data. Toufaily, Zalan and Dhaou [164] studied the differences between drivers for permissioned and permissionless blockchain adoption through a series of focus group interviews. Based on the findings, they developed a conceptual framework for blockchain adoption that can be empirically validated in future studies.

5.1.2 Constructivism/Interpretivism

Unlike positivism, constructivism/interpretivism assumes that realities do not objectively exist but are constructed in individuals' minds or socially constructed [502]. Therefore, IS research studies that adopt the research paradigm of constructivism/interpretivism tend to explore the meanings of an IS phenomenon from the perspectives of different actors [73].

We identified 16 IS studies that investigated blockchain-related issues from the perspective of constructivism/interpretivism. For example, Palas and Bunduchi [231] investigated how different health care sector stakeholders understand and interpret blockchain's value through a literature review and a series of interviews. Renwick and Gleasure [234] investigated the attitudes of different parties in a cryptocurrency community (including users, developers, cryptographic researchers, corporate architects, and government regulators) toward blockchain's privacy-related issues, through a series of interviews. Divergence in attitudes and understandings was identified among different parties. These disagreements may shape the future development of blockchain.

5.1.3 Criticalism

Criticalism criticizes the status quo and challenges the social assumptions about the distribution of power, alienation, and domination [501]. The ultimate goal of criticalism is to reveal and eliminate alienation and domination in culture [503]. IS studies based on the research paradigm of criticalism may investigate how individuals use IS to reinforce their power and domination [73].

Only three studies have investigated blockchain-related issues from the perspective of criticalism. For example, Treiblmaier [240] questioned the intrinsic value of blockchain and highlighted three potential perspectives for understanding its intrinsic value. In addition, Kavanagh and Ennis [238] proposed that blockchain could facilitate the emergence of a new organizational form, "blockocracy," which will result in the redistribution of power. Accordingly, they introduced future lines of inquiry prompted by this new corporate form.

5.1.4 Pragmatism

Pragmatism is a problem-solving–oriented paradigm [72, 504]. IS research studies that adopt this paradigm will focus on developing and applying IS artifacts and providing prescriptions for solving a problem or achieving a goal [504, 505].

We identified 265 studies investigating blockchain-related issues from the perspective of pragmatism. For example, Yong, Shen, Liu, Li, Chen and Zhou [433] developed a blockchain-based vaccine record system that incorporates machine learning to support vaccine traceability and address the problems of vaccine expirations and vaccine record fraud. In addition, Zamani, He and Phillips [438] developed general guidelines for blockchain users to help them mitigate attacks and reduce cyber security risks when using blockchain technologies.

5.2 Research Methodologies

The research methodologies adopted by the 443 articles were grouped into seven categories following the scheme proposed by Wu, Ngai, Wu and Wu [506]: case study (70 articles), conceptual approach (126), experiment (28), focus group interview (7), modeling and simulation (123), secondary data analysis (58), and survey (31). Table 3 presents the categorization of methodologies and the articles' corresponding distribution.

Approximately 28% of the identified studies (126 articles) used the conceptual approach to investigate blockchain-related issues. Of these studies, only 44 derived their findings based on a systematic literature review. The relatively large proportion of studies using the conceptual approach implies the existence of research opportunities for blockchain studies because conclusions drawn based on the conceptual approach need further verification and validation by other methods.

Approximately 16% of the identified studies (70 articles) adopted the case study as the research methodology. Among these studies, 27 used a single case, whereas 43 used multiple cases to validate their ideas or draw conclusions. The interview was the most frequently used technique for data collection (50 articles), followed by documentary data collection (33) and observation (10). However, 18 of the identified case studies were based only on publicly available secondary documentary data; another 18 used more than one technique for data collection.

Table 3. Description of Methodologies

Methods	Method Description	Articles
Case study (**N** = 70; **Prop** = 15.8%)	These studies explored an issue using intensive case analysis based on interviews, observations, and analysis in a specific context.	[28, 35, 37, 52, 80, 87, 88, 95, 103, 105, 117, 121, 122, 125, 126, 130, 132, 135, 136, 141, 153, 162, 163, 169, 172, 174, 183, 186, 191, 193, 202, 203, 217, 220, 222-225, 227, 229-231, 234, 236, 237, 239, 258, 280, 282, 291, 299, 300, 317, 323, 325, 326, 337, 370, 390, 393, 395, 397, 404, 438, 439, 458, 460, 469, 486, 493]
Conceptual approach (**N** = 126; **Prop** = 28.4%)	Instead of empirical data, these studies drew conclusions based on the authors' experiences, the literature, current practices, situations, and imagined scenarios.	[5, 30, 32, 34, 38-43, 74, 82, 85, 89, 91, 94, 98-100, 102, 111, 112, 118, 128, 134, 138, 139, 147, 149, 152, 154, 157, 159-161, 165-167, 170, 171, 175, 184, 185, 189, 197, 198, 200, 210, 216, 218, 226, 228, 233, 235, 238, 240, 245, 246, 248, 250, 253-255, 259-262, 265, 266, 270, 272, 276, 277, 279, 288, 289, 297, 306, 307, 309-311, 322, 332, 334, 344, 347, 351, 353, 356, 364, 365, 369, 372-375, 379, 380, 383, 386, 396, 398-400, 405, 407, 409, 412, 417, 425, 449, 451, 454, 455, 464, 467, 474, 476, 477, 484, 485, 488-490, 498]
Experiment (**N** = 28; **Prop** = 6.3%)	These studies validated system designs or research models through free simulation or experiments on a prototype.	[79, 115, 156, 196, 215, 249, 263, 268, 269, 278, 283, 294, 302, 308, 321, 327, 343, 349, 384, 428, 431, 434, 440, 443, 453, 457, 459, 472]
Focus group interview (**N** = 7; **Prop** = 1.6%)	These studies explored issues or validated ideas using focus group interviews.	[3, 124, 142, 155, 164, 271, 362]
Modeling and simulation (**N** = 123; **Prop** = 27.8%)	These studies validated designs or research models using mathematical modeling or simulation data.	[36, 86, 93, 101, 131, 137, 144, 150, 168, 173, 176, 179, 181, 188, 190, 195, 212, 221, 242-244, 247, 251, 252, 256, 257, 264, 267, 273-275, 281, 284-287, 290, 292, 293, 295, 298, 303-305, 312, 314, 315, 319, 320, 324, 339, 341, 342, 345, 346, 350, 352, 354, 357-359, 361, 363, 366-368, 371, 376-378, 382, 385, 387-389, 391, 392, 394, 401, 403, 406, 410, 411, 413-415, 418, 419, 421, 423, 424, 427, 429, 430, 435-437, 441, 442, 446, 448, 450, 452, 456, 461, 462, 465, 466, 468, 470, 471, 473, 475, 478-481, 483, 487, 494, 495, 497, 500]
Secondary data analysis (**N** = 58; **Prop** = 13.1%)	These studies explored issues or validated ideas or designs using secondary data.	[75-78, 83, 84, 106-110, 114, 120, 127, 140, 143, 148, 201, 205, 206, 208, 211, 213, 232, 296, 301, 313, 316, 318, 328-331, 333, 335, 336, 338, 340, 348, 355, 360, 381, 402, 416, 420, 422, 426, 432, 433, 444, 445, 447, 463, 482, 491, 492, 496, 499]
Survey (**N** = 31; **Prop** = 7.0%)	These studies used questionnaires to obtain quantitative or qualitative data to explore issues or validating research models or system designs.	[81, 90, 92, 96, 97, 104, 113, 116, 119, 123, 129, 133, 145, 146, 151, 158, 177, 178, 180, 182, 187, 192, 194, 199, 204, 207, 209, 214, 219, 241, 408]

*__N:__ Number of studies; **Prop:** Proportion.

5.3 Theoretical Frameworks

We also reviewed the theories that were explicitly studied in the identified articles. The results showed that many theories were used to understand and analyze blockchain-related questions. Among the 67 theories identified from the literature, the majority (i.e., 47) were borrowed from other disciplines, which are often adopted in IS literature. Table 4 summarizes the theoretical frameworks borrowed from other disciplines. Most of these theories were used in only one study; the exceptions were game theory (6 articles), agency theory (3), the resource-based view (3), signaling theory (3), affordance-actualization theory (2), institutional theory (2), public-value theory (2), social exchange theory (2), systems theory (2), and the value-focused thinking framework (2).

Table 4. Theories from Other Disciplines Identified from the Literature

Theory	Methodologies	Articles
Affordance-actualization Theory	CS; SDA	[95, 492]
Agency Theory	CS	[130, 225, 493]
Claim Theories	CA	[185]
Commodity Theories	CA	[185]
Competitive Performance Model	Sur	[177]
Computational Complexity Theory	CS	[282]
Contract Theory	M&S	[437]
Cooperative Theory	CS	[323]
Decision Theory	CA	[262]
Ecological Perspective	CS	[237]
Economic Theory	SDA	[110]
Framework of Universal Composability	M&S	[285]
Functional Leadership Theory	SDA	[211]
Game Theory	M&S	[36, 131, 168, 190, 212, 221, 293]
Graph Theory	CA	[198]
Hofstede's Cultural Theory	Survey	[151]
Institutional Theory	CS	[393, 493]
Mean-risk Theory	M&S	[86]
Metcalfe's Law	SDA	[75]
Multiple-channel Communication Theory	SDA	[84]
Optimization Theory	SDA	[426]
Practice-based View	Sur	[214]
Probability Theory	M&S	[324]
Process-problem-solution Framework	CS	[136]
Protection Motivation Theory	Sur	[209]
Psychological Ownership Theory	SDA	[208]
Public-value Theory	CS	[88, 153]
Queuing Game Model	SDA	[206]
Queuing Theory	M&S	[251]
RBV	CS; Sur	[96, 135, 199]
Regret Theory	Sur	[133]
Resource Dependence Perspective	CS	[135]
Self-determination Theory	CS	[172]
Service-dominant Logic	CS	[220]
Signaling Theory	Exp; SDA	[83, 143, 196]
Social Capital Theory	SDA	[208]
Social Exchange Theory	CS; Exp	[215, 220]
Stakeholder Theory	CS	[153]
SWOT Theory	CA	[138]
Systems Theory	Sur	[113, 187]
Theory of Disintermediation	CS	[163]
Theory of Faking Likelihood	Exp	[115]
Theory of Purchasing Power Parity	M&S	[93]
Transaction Cost Theory	Exp	[443]
Trust Transfer Theory	Exp	[156]

User Experiences Framework	CS	[317]
Value-focused Thinking Framework	CS; M&S	[169, 378]

***CS:** Case Study; **CA:** Conceptual Approach; **Exp:** Experiment; **FGI:** Focus Group Interview; **M&S:** Modeling and Simulation; **SDA:** Secondary Data Analysis; **Sur:** Survey.

In addition, we identified 12 native IS theories that have been used to guide the inquiry of blockchain. Most of these theories were used once, with the exceptions of decision science research theory (20 articles), the unified theory of acceptance and use of technology/technology acceptance model (UTAUT/TAM) (9), diffusion-of-innovation (DoI) theory (5), and the technology–organization–environment (TOE) framework (5). Table 5 summarizes the native IS theories identified from the literature.

Table 5. Native IS Theories Identified from the Literature

Theory	Methodologies	Articles
Business Model Framework	CS	[231]
Capture, Understand, and Present Framework	SDA	[106]
Confidentiality-Integrity-Accessibility Triad Model	CS	[174]
Database Audit Theory	M&S	[481]
Design Science Research Theory	CS; CA; Exp; FGI; M&S; Sur	[241, 246, 253, 267-269, 299, 315, 362, 367, 370, 375, 384, 385, 397, 399, 440, 486, 488, 495]
DOI Theory	CS; CA; FGI; SDA; Sur	[28, 85, 108, 164, 207]
Fit-viability Model	Sur	[129]
Organizing Framework for Social Media Research	CA	[5]
Organizing Visions Theory	SDA	[232]
Theory of Polycentric Information Commons	CA	[226]
TOE Framework	CA; FGI; Sur	[40, 85, 104, 164, 178]
UTAUT/TAM	CA; SDA; Sur	[81, 90, 91, 107, 116, 119, 145, 171, 219]

***CS:** Case Study; **CA:** Conceptual Approach; **Exp:** Experiment; **FGI:** Focus Group Interview; **M&S:** Modeling and Simulation; **SDA:** Secondary Data Analysis; **Sur:** Survey.

We also identified attempts to develop new theories to facilitate the investigation of blockchain-related issues. Table 6 summarizes these native blockchain theories. They include (1) artificial general intelligence (AGI) safety theory, (2) blockchain governance framework, (3) EDGE supply chain framework, (4) fit-network model, (5) integrated process, institutional, market, and technology framework for blockchain adoption, (6) sensor data protection system design theory, and (7) smart network theory. However, except for the sensor data protection system design theory, blockchain governance framework, and fit-network model, these native blockchain theories were neither built on nor validated by empirical data.

Table 6. Native Blockchain Theories Identified from the Literature

Theory	Methodologies	Articles
AGI Safety Theory	CA	[266]
Blockchain Governance Framework	CS	[141]
EDGE Supply Chain Framework	CA	[451]
Fit-network Model	FGI	[155]
Integrated Process, Institutional, Market, Technology Framework for Blockchain Adoption	CA	[41]
Sensor Data Protection System Design Theory	FGI	[271]
Smart Network Theory	CA	[166]

***CS:** Case Study; **CA:** Conceptual Approach; **Exp:** Experiment; **FGI:** Focus Group Interview; **M&S:** Modeling and Simulation; **SDA:** Secondary Data Analysis; **Sur:** Survey.

In sum, of the 67 identified theoretical frameworks, only 14 were used more than once, which indicates the variety of theoretical perspectives that researchers have adopted to explore blockchain-related issues. However, we found that 331 of the 443 identified articles did not use or explicitly state any theory. Together with the relatively wide range of theoretical frameworks used to study blockchain-related issues, this fact implies a lack of widely accepted theoretical lenses to analyze blockchain-related issues, such as implementing blockchain-based applications.

5.4 Interactions with Other Technologies

A significant proportion of identified studies investigated blockchain in connection with other technologies. In sum, 37 technologies were identified, as listed in Table 7. Among these technologies, the Internet-of-things (IoT) was the most frequently mentioned technology (39 articles), followed by health care systems (13), AI (10), cloud computing (10), knowledge management systems (4), public key infrastructure (PKI) (4), e-voting systems (3), federated learning (3), fog computing (3), near-field communication (NFC), and radiofrequency identification (RFID) (3), smart grid (3), traffic and incident management systems (3), access management systems (2), machine learning (2), review and recommendation systems (2), rockets and satellites (2), and self-sovereign identity (2). The remaining 20 technologies were investigated only once in connection with blockchain.

The identified studies proposed integrating blockchain with the technologies mentioned above because of blockchain's immutability and decentralization [4-6]. Hence, blockchain would improve the security level of these technologies or allow them to operate without a trusted third-party service provider. For example, Preuveneers, Joosen and Ilie-Zudor [382] proposed a private blockchain-based system to secure the IoT-enabled data flow-oriented networked production process. They found that the system could guarantee the data transparency, integrity, authenticity, and authorization of data flow-oriented Industry 4.0 processes. Adja, Hammi, Serhrouchni and Zeadally [243] developed a blockchain-based certification revocation management and status verification system for PKI without a commonly trusted authority.

The identified studies also showed that these technologies can tackle blockchain's existing problems. For example, Albizri and Appelbaum [246] proposed using IoT as the trusted oracle of a smart contract, instead of people, because IoT devices are less susceptible to collusion and bribery than people. Wang, Cheng, Zheng, Yang and Zhu [416] developed an AI-based method to detect Ponzi schemes, a classic type of fraud, in blockchain-based smart contracts.

Table 7. Technologies Interacting with Blockchain

Technology	Articles
Access Management Systems: *The systems that decide whether a request for accessing a particular computing resource made by a subject (for example, a user) is legitimate.*	[283, 392]
Accounting Information Systems: *The systems that business users use to collect, store, management, process, retrieve, and report financial data*.	[279]
AI: *The technologies that equip computers to make decisions like human beings*.	[173, 254, 258, 266, 281, 291, 356, 360, 416, 432, 492]
Big Data: *Data with high volume, variety, and velocity characteristics*.	[111, 262, 291, 341, 356, 404]
Chatbot: *A software application that can conduct online conversations like a human agent.*	[230]
Cloud Computing: *A pool of shared computing resources that people can access through the Internet, such as storage, computing power, and applications*.	[148, 253, 257, 265, 285, 314, 338, 341, 348, 355, 406, 410, 441, 462, 473]
Cloudlet: *A trusted and resource-rich cluster of computers that is well-connected to the Internet and available for nearby mobile devices*.	[377]
Data Analytics: *Analyzing datasets to uncover hidden patterns to help make informed decisions*.	[291]
Digital Signature: *A digital solution for ensuring user identification and data integrity using cryptographic algorithms*.	[261]
Digital Twins: *A virtual representation of an object over its entire lifecycle, which can be used to provide insights for managing the focal object*.	[384]
Dispute Resolution Platforms: *The online platforms that facilitate the formation of resolutions of disputes between parties*.	[258]
e-Bidding System: *An online auction system for letting people compete for the ownership of products or services by making higher and higher bids*.	[391]
Edge Computing: *The distribution of data, applications, and services to the edge of a network close to the data source, which can reduce the pressure on the cloud*.	[338, 349, 442, 496]
e-Marketplace: *The virtual places where potential sellers and buyers can interact and transact*.	[323]
e-Voting Systems: *An election or vote that is implemented using electronic means*.	[309, 321, 379, 500]
Federated Learning: *A decentralized machine learning approach that does not require sharing raw data sets*.	[248, 308, 411, 470]
Fog Computing: *The middle layer between the cloud and end-users that performs some of the tasks required by end-users to reduce latency, network load, and energy consumption*.	[257, 293, 410, 473]
Healthcare Systems: *The information systems that facilitate the provision of healthcare services*.	[156, 245, 305, 329, 345, 358, 362, 364, 372, 395, 396, 419, 452]
Human Resource Management Systems: *The information systems that facilitate important tasks for the human resources department*.	[183]
IoT: *A network of sensors, machines, and objects that perceive the physical environment and exchange data through the Internet*.	[39, 91, 130, 167, 187, 242, 244, 246-249, 252, 254, 262-264, 271, 281, 282, 290-293, 298, 303, 308, 312, 339, 357, 376, 377, 382, 387, 403, 410, 411, 415, 437, 442, 445, 451, 456, 461, 462, 473, 478, 489, 490, 495]
KMS: *The information systems that support knowledge management in organizations*.	[241, 348, 349, 425]
Machine Learning: *Technologies that equip computers and machines to learn or improve performance based on available data*.	[433, 482]
Neural Network and Deep Learning: *Subsets of AI that allow computers to process data in a way inspired by the human brain*.	[316, 472, 497]

NFC and RFID: *A contactless connection technology that allows data transmission within a short distance.*	[187, 244, 300]
PKI: *The infrastructure for managing digital certificates of entities using public key encryption.*	[243, 327, 428, 446, 495]
Private Key Generator: *A trusted third party that generates user private keys.*	[456]
Quantum Computation: *An emerging technology that harnesses the laws of quantum mechanics to solve problems that are too complex for conventional computers.*	[242]
Quick Response Code: *A 2D barcode version that can contain more information than a conventional barcode.*	[300]
Review and Recommendation Systems: *The functions of e-commerce platforms that provide recommendations to customers and allow customers to write reviews concerning products.*	[38, 454]
Rockets and Satellites: *The artificial objects used for space travel or placed into orbit in outer space for a certain purpose.*	[217, 344]
Self-sovereign Identity: *A portable digital identity for its owner to obtain various services in the digital world.*	[476, 486]
Semantic Search: *A search algorithm that can understand the semantic meaning of searching keywords.*	[426]
Smart Devices: *Electronic devices that can work autonomously and interactively, generally connected to networks.*	[316]
Smart Grid: *An electricity network that enabled a two-way flow of electricity and data between energy suppliers and consumers.*	[121, 168, 262, 273, 342]
Software Defined Networking: *A virtualization approach to network management.*	[273]
Thin Client: *A low-performance computer optimized for connecting to a server-based computing environment.*	[309]
Traffic and Incident Management Systems: *The information systems that facilitate the management of traffic and transport incidents.*	[320, 360, 368]

5.5 Blockchain-based Innovations

Blockchain is a technology that can serve as the foundation for creating new processes, systems, and services [10]. A total of 73 blockchain-based innovations were identified during our review process. We adopted the three-set model of IS innovation proposed by Lyytinen and Rose [507] to summarize the blockchain-based innovations identified in the IS literature. The three-set model suggests three types of innovations that mutually affect each other: IS base innovations, system development innovations, and service innovations. IS base innovation describes changes in the base technology in terms of functionality, efficiency, architecture, and reliability, which can be enabled by new modeling and design principles [507]. In the case of blockchain (i.e., base innovations in blockchain), these changes may be done by improving its scalability and efficiency by modifying its consensus protocol or incorporating a new development process [397, 401]. System development describes changes in the tools and processes of developing systems, which are facilitated and enabled by the focal base IS [507]. In the case of blockchain (i.e., innovations in systems development enabled by blockchain), these changes refer to new tools and processes based on blockchain that will allow further innovations. For example, Putz, Dietz, Empl and Pernul [384] created a blockchain-based digital twin to provide business process modeling to facilitate innovation in business processes. Service innovation describes innovations in business functions or processes enabled by the focal base IS [507]. In the case of blockchain (i.e., innovations in services enabled by blockchain), these changes can refer to new systems or business processes enabled by blockchain. For example, blockchain can be used to develop a decentralized peer review system for open-access academic journals [408]. Tables 8-10 present the types of blockchain innovations identified from the literature.

5.5.1 Base Innovations in Blockchain

We identified 13 specific base innovations in blockchain from the literature, which are given in Table 8. The most frequently discussed base innovation in blockchain was blockchain efficiency and scalability improvement (20 articles), followed by blockchain auditing and governance (15), blockchain security improvement (14), blockchain vulnerabilities identification (12), the value of blockchain (8), evaluation of blockchain (7), blockchain development (5), blockchain data integrity and maintenance (4), deanonymizing blockchain (4), blockchain data manipulation (3), and regulatory compliance of blockchain (3).

It is not surprising that there have been numerous studies about improving the efficiency and scalability of blockchain because these have been considered significant issues in blockchain [508-510]. For example, Ekanayake and Halgamuge [290] developed a lightweight blockchain framework based on the master–slave blockchain paradigm to reduce the cost of computationally intensive mining processes and network traffic while fairly rewarding concurrent blockchain miners. In addition, Yu, Li and Zhao [434] proposed a new version of blockchain using the concept of virtual block group to improve the scalability of blockchain without compromising blockchain's reliability and security.

It is also not surprising that there were multiple studies about auditing, governing, or making blockchain comply with laws and regulations. The reason is that the immutability and decentralization of blockchain may lead to challenges in handling illicit data or current laws and regulations, such as the right to be forgotten stated in the General Data Protection Regulation (GDPR). For example, Rieger, Guggenmos, Lockl, Fridgen and Urbach [390] made recommendations for ensuring that blockchain-based applications comply with the GDPR. van Pelt, Jansen, Baars and Overbeek [141] developed a framework for blockchain governance that highlighted six dimensions—formation and context, roles, incentives, memberships, communication, and decision making, and three layers—off-chain community, off-chain development, and on-chain protocol.

We identified numerous attempts to improve the security level of blockchain or identify the existing vulnerabilities of blockchain even though blockchain is considered to have a high level of security [43]. For example, Khan, Arshad and Khan [321] highlighted the conditions that may make blockchain-based e-voting systems vulnerable to transaction malleability attacks. Yang, Chang, Misic and Misic [423] found that selfish mining behaviors could compromise the security level of both Bitcoin and Ethereum. Therefore, they developed a model to detect the existence of selfish miners in a blockchain network.

Interestingly, although Bitcoin is usually regarded as a technology with high anonymity because the identities of users are protected by pseudonyms [10], several attempts have been made to show that Bitcoin can be deanonymized. For example, Jawaheri, Sabah, Boshmaf and Erbad [318] demonstrated how to deanonymize the parties involved in Bitcoin transactions. Additionally, Sun Yin, Langenheldt, Harlev, Mukkamala and Vatrapu [432] proposed a machine learning approach to disclosing the true identities of Bitcoin users.

Table 8. Base Innovations in Blockchain Identified from the Literature

Blockchain Innovation	Description	Articles
Blockchain Auditing and Governance	These studies focus on methods for auditing and governing blockchain.	[124, 125, 141, 142, 152, 153, 157, 159, 184, 191, 216, 234, 253, 286, 458]
Blockchain Data Integrity and Maintenance	These studies focus on developing the methods or improving the algorithm of blockchain to improve and maintain the data integrity of the blockchain.	[35, 169, 246, 459]
Blockchain Data Manipulation	These studies focus on designing methods for extracting, organizing, arranging, and cleansing the data stored in blockchain.	[447, 466, 472]
Blockchain Development	These studies focus on the process and issues concerning the development of blockchain-based technologies.	[34, 211, 397, 398, 465]
Blockchain Efficiency and Scalability Improvement	These studies focus on the alteration of the underlying algorithm of blockchain to improve the efficiency and scalability of blockchain.	[76, 275, 290, 304, 324, 339, 340, 346, 389, 401, 402, 407, 414, 415, 431, 434, 435, 448, 478, 480]
Blockchain Mining Strategies	These studies focus on different types of blockchain mining strategies used by blockchain miners.	[144]
Blockchain Security Improvement	These studies focus on improving blockchain's security level by either improving its algorithm or integrating blockchain with other technologies.	[294-296, 352, 366, 394, 416, 417, 420, 423, 444, 468, 475, 494]
Blockchain Vulnerabilities Identification	These studies identify the vulnerabilities or security issues of blockchain.	[110, 251, 284, 301, 313, 321, 386, 413, 438, 470, 497, 499]
Centralization of Blockchain	This study examines the phenomenon of different blockchain implementations becoming more centralized, which may compromise the security level of the blockchain.	[149]
Deanonymizing Blockchain	These studies focus on methods or tools to identify the parties involved in transactions using blockchain.	[318, 381, 432, 482]
Evaluations of Blockchain	These studies focus on tools or methods to evaluate the effectiveness and performance of blockchain implementations.	[30, 89, 113, 421, 436, 463, 483]
Regulatory Compliance of Blockchain	These studies focus on the issues of blockchain in connection with compliance with laws and regulations.	[94, 281, 390]
Value of Blockchain	These studies explore the price or intrinsic value of different blockchain implementations.	[75, 101, 109, 114, 127, 150, 239, 240]

5.5.2 Innovations in System Development Enabled by Blockchain

We identified 14 innovations in system development enabled by blockchain. These innovations can further support innovations in other business processes. Table 9 presents the innovations in system development enabled by blockchain identified from the literature. The most frequently discussed innovations in system development enabled by blockchain were IoT protection and implementation (35 articles), followed by identity and access management (13), information governance and data auditing (4), cloud computing support (3), cyber security (3), distributed data analytics (3), self-organizing blockchain communities (2), and software engineering support (2). The remaining 6 innovations in system development enabled by blockchain were studied once in the literature.

It is not surprising that many identified innovations in system development enabled by blockchain were about using blockchain to protect and support IoT systems because IoT is the most frequently mentioned technology among the identified blockchain studies. For example, Chanson, Bogner, Bilgeri, Fleisch and Wortmann [271] proposed a blockchain-based sensor data protection system design theory to ensure the tamper-resistant gathering, processing, and exchange of IoT sensor data in a privacy-preserving, scalable, and efficient manner. Preuveneers, Joosen and Ilie-Zudor [382] proposed a private blockchain-based system to secure the IoT-enabled data flow-oriented networked production process. They found that the system can guarantee the data transparency, integrity, authenticity, and authorization of data flow-oriented Industry 4.0 processes.

Blockchain was often proposed as a way of supporting identity and access management across different business processes. Identity and access management is indispensable in Web-based applications that need effective identity verification methods, such as e-banking and e-commerce. For example, Kubilay, Kiraz and Mantar [327] developed a blockchain-based PKI to make the certificate authority more transparent. Di Francesco Maesa, Mori and Ricci [283] automated access control policies using a blockchain-based smart contract to eliminate the possibility of human errors.

Moreover, blockchain can be used to reinvent cloud computing. For example, Zhang, Yang, Xie and Liu [441] developed a securely authorized deduplication scheme based on blockchain to ensure the confidentiality and security of the users' data stored on cloud servers when eliminating redundant data. Dorsala, Sastry and Chapram [285] designed a smart contract–based solution for achieving fair payments for verifiable cloud computing without a trusted intermediary.

Beyond creating new challenges and problems for information governance and auditing, blockchain can also be used as a solution to conduct information governance and data auditing. For example, Lu, Zhang, Shi, Kumari and Choo [355] developed a decentralized data integrity auditing scheme based on blockchain to verify the integrity of outsourced data, such as the data stored in cloud servers. Qiu [481] proposed to use blockchain to manage the audit server scheme for auditing encrypted data.

Table 9. Innovations in System Development Enabled by Blockchain Identified from the Literature

Blockchain Innovation	Description	Articles
Cloud Computing Support	These studies propose using blockchain to support the implementation of cloud computing.	[265, 285, 441]
Cyber Security	These studies propose using blockchain to improve cyber security.	[351, 429, 476]
Data Aggregation Support	This study proposes using blockchain to facilitate efficient data aggregation.	[388]
Digital Twin Protection	This study proposes using blockchain to protect digital twins.	[384]
Distributed Data Analytics	These studies propose approaches to conducting data analytics on a blockchain.	[330, 331, 333]
Identity and Access Management	These studies propose using blockchain to supply identity and access management.	[243, 261, 283, 292, 311, 322, 327, 363, 392, 405, 424, 427, 428]
Information Governance and Data Auditing	These studies propose using blockchain for information governance and data auditing.	[228, 341, 355, 481]

IoT Data Monetization	This study proposes using blockchain to monetize data generated by IoT.	[249]
IoT Protection and Implementation	These studies propose using blockchain to protect or support the implementation of IoT.	[39, 167, 242, 244, 247, 248, 252, 254, 257, 264, 271, 282, 293, 298, 303, 308, 312, 357, 376, 377, 382, 387, 403, 410, 411, 437, 442, 445, 456, 461, 462, 473, 489, 490, 495]
Log Record Management	This study proposes using blockchain to store and manage log records of computers.	[385]
Monitoring AI	This study proposes using blockchain to monitor the behaviors of AI.	[266]
Privacy Preservation	This study proposes using blockchain to protect the privacy of users of online services.	[484]
Self-organizing Blockchain Communities	These studies focus on the self-organizing communities in developing blockchain technologies.	[224, 229]
Software Engineering Support	These studies propose using blockchain to support the software engineering process.	[302, 457]

5.5.3 Innovations in Services enabled by Blockchain

From the literature, we identified 56 innovations in services enabled by blockchain. Table 10 presents the innovations in services enabled by blockchain identified from the literature. The most frequently discussed innovation in services enabled by blockchain was supply chain management (SCM) (55 articles), followed by health care systems (23), sustainable development (14), innovative business models (11), cryptocurrencies (10), business process management and implementation (9), fraud prevention (8), asset trading (6), initial coin offering (ICO) (5), smart grid support (5), contract execution and auditing (4), data trading (4), information sharing (4), knowledge management (4), public health management (4), record management (4), transactions support (4), business network implementation (3), e-marketplace (3), e-voting (3), FinTech (3), traffic and incidents management (3), accounting systems (2), automation of public services (2), credit reporting and evaluation (2), customer relationship management (CRM) (2), insurance management (2), peer review (2), real estate transactions (2), and recommendations and reviews protection (2). The remaining 26 innovations in services enabled by blockchain were studied in the literature only once.

It is worth noting that we identified a significant number of studies about integrating blockchain into SCM. This is unsurprising because blockchain is a hot topic in SCM because many blockchain-based SCM systems have already been implemented in practice. For example, food supply and retail giants such as Walmart, Tyson Foods, and Nestlé have collaborated with IBM to use blockchain technology to improve the authenticity and transparency of the food supply chain [511]. Therefore, it is not surprising that we identified numerous studies about integrating blockchain into the supply chain. For example, Yong, Shen, Liu, Li, Chen and Zhou [433] proposed a blockchain-based SCM vaccine system that incorporates machine learning to support vaccine traceability and address the problems of vaccine expiration and vaccine record fraud. In addition, Gökalp, Gökalp and Çoban [104] identified 14 key determinants of organizational adoption of blockchain-based SCM systems based on the TOE framework.

The three types of blockchain-based innovation are interrelated. As the base innovation, blockchain is a foundation and antecedent of innovations in systems development and innovations in service. The changes made in terms of the functionalities and reliability of blockchain will affect how it is used for further innovations in system development and services. Systems development and innovations in service enabled by blockchain may also contribute to evolution and innovation in blockchain architecture. For example, implementing a blockchain-based SCM system may make the partners in

SCM realize blockchain's limitations, such as the inefficient use of computing resources. As a result, Haouari, Mhiri, El-Masri and Al-Yafi [304] were motivated to develop a new consensus protocol for blockchain (i.e., proof-of-useful-work) to enable it to use computing resources more efficiently. Last, the systems development and innovations in services enabled by blockchain may also affect each other. For example, blockchain-based IoT systems can be applied to reinvent the process of SCM, whereas the implementation of blockchain-based SCM systems may trigger the need for innovations in the tools and processes enabled by blockchain, such as blockchain-based IoT [451].

Table 10. Innovations in Services Enabled by Blockchain Identified from the Literature

Blockchain Innovation	**Description**	**Articles**
Accounting Systems	These studies focus on blockchain-based accounting systems.	[279, 488]
Assets Trading	These studies focus on using blockchain to support asset trading.	[79, 186, 196, 367, 439, 440]
Automation of Public Services	These studies focus on using blockchain to automate the services provided by governments.	[210, 291]
Blockchain-based Banking	This study focuses on banking services based on blockchain.	[154]
Blockchain-based Communities	This study focuses on virtual communities based on blockchain.	[208]
Blockchain-based Resumé	This study focuses on using blockchain to store resumés.	[115]
Business Network Implementation	These studies focus on using blockchain to support inter-firm business processes.	[91, 122, 155]
Business Process Management and Implementation	These studies focus on using blockchain to manage or implement business processes.	[134, 148, 173, 182, 270, 276, 278, 299, 469]
Contract Execution and Auditing	These studies focus on using blockchain to audit contracts or automatically execute a contract.	[288, 297, 354, 479]
Credit Reporting and Evaluation	These studies focus on designing blockchain-based systems for reporting and evaluating businesses' credit records.	[350, 404]
CRM	These studies focus on using blockchain to implement customer relationship management.	[172, 491]
Cryptocurrencies	These studies focus on about different types of cryptocurrencies.	[3, 86, 98, 112, 128, 133, 151, 206, 226, 230]
Data Trading	These studies focus on using blockchain to support the trading of data.	[338, 418, 471, 496]
Digital Wallets	This study focuses on blockchain-based financial applications allowing users to store funds, make transactions, and track payments on their smart devices.	[209]
Dispute Resolution Platforms	This study focuses on dispute resolution platforms developed based on blockchain.	[258]
e-Marketplace	These studies focus on blockchain-based platforms allowing buyers and sellers to transact.	[195, 323, 391]
Employee Benefits Scheme Implementation	This study focuses on a blockchain application used to distribute benefits to employees.	[183]
Encouraging Participation in Platform Economy	This study focuses on using a blockchain-based token to encourage users' participation in platforms.	[93]
e-Voting	These studies focus on online voting systems based on blockchain.	[309, 379, 500]
Fake News Detection	This study focuses on a blockchain-based solution for detecting fake news.	[274]
FinTech	These studies focus on financial technologies enabled by blockchain.	[95, 138, 220, 310, 492]
Fraud Prevention	These studies focus on the use of blockchain to help prevent crimes and fraud.	[36, 315, 370, 374, 375, 393, 474, 486]
Healthcare Systems	These studies focus on healthcare systems developed based on blockchain.	[74, 156, 231, 245, 305, 306, 329, 332, 334, 345, 356, 358,

		362, 364, 372, 383, 395, 396, 419, 452, 467]
ICO	These studies focus on fundraising using cryptocurrencies.	[77, 83, 84, 143, 193]
Industry 4.0 Support	This study focuses on integrating blockchain into various industry 4.0 applications.	[455]
Information Sharing	These studies focus on using blockchain to support information sharing among parties.	[215, 314, 369, 380]
Innovative Business Models	These studies focus on the new business models enabled by blockchain.	[78, 87, 146, 162, 175, 185, 205, 213, 225, 238, 336]
Insurance Management	These studies focus on blockchain-based insurance systems.	[443, 498]
Intellectual Property Management	This study develops a blockchain-based system for managing intellectual property.	[319]
Knowledge Management	These studies focus on the integration of blockchain into the knowledge management process.	[241, 348, 349, 425]
Land Titling	This study focuses on using blockchain to assist land titling.	[409]
Law Enforcement	This study focuses on using blockchain for regulatory reporting.	[105]
Loot Box Sales	This study develops a virtual item lucky drawing approach for video games based on blockchain.	[268]
Market Prediction	This study develops a blockchain-based implementation for market prediction.	[267]
Meeting Minutes Taking	This study develops a blockchain-based framework for meeting minutes management.	[487]
Meme Discovery	This study develops a blockchain-based multiagent system for meme discovery and prediction in a social network.	[422]
Peer Review	These studies develop blockchain-based decentralized peer review systems for academic research studies.	[255, 408]
Photo Forensics	This study develops a blockchain-based photo forensics scheme.	[453]
Procurement Process Implementation	This study develops a blockchain-based tender evaluation method for the procurement process.	[343]
Public Health Management	These studies focus on using blockchain to prevent pandemic outbreaks by improving public health.	[272, 300, 371, 450]
Real Estate Transaction	These studies focus on using blockchain to protect real estate transactions.	[287, 359]
Recommendations and Reviews Protection	These studies focus on using blockchain to protect product recommendation and review systems.	[38, 454]
Record Management	These studies focus on using blockchain for record management.	[99, 260, 337, 400]
Risk Management	This study focuses on applying blockchain to control contextualized business risks.	[223]
Rocket and Satellite Launching Systems	This study develops blockchain-based rocket and satellite launching systems.	[344]
SCM	These studies focus on integrating blockchain into the processes of SCM.	[80, 82, 85, 92, 96, 102-104, 116-119, 123, 126, 130-132, 137, 140, 145, 158, 163, 178-181, 187, 188, 190, 192, 194, 199, 200, 202, 204, 207, 212, 217, 218, 222, 227, 236, 256, 263, 269, 280, 325, 326, 335, 353, 361, 430, 433, 451, 493]
Search Results Protection	This study develops a blockchain-based verification mechanism to ensure the trustworthiness of search results.	[426]
Service Level Agreement	This study develops a smart contract-based service level agreement model.	[406]
Sharing Economy	This study focuses on blockchain-based trust-free sharing economy platforms.	[307]
Smart Device Protection	This study proposes using blockchain to protect smart devices from malicious applications.	[316]

Smart Grid Support	These studies focus on using blockchain to support smart grids.	[121, 168, 262, 273, 342]
Sustainable Development	These studies focus on using blockchain to achieve economic, ecological, and social sustainability.	[42, 88, 120, 135, 136, 161, 203, 214, 328, 365, 378, 399, 460, 485]
Tokenized Funds	This study focuses on blockchain-traded funds.	[277]
Traffic and Incidents Management	These studies focus on blockchain-based traffic and incident management.	[320, 360, 368]
Transactions Support	These studies focus on using blockchain to support different types of transactions.	[52, 90, 446, 477]
Traveler Experience	This study focuses on a blockchain-based system developed to improve travelers' experiences.	[464]

5.6 Forms of Blockchain Studied

Notably, approximately half of the identified studies did not specify the forms of blockchain studied. Only 220 studies articulated the forms of blockchain. Table 11 presents the forms of blockchain studied in the literature. In total, 26 forms of blockchain platforms were identified. Ethereum was the most frequently mentioned (74 articles), followed by Hyperledger Fabric (34), Bitcoin (19), Cardossier (3), Multichain (3), Corda (2), EOSIO (2), and Hyperledger Composer (2). The remaining 18 blockchain platforms were studied once.

Among the studies that articulated the forms of blockchain, 66 investigated a particular category of blockchain platforms rather than focusing on a specific blockchain platform. For example, some studies stated that they focused on cryptocurrencies without targeting a particular cryptocurrency, such as Bitcoin or Ethereum [86, 151]. In total, 7 blockchain categories were identified. The most frequently studied blockchain category was smart contracts (19 articles), followed by permissioned blockchain (16), cryptocurrencies (15), permissionless blockchain (6), consortiums (7), and decentralized autonomous organizations (DAOs) (3). Additionally, there was one study about hybrid blockchain.

The performance and some characteristics of blockchains depend on the forms of blockchain implemented. For example, Bitcoin's energy consumption can be several times higher than a privately owned, permissioned blockchain-based system [30]. Moreover, different forms of blockchain have different emphases. They may adopt different consensus protocols, which affects their sensitivity, security, and efficiency [415, 436]. Therefore, there is a significant gap in the IS literature on blockchain, as most identified studies do not specify the forms of blockchain being studied.

Table 11. Forms of Blockchain Identified from the Literature

Forms of Blockchain		Articles
Blockchain Category	Consortium	[222, 258, 273, 275, 344, 417, 442, 488]
	Cryptocurrencies	[75, 78, 86, 98, 101, 110, 128, 151, 226, 230, 238, 240, 386, 389, 477]
	DAOs	[184, 224, 225]
	Hybrid Blockchain	[342]
	Permissioned Blockchain	[28, 89, 119, 163, 164, 220, 253, 291, 308, 321, 330, 333, 368, 375, 385, 495]
	Permissionless Blockchain	[28, 149, 163, 164, 291, 352, 424, 436]
	Smart Contract	[91, 94, 203, 216, 246, 266, 270, 276, 376, 397, 398, 412, 413, 465, 471, 473, 492, 493, 496]
Blockchain Platform	ABEY	[402]
	Authcoin	[366]
	BigchainDB	[249]

	Bitcoin	[3, 109, 112, 114, 127, 133, 150, 206, 229, 284, 295, 318, 340, 381, 423, 432, 482, 494, 497]
	Ethereum	[423]
	Bubichain	[172]
	Cardossier	[186, 439, 440]
	Corda	[105, 425]
	Emercoin	[324]
	EOSIO	[370, 447]
	Ethereum	[35, 76, 132, 148, 202, 215, 244, 268, 269, 271, 278, 283, 285-288, 294, 296, 297, 299, 301-303, 312, 313, 315, 320, 327, 329, 335, 336, 338, 345, 348, 361, 363, 364, 367, 372, 377, 384, 388, 394, 403, 408, 415, 416, 418-420, 425-428, 433, 441, 444, 452-454, 457, 461-463, 466, 472, 475, 479, 480, 484, 487, 498-500]
	GloreChain	[470]
	Hyperledger Composer	[267, 378]
	Hyperledger Fabric	[117, 122, 130, 212, 241, 247, 252, 274, 292, 293, 298, 314, 322, 339, 350, 355, 357-360, 362, 371, 380, 399, 405, 421, 422, 425, 443, 450, 456, 460, 467, 468]
	Hyperledger Indy	[486]
	Hyperledger Sawtooth	[263]
	Monero	[234]
	Multichain	[331, 382, 425]
	Namecoin	[243]
	Peer-review Coin	[255]
	Quorum	[256]
	Scrybe	[251]
	Steemit	[208]
	Symbol from NEM	[464]
	TrustChain	[261]
	VeChain	[305]

5.7 Application Sectors

We identified 37 application sectors of blockchain-based systems from the literature. Table 12 presents the results. The most frequently mentioned application sector was health care (33 articles), followed by finance (32), supply chain (30), public sector (28), business (26), manufacturing (12), transport and logistics (12), laws and regulations (11), e-commerce (7), food (7), accounting (6), the second-hand car market (6), energy (4), small and medium enterprises (SMEs) (4), smart cities (4), agriculture (3), retailing (3), software engineering (3), academic research (2), astronomy (2), construction (2), education (2), insurance (2), real estate market (2), recruitment market (2), and social networking (2). The remaining 11 application sectors were studied once in the literature.

The health care sector attracted attention from blockchain researchers. For example, Margheri, Masi, Miladi, Sassone and Rosenzweig [358] developed a blockchain-based platform for managing the provenance tracking of electronic health care records to comply with the latest health care standards and follow patient-informed consent preferences. Shao, Zhang, Brown and Zhao [156] investigated the factors driving people's intention to use a blockchain-enabled health care mutual aid platform.

Although some governments have outlawed or are considering outlawing cryptocurrency [512], many identified studies focused on the applications of blockchain in the public sector to improve government service. For example, to prevent epidemics, Pandey and Litoriya [371] developed a blockchain-based system to help governments track and trace the disease and treatment history of passengers who arrive at immigration counters. Mora, Mendoza-Tello, Varela-Guzman and Szymanski [365] discussed how governments could use blockchain technology to achieve the United Nations' sustainable development goals through service delivery, resource management, and city administration.

Because blockchain is commonly characterized as a finance technology [310, 513], it is unsurprising that we have identified numerous IS studies about applying blockchain in the finance sector. For example, Osmani, El-Haddadeh, Hindi, Janssen and Weerakkody [138] explored the benefits, opportunities, costs, risks, and challenges of blockchain applications in the context of banking and finance services. Fridgen, Radszuwill, Schweizer and Urbach [299] designed a blockchain-based business process reengineering for a letter of credit; the new process combined the advantages of blockchain-based process optimization and blockchain-based business process disruption.

Many studies attempted to apply blockchain to the general business context. Chong, Lim, Hua, Zheng and Tan [87] proposed a typology of blockchain-inspired business models. They identified five main types of blockchain-inspired business models according to the business's value creation logic, value capturing mechanism, and challenges. Pedersen, Risius and Beck [37] proposed a decision model to help businesses determine whether to adopt blockchain and what type of blockchain should be adopted.

Beyond facilitating SCM, blockchain can contribute to the supply chain sector in various ways. For example, Cho, Lee, Cheong, No and Vasarhelyi [36] advocated applying blockchain to value added tax report systems to prevent value added tax related fraud in the supply chain. Wang, Luo, Lee and Benitez [220] explored the blockchain-enabled value creation process in supply chain finance, and showed how blockchain-based supply chain finance solutions can help supply chain participants to create value.

Table 12. Application Sectors Identified from the Literature

Application Sector	Articles
Academic Research	[255, 408]
Accounting	[142, 157, 253, 276, 279, 488]
Agriculture	[118, 137, 217]
Airport Industry	[227]
Astronomy	[188, 344]
Business	[37, 41, 78, 87, 121, 134, 148, 155, 162, 164, 173, 177, 183, 189, 195, 205, 219, 223, 239, 278, 307, 322, 323, 347, 391, 486]
Construction	[194, 198]
e-Commerce	[165, 221, 297, 343, 353, 454, 491]
Education	[363, 485]
Energy	[168, 262, 342, 361]
Finance	[77, 83, 84, 90, 93, 95, 96, 109, 127, 128, 130, 133, 138, 143, 146, 152, 154, 184, 193, 213, 230, 250, 267, 277, 288, 299, 310, 370, 375, 404, 477, 492]
Food	[80, 85, 92, 181, 203, 263, 493]
Healthcare	[74, 131, 132, 156, 197, 215, 231, 245, 305, 306, 314, 329-336, 345, 356, 358, 364, 372, 383, 395, 396, 419, 433, 470, 472, 473, 490]
Insurance	[443, 498]
International Trade	[270]
Laws and Regulations	[94, 105, 153, 191, 234, 258, 300, 315, 374, 390, 458]
Luxury Goods	[280]
Manufacturing	[187, 192, 207, 214, 298, 348-350, 382, 406, 455, 489]
Marketing	[172]
Multinational Enterprises	[387]
Public Sector	[88, 120, 125, 136, 147, 159, 161, 169, 174, 179, 210, 233, 272, 291, 328, 362, 365, 369, 371, 378, 380, 399, 405, 409, 450, 452, 467, 474]
Real Estate Market	[287, 359]
Recruitment Market	[115, 201]
Retailing	[122, 204, 222]

Second-hand Car Market	[79, 186, 196, 367, 439, 440]
Service	[119]
SMEs	[81, 178, 182, 469]
Smart Cities	[242, 292, 357, 407]
Smart Home	[252]
Social Network	[208, 422]
Software Engineering	[302, 319, 457]
Supply Chain	[36, 82, 91, 102-104, 113, 117, 123, 135, 140, 145, 158, 163, 180, 190, 199, 200, 212, 218, 220, 246, 256, 269, 325, 326, 393, 451, 459, 460]
Tourism	[464]
Transport And Logistics	[116, 126, 202, 236, 241, 264, 273, 304, 320, 360, 368, 430]
Video Game	[268]
Warehouse	[171]
Wine	[28]

5.8 Phases of Blockchain Innovation

Finally, we carefully reviewed the identified articles according to the phase of blockchain innovation. The identified articles were classified this way rather than using research classification frameworks, such as the TOE framework and people–process–technology framework, because the essential elements described in these frameworks are missing in most of the identified studies. However, the identified articles can be effectively categorized according to the phase of blockchain innovation they deal with; this in turn sheds light on the status and future trends of blockchain studies in the IS discipline. Therefore, we adopted the iterative inductive classification approach by Ngai and Gunasekaran [70] to classify the identified studies, making use of the three-phase classification framework of IS innovation of Xiao, Califf, Sarker and Sarker [71]. Table 13 summarizes the distribution of articles across each category.

Our classification process was as follows. According to the three-phase classification framework of IS innovation, IS innovations involve three key phases: (1) system design, (2) implementation, and (3) impacts [71]. Therefore, in the first iteration of our classification, we tried to fit the identified 443 studies into these three categories. We categorized 188 articles into the system design category, 114 into the implementation category, and 68 into the impacts category. However, 73 articles could not be categorized into any of these categories. These articles highlight the directions and opportunities for future blockchain research and cover more than the IS innovation phase. Therefore, we created a new category (i.e., research agenda) and conducted a second iteration. In this iteration, we found that three system design studies had been miscategorized as implementation studies. As a result, we assigned 73 articles to the research agenda category, 191 to the system design category, 111 to the implementation category, and 68 to the impacts category.

During our review process, we found that inside the implementation category, a significant number of articles did not involve the actual implementation of blockchain-based innovations but the intention and decision to adopt them. According to the IS adoption literature, the intention to adopt IS and actual implementation of IS are affected by different factors [514]. Therefore, we created an extra category (i.e., adoption) and conducted the third iteration. In this iteration, we assigned 73 articles to the research agenda category, 191 to the system design category, 39 to the adoption category, 72 to the implementation category, and 68 to the impacts category.

Table 13. Phases of Blockchain Innovation

The Phase of Blockchain Innovation	Definition	Articles

Research Agenda (N = 73; Prop = 16.5%)	These studies mainly aimed to highlight directions and opportunities for future blockchain research. Some of the conclusions were based on a literature review.	[5, 32, 34, 38, 39, 42, 43, 94, 97, 98, 111, 112, 128, 134, 139, 147, 152, 154, 158, 160, 165-167, 185, 189, 197, 198, 200, 210, 216, 228, 233, 238, 240, 245, 248, 254, 258-260, 265, 266, 272, 279, 280, 289, 291, 306, 307, 310, 311, 323, 328, 332, 347, 356, 365, 369, 373, 379, 383, 393, 396, 412, 439, 449, 451, 455, 467, 474, 485, 489, 490]
System Design (N = 191; Prop = 43.1%)	These studies focused on improving the existing blockchain algorithm or designing blockchain-based applications for various industries or purposes.	[52, 193, 241-244, 246, 247, 249, 251, 252, 255-257, 261-264, 267-271, 273-275, 277, 278, 281-288, 290, 292-295, 297-300, 302-305, 308, 309, 312, 314-316, 319, 320, 322, 324, 327, 329-331, 333, 335, 336, 338-346, 348-350, 352-355, 357-364, 367, 368, 370-372, 374-378, 380, 382, 384, 385, 387-389, 391, 392, 394, 395, 397-411, 413-415, 417-420, 422-431, 433-435, 437, 440-443, 445, 446, 448, 450, 452-454, 456, 457, 459-462, 464-466, 468, 470-473, 475, 477-481, 483, 484, 486, 487, 491-496, 498-500]
Adoption (N = 39; Prop = 8.8%)	These studies investigated factors determining the organizational or individual adoption of blockchain-based systems.	[3, 28, 36, 37, 40, 41, 81, 82, 85, 90, 96, 102-104, 106-108, 116-119, 129, 133, 137, 145, 156, 164, 169-171, 176, 178, 190, 209, 212, 219, 232, 237, 239]
Implementation (N = 72; Prop = 16.3%)	These studies mainly explored the determinants of the successful implementation of blockchain-based systems or individual usage behaviors of blockchain-based systems. They also investigated auditing and governance issues during the blockchain implementation.	[35, 77, 80, 84, 87, 93, 95, 99, 110, 114, 121, 122, 124, 125, 132, 141, 142, 144, 148-151, 153, 155, 157, 159, 162, 175, 182, 184, 186, 191, 205, 206, 208, 211, 220, 224-226, 229, 230, 234, 236, 253, 276, 296, 301, 313, 317, 318, 321, 326, 334, 337, 351, 366, 381, 386, 390, 416, 432, 436, 438, 444, 447, 458, 469, 476, 482, 488, 497]
Impacts (N = 68; Prop = 15.3%)	These studies investigated the impacts of the implementation of blockchain-based systems.	[30, 74-76, 78, 79, 83, 86, 88, 89, 91, 92, 100, 101, 105, 109, 113, 115, 120, 123, 126, 127, 130, 131, 135, 136, 138, 140, 143, 146, 161, 163, 168, 172-174, 177, 179-181, 183, 187, 188, 192, 194-196, 199, 201-204, 207, 213-215, 217, 218, 221-223, 227, 231, 235, 250, 325, 421, 463]

We summarize the findings in Table 14, which matches the common themes extracted from the literature review. In addition, the information in this table shows how each phase of blockchain innovations has been investigated in terms of the research paradigm, theoretical framework, technologies, blockchain-based innovations, forms of blockchain, and application sectors.

Table 14. Summary of Literature Review

	Research Agenda	System Design	Adoption	Implementation	Impacts
Research Paradigm	Positivism; Constructivism/Interpretivism; Criticalism; Pragmatism	Positivism; Pragmatism	Positivism; Constructivism/Interpretivism; Criticalism	Positivism; Constructivism/Interpretivism; Pragmatism	Positivism; Constructivism/Interpretivism; Pragmatism
Methodology	Case Study; Conceptual Approach; Secondary Data Analysis; Survey	Case Study; Conceptual Approach; Experiment; Focus Group Interview; Modeling and Simulation; Secondary Data Analysis; Survey	Case Study; Conceptual Approach; Experiment; Focus Group Interview; Modeling and Simulation; Secondary Data Analysis; Survey	Case Study; Conceptual Approach; Experiment; Focus Group Interview; Modeling and Simulation; Secondary Data Analysis; Survey	Case Study; Conceptual Approach; Experiment; Modeling and Simulation; Secondary Data Analysis; Survey
Theoretical Framework	• *Native Blockchain Theories:* (AGI Safety Theory; EDGE Supply Chain Framework; Smart Network Theory) • *Native IS Theories:* (Organizing Framework for Social Media Research) • *Theories from other Disciplines:* (Claim Theories; Commodity Theories; Cooperative Theories; Graph Theory; Institutional Theory)	• *Native Blockchain Theories:* (Sensor Data Protection System Design Theory) • *Native IS Theories:* (Database Audit Theory; Decision Science Research Theory) • *Theories from other Disciplines:* (Affordance-actualization Theory; Agency Theory; Computational Complexity Theory; Contract Theory; Decision Theory; Framework of Universal Composability; Game Theory; Institutional Theory; Optimization Theory; Probability Theory; Queuing Theory; Transaction Cost Theory; Value-focused Thinking Framework)	• *Native Blockchain Theories:* (Integrated Process, Institutional, Market, Technology Framework for Blockchain Adoption) • *Native IS Theories:* (Capture, Understand, and Present Framework; DoI Theory; Fit-viability Model; Organizing Visions Theory; TOE Framework; UTAUT/TAM; Value-sensitive Design Perspective) • *Theories from other Disciplines:* (Ecological Perspective; Game Theory; Protection Motivation Theory; RBV; Regret Theory; Trust Transfer Theory; Value-focused Thinking Framework)	• *Native Blockchain Theories:* (Blockchain Governance Framework; Fit-network Model) • *Native IS Theories:* (Design Science Research Theory; Theory of Polycentric Information Commons) • *Theories from other Disciplines:* (Affordance-actualization Theory; Agency Theory; Economic Theory; Functional Leadership Theory; Hofstede's Cultural Theory; Multiple-channel Communication Theory; Psychological Ownership Theory; Public-value Theory; Queuing Game Model; Service-dominant Logic;	• *Native IS Theories:* (Business Model Framework; Confidentiality-Integrity-Accessibility Triad Model; DoI Theory; UTAUT/TAM) • *Theories from other Disciplines:* (Agency Theory; Competitive Performance Model; Game Theory; Mean-risk Theory; Metcalfe's Law; Practice-based View; Process-problem-solution Framework; Public-value Theory; RBV; Resource Dependence Perspective; Self-determination Theory; Signaling Theory; Social Exchange Theory; SWOT Theory; Systems Theory; Theory of Disintermediation; Theory of Faking Likelihood)

				Social Capital Theory; Social Exchange Theory; Stakeholder Theory; Theory of Purchasing Power Parity; User Experiences Framework)	
Technologies	Accounting Information Systems; AI; Big Data; Cloud Computing; Data Analytics; Dispute Resolution Platforms; e-Marketplace; e-Voting Systems; Federated Learning; Healthcare Systems; IoT; Review and Recommendation Systems	Access Management Systems; AI; Big Data; Cloud Computing; Cloudlet; Digital Signature; Digital Twins; e-Bidding Systems; Edge Computing; e-Voting Systems; Federated Learning; Fog Computing; Healthcare Systems; IoT; KMS; Lightning Network; Machine Learning; NFC and RFID; Neural Network and Deep Learning; PKI; Private Key Generator; Quantum Computation; Quick Response Code; Review and Recommendation Systems; Rockets and Satellites; Self-Sovereign Identity; Semantic Search; Smart Devices; Smart Grid; Software Defined Network; Thin Clients; Traffic and Incident Management Systems	Healthcare Systems	AI; Chatbot; Cloud Computing; e-Voting Systems; Machine Learning; Neural Network and Deep Learning; Self-sovereign Identity; Smart Grid	AI; Human Resource Management Systems; IoT; NFC and RFID; Rockets and Satellites; Smart Grid
Blockchain-based Innovations	• *Base Innovations in Blockchains:* (Blockchain Auditing and Governance; Blockchain Development; Regulatory Compliance of Blockchain; Values of Blockchain) • *Innovations in Systems Development Enabled by Blockchain:* (Cloud	• *Base Innovations in Blockchains:* (Blockchain Auditing and Governance; Blockchain Data Integrity and Maintenance; Blockchain Data Manipulation; Blockchain Development; Blockchain Efficiency Improvement; Blockchain Scalability Improvement; Blockchain	• *Base Innovations in Blockchains:* (Blockchain Data Integrity and Maintenance; Values of Blockchain) • *Innovations in Services Enabled by Blockchain:* (Cryptocurrencies; Digital Wallets; Fraud Prevention; Healthcare Systems; SCM; Transaction Support)	• *Base Innovations in Blockchains:* (Blockchain Auditing and Governance; Blockchain Data Integrity and Maintenance; Blockchain Data Manipulation; Blockchain Development; Blockchain Mining Strategies; Blockchain Security Improvement; Blockchain Vulnerabilities	• *Base Innovations in Blockchains:* (Blockchain Efficiency Improvement; Evaluations of Blockchain; Values of Blockchain) • *Innovations in Services Enabled by Blockchain:* (Asset Trading; Blockchain-based Resumé; Business Network Implementation;

	Computing Support; Identity and Access Management; Information Governance and Data Auditing; IoT Protection and Implementation; Monitoring AI) • *Innovations in Services Enabled by Blockchain:* (Accounting Systems; Asset Trading; Automation of Public Services; Blockchain-based Banking; Business Process Management and Implementation; Cryptocurrencies; Dispute Resolution Platforms; e-Marketplace; e-Voting; FinTech; Fraud Prevention; Healthcare Systems; Industry 4.0 Support; Information Sharing; Innovative Business Models; Public Health Management; Recommendations and Reviews Protection; Record Management; SCM; Sharing Economy; Sustainable Development)	Security Improvement; Blockchain Vulnerabilities Identification; Evaluations of Blockchain; Regulatory Compliance of Blockchain) • *Innovations in Systems Development Enabled by Blockchain:* (Cloud Computing Support; Cyber Security; Data Aggregation Support; Digital Twin Protection; Distributed Data Analytics; Identity and Access Management; Information Governance and Data Auditing; IoT Data Monetization; IoT Protection and Implementation; Log Record Management; Privacy Preservation; Software Engineering Support) • *Innovations in Services Enabled by Blockchain:* (Asset Trading; Business Process Management and Implementation; Contract Execution and Auditing; Credit Reporting and Evaluation; CRM; Data Trading; e-Marketplace; e-Voting; Fake News Detection; FinTech; Fraud Prevention; Healthcare Systems; ICO; Information Sharing; Innovative Business Models; Insurance Management; Intellectual Property Management; Knowledge Management; Land Titling; Loot Box Sales; Market Prediction; Meeting Minutes		Identification; Centralization of Blockchain; Deanonymizing Blockchain; Evaluations of Blockchain; Regulatory Compliance of Blockchain; Values of Blockchain) • *Innovations in Systems Development Enabled by Blockchain:* (Cyber Security; Self-Organizing Blockchain Communities) • *Innovations in Services Enabled by Blockchain:* (Accounting Systems; Asset Trading; Blockchain-based Communities; Business Network Implementation; Business Process Management and Implementation; Cryptocurrencies; Encouraging Participation in Platform Economy; FinTech; Healthcare Systems; ICO; Innovative Business Models; Record Management; SCM; Smart Grid Support)	Business Process Management and Implementation; CRM; Cryptocurrencies; e-Marketplace; Employee Benefits Scheme Implementation; FinTech; Healthcare Systems; ICO; Information Sharing; Innovative Business Models; Law Enforcement; Risk Management; SCM; Smart Grid Support; Sustainable Development)

		Taking; Meme Discovery; Peer Review; Photo Forensics; Procurement Process Implementation; Public Health Management; Real Estate Transaction Protection; Recommendations and Reviews Protection; Record Management; Rocket and Satellite Launching Systems; SCM; Search Results Protection; Service Level Agreement; Smart Device Protection; Smart Grid Support; Sustainable Development; Tokenized Funds; Traffic and Incidents Management; Transactions Support; Traveler Experience)			
Forms of Blockchain	Bitcoin; Cardossier; Consortium; Cryptocurrencies; Hyperledger Fabric; Permissioned Blockchain; Permissionless Blockchain; Smart Contract	ABEY; BigchainDB; Bitcoin; Cardossier; Consortium; Corda; Cryptocurrencies; Emercoin; EOSIO; Ethereum; GloreChain; Hybrid Blockchain; Hyperledger Composer; Hyperledger Fabric; Hyperledger Indy; Hyperledger Sawtooth; Multichain; Namecoin; Peer-review Coin; Permissioned Blockchain; Permissionless Blockchain; Quorum; Scrybe; Smart Contract; Symbol from NEM; TrustChain; VeChain	Bitcoin; Hyperledger Fabric; Permissioned Blockchain; Permissionless Blockchain	Authcoin; Bitcoin; Cardossier; Consortium; Cryptocurrencies; DAOs; EOSIO; Ethereum; Hyperledger Fabric; Monero; Permissioned Blockchain; Permissionless Blockchain; Smart Contract; Steemit	Bitcoin; Bubichain; Consortium; Corda; Cryptocurrencies; Ethereum; Hyperledger Fabric; Permissioned Blockchain; Permissionless Blockchain; Smart Contract
Application Sectors	Accounting; Business; Construction; e-Commerce; Education; Finance; Healthcare; Laws and Regulations; Luxury Goods; Manufacturing; Public Sector;	Academic Research; Astronomy; Business; e-Commerce; Education; Energy; Finance; Food; Healthcare; Insurance; International Trade; Laws and Regulations; Manufacturing; Multi-national	Agriculture; Business; Finance; Food; Healthcare; Public Sector; Service; SMEs; Supply Chain; Transport and Logistics; Warehouse; Wine	Accounting; Business; Finance; Food; Healthcare; Laws and Regulations; Public Sector; Retailing; Second-hand Car Market; SMEs; Social Network; Supply Chain; Transport and Logistics	Agriculture; Airport Industry; Astronomy; Business; Construction; e-Commerce; Energy; Finance; Food; Healthcare; Laws and Regulations; Manufacturing; Marketing; Public Sector;

	Second-hand Car Market; Supply Chain	Enterprises; Public Sector; Real Estate Market; Second-hand Car Market; Smart Cities; Smart Home; Social Network; Software Engineering; Supply Chain; Tourism; Transport and Logistics; Video Games			Recruitment Market; Retailing; Second-hand Car Market; Supply Chain; Transport and Logistics

5.8.1 Research Agenda

Blockchain is still a nascent area for the IS literature; the earliest blockchain study identified in this field was published in 2016 [e.g., 337]. Therefore, it is not surprising that a significant number of identified studies proposed research agendas because of the need to highlight directions for future research in this nascent area.

These research agendas highlighted blockchain research opportunities from various perspectives. Some advocated research exploring the potential of using blockchain as a solution to complex problems that are unsolvable by alternative technologies because of the unique capabilities that blockchain offers [e.g., 185, 266]. Other research agendas highlighted opportunities to integrate other technologies with blockchain, such as AI, big data, and IoT [e.g., 111, 254]. We also identified some research agendas highlighting the challenges for organizations and society resulting from the implementation of blockchain and calling for solutions to these challenges [e.g., 147, 160]. Finally, some research agendas called attention to research studies that considered blockchain from the perspective of a particular discipline [e.g., 310, 396], whereas some research agendas called for research studies focusing on a specific type of blockchain [e.g., 94, 347].

The research agenda is the only category of blockchain studies involving all four IS research paradigms (i.e., positivism, constructivism/interpretivism, criticalism, and pragmatism). Remarkably, most of the identified research agendas were grounded in pragmatism because they mainly advocated applying blockchain to tackle particular problems or issues. Therefore, these studies were problem-solving-oriented. It is worth noting that the only two identified research studies grounded in criticalism were also research agendas.

Beyond the conceptual approach, some blockchain research agendas highlighted future opportunities based on the case study, secondary data analysis, and survey. For example, Barnett and Treleaven [258] emphasized the opportunities to use blockchain with AI and IoT to provide online dispute resolution based on several case studies of online resolution platforms. However, most research agendas were based on the authors' experiences, the literature, current practices, situations, and imagined scenarios.

The majority of the research agendas were not proposed based on a theory. As a result, only eight explicitly stated their theoretical frameworks. However, of these eight, three developed native blockchain theories, which accounted for nearly half of the theoretical frameworks used in the identified research agendas.

As mentioned previously, numerous research agendas highlighted the integration of blockchain with other technologies. Therefore, it is unsurprising that we identified 12 technologies other than blockchain mentioned in the research agendas. We also found that these research agendas highlighted numerous research opportunities for studies of blockchain-based innovations. However, most of them were concerned with the innovations in system development and services enabled by blockchain, rather than the base innovation of blockchains. This finding is surprising because blockchain is well-known for its lack of speed and efficiency and its high energy consumption [21, 436], but we did not identify any research agenda highlighting the need to improve blockchain's processing speed and energy efficiency.

Most of the identified research agendas were rather general because they did not specify a particular form of blockchain they focused on. However, these research agendas highlighted 13 application sectors for blockchain.

5.8.2 System Design

A relatively large proportion of the identified blockchain studies focused on designing blockchain architecture or applications. This is understandable, given that system design is the prerequisite for realizing systems and adopting sequential activities [515].

We identified four main groups of blockchain system design studies. First, some system design studies focused on enhancing the architecture of blockchain to improve its efficiency or security [e.g., 340, 414, 431]. Second, some attempted to incorporate other technologies, such as AI or IoT, to address blockchain's limitations [e.g., 246, 281]. Third, some identified system design studies attempted to use blockchain to support other technologies [e.g., 268, 271]. Last, some system design studies developed blockchain-based applications to support different business processes, such as SCM and knowledge sharing [e.g., 241, 263, 353].

Except for the study by Bachmann, Drasch, Fridgen, Miksch, Regner, Schweizer and Urbach [193], all of the blockchain system design studies identified were grounded in pragmatism, given that they aimed to develop blockchain-based innovations or improve the base innovations of blockchain to achieve a specific goal. Nearly 53% of the system design studies verified the proposed designs using modeling and simulation. Only 17.8% of the identified system design studies used either case studies or experiments to validate the systems developed. It might be relatively costly or difficult to deploy a complete blockchain-based system or prototype in a real-world setting to conduct a case study or experiment. However, it is worth noting that nearly 16% of system design studies did not attempt to validate the systems developed.

Only 16.8% of the system design studies used a theoretical framework to guide the system development process. Design science research theory was the most frequently used theoretical framework among these studies. We also identified one native blockchain theory among the theoretical frameworks used in the system design studies. Surprisingly, most of the identified blockchain system design studies did not explicitly state the forms of blockchain they focused on.

We identified many technologies in connection with blockchain, base innovations in blockchains, innovations in system development, and services enabled by blockchain from these studies. Moreover, we also identified many application sectors from these studies. The number of technologies, base innovations in blockchains, innovations in blockchains, innovations in system development and services, and application sectors identified among the system design studies far outnumbered those identified among the blockchain research agendas. This may imply that the existing blockchain research agendas have only made limited contributions to the current development of the literature on blockchain system design.

5.8.3 Adoption

Adoption is a major topic in IS literature. In this literature review, we also identified numerous studies that investigated the factors determining the decision-making process of blockchain adoption. The identified blockchain adoption studies can be classified into two main groups. The first concerns the organizational blockchain adoption [e.g., 28, 145]. The second concerns the individual adoption of blockchain-based applications or services [e.g., 90, 133].

Except for the study by Ostern, Holotiuk and Moormann [239], all of the blockchain adoption studies identified were grounded in either positivism or constructivism/interpretivism. Among these studies, positivistic research studies accounted for the majority. This confirms that positivism is the dominant research paradigm in the IS behavioral literature [48]. More than half of the blockchain adoption studies adopted a quantitative research approach (i.e., experiments, modeling and simulation, secondary data analysis, and surveys). However, we found that approximately 21% of the identified blockchain adoption studies did not empirically validate their research model.

Unlike the studies of other phases of blockchain innovations, most of the blockchain adoption studies were guided by theoretical frameworks, and only ten did not use any theoretical framework. UTAUT/TAM, the TOE framework, and DoI theory dominated the theoretical frameworks. However, IT artifacts are equally crucial to theoretical frameworks and were overlooked in most blockchain adoption studies. We only identified one blockchain adoption study that specified the technologies integrated into the focal blockchain system of the study. We also found that around 41% of the identified blockchain adoption studies did not articulate the types of blockchain-based innovations being studied. Among the blockchain adoption studies that stated the types of blockchain innovations, around 65% focused on the adoption of blockchain-based SCM. Moreover, around 82% of these blockchain adoption studies did not specify the focal forms of blockchain to be studied.

Context was also left unspecified in a significant proportion of the blockchain adoption literature. Approximately 28% of the blockchain adoption studies did not include the application sectors of blockchain-based innovations. We identified 12 application sectors of blockchain from the identified blockchain adoption studies.

5.8.4 Implementation

The adoption of blockchain-based systems would not automatically generate value. Instead, the value of these systems is created when they are implemented and used. Therefore, some researchers have attempted to develop guidelines for implementing blockchain-based applications or investigating the issues raised by the implementation process.

These studies investigated the issues related to blockchain implementation from different perspectives. First, we identified some studies exploring the critical success factors for implementing blockchain-based applications in organizations [e.g., 80, 326]. Second, some aimed to discover how organizations use blockchain to enable innovative business models [e.g., 87, 162]. Third, some blockchain implementation studies aimed at formulating guidelines for the successful implementation of blockchain-based projects in organizations, such as selecting the appropriate blockchain platform or highlighting the issues that needed to be addressed to ensure successful blockchain implementation [e.g., 121, 334]. Fourth, we identified some studies developing guidelines for handling technical issues during the implementation of blockchain-based applications, such as managing unwanted data and detecting illicit user behaviors [e.g., 35, 444]. Fifth, some identified studies explored the new governance issues arising from blockchain implementation and formulated the corresponding solutions [e.g., 142, 191, 234]. Last, some identified studies focused on uncovering individuals' blockchain-based systems usage behaviors [e.g., 114, 151].

We found that the blockchain implementation studies identified were grounded in positivism, constructivism/interpretivism, and pragmatism. Interestingly, approximately 40% were grounded in pragmatism, as they mainly focused on providing guidelines or a model for blockchain implementation. For example, because of its immutability, Carvalho, Merhout, Kadiyala, and Bentley [241] developed guidelines for handling bad blocks in DAOs. A possible reason is that because blockchain is relatively complex and new to both organizations and researchers, guidelines for blockchain implementations are needed.

Nearly 38% of the blockchain implementation studies were based on case studies, whereas around 39% were based on quantitative methodologies (i.e., experiments, modeling and simulation, secondary data analysis, and surveys). Around 19% of the blockchain implementation studies were not empirically validated but based on the conceptual approach. At the same time, only 23.6% of the identified blockchain implementation studies used a theoretical framework. It is not desirable for a study to lack both a theoretical framework and empirical validation.

Although adoption is usually characterized as the antecedent of implementation [71], the literature on blockchain adoption and implementation does not cover the same set of technologies connected with blockchain, blockchain-based innovations, forms of blockchain, and application sectors. Specifically, the blockchain implementation studies covered the implementation of numerous innovations in systems development enabled by blockchain, but the blockchain adoption studies did not. This implies that the blockchain adoption and implementation literatures are not well connected.

We identified 14 forms of blockchain from the blockchain implementation studies. However, approximately 47% of the blockchain implementation studies did not articulate the forms of blockchain being studied. In addition, more than half of the blockchain implementation studies did not specify the application sectors, and 13 application sectors of blockchain-based innovations were identified.

5.8.5 Impacts

This category of research studies focused on the impacts and outcomes of blockchain implementation. Some of these studies focused on the benefits to organizations of blockchain implementation, such as improved operational efficiency and data security [e.g., 140, 174]. Moreover, some identified studies developed frameworks or objective metrics for measuring the impacts and performance of blockchain-based applications [e.g., 89, 113]. Last, we also identified some studies that focused on predicting the values of blockchain-based assets [e.g., 109, 127].

Most of the identified studies on the impacts of blockchain were grounded in positivism, whereas constructivism/interpretivism and pragmatism grounded around 4% and 7% of the studies, respectively. Quantitative research methodologies (i.e., experiments, modeling and simulation, secondary data analysis, and surveys) were used in about 59% of the identified studies of blockchain's impacts, whereas case studies and conceptual approaches accounted for the rest.

We identified numerous native IS theories and theories from other disciplines from the studies on blockchain's impacts. However, we did not identify any native blockchain theory even though blockchain has a number of unique features. Furthermore, although there was some overlap in the technologies interacting with the blockchain, types of blockchain-based innovations, forms of blockchain being studied, and application sectors between the blockchain implementation studies and studies of blockchain's impacts, the overlap was relatively limited. This implies that the blockchain implementation and impact literatures are not well connected.

6 Agenda for Future Research

Based on the detailed analysis of blockchain studies in the previous section, we established 15 open-ended research questions that should be explored in the future. The following subsections provide research questions according to the major building blocks of the research framework for blockchain studies.

6.1 Research Paradigm

We could only identify three research studies grounded in criticalism. However, research studies from the perspective of criticalism could be fruitful. As mentioned above, criticalism criticizes the status quo and challenges taken-for-granted social assumptions about power distribution, alienation, and domination [501]. Therefore, the emergence of blockchain offers many opportunities for critical studies because of its nature. First, blockchain is decentralized and distributed [5, 516]. Therefore, the role of dominating and trusted central third parties in some industries will be eliminated if blockchain is implemented in those focal industries. Blockchain research from the criticalism perspective can investigate the effects of decentralization on the current ecosystems and structures of industries. Second, blockchain is immutable. It is impossible for governments to remove unfavorable or sensitive information. Studies of blockchain from the criticalism perspective can investigate how blockchain can empower and help individuals fight against powerful authorities or organizations.

We could only identify relatively few blockchain research studies grounded in constructivism/interpretivism. However, because people with different backgrounds tend to conceptualize blockchain differently [139], constructivism/interpretivism, which focuses on exploring the meanings of an IS phenomenon from the perspectives of different actors, may generate meaningful insights. For example, it would be interesting to understand whether divergent conceptualizations of blockchain exist in an organization and how these conceptualizations might converge. Therefore, we propose the following future research question:

FQ1: *How can criticalism and constructivism/interpretivism contribute to our knowledge of blockchain from different perspectives?*

6.2 Theoretical Framework

A relatively large proportion of identified studies were not based on theories. However, theories and models are valuable and parsimonious tools for understanding a phenomenon or the relationship between observed or approximated units in the empirical world [517, 518]. Moreover, they can also be used as perspectives or paradigms to guide studies' design [519, 520]. Therefore, beyond the theoretical framework identified in this literature search, some promising theories for guiding future blockchain research should be identified.

Information Processing View of Organization: In the context of blockchain research, the information processing view of organization (IPVO) can be used as a theoretical lens to understand how adopting blockchain-enabled business solutions can improve the performance of focal organizations. IPVO provides a contingent view of organizations' information processing needs and processing capacities [521]. Therefore, organizations should ensure that their information processing capacities match their information processing needs to achieve superior performance [522].

Organizations adopt information systems [523], such as business solutions enabled by blockchain technology, to improve their information processing capacities to match their information processing needs. For example, accurate and timely information is needed to fight fraud and abuse in the insurance industry. Transparent and immutable data stored in the distributed ledger enabled by blockchain technology can help insurance companies match their information processing capacities with their information processing needs [524]. Using IPVO as a theoretical lens, researchers can investigate how organizations' need to match their information processing capacities with their information processing needs drive the adoption of blockchain technology. Furthermore, the researcher may investigate how adopting blockchain technology can improve organizations' information processing capacities and match their information processing needs, leading to improved organizational performance.

Coopetition Theory: Coopetition theory is highly suited for blockchain research because the implementation of blockchain-enabled business solutions may give rise to situations of coopetition, which refers to "simultaneously cooperative and competitive behavior" [525]. The reason is that the business solutions enabled by blockchain require adopters to share their hardware and data to achieve their proposed benefits [526, 527]. However, adopters may also be competitors themselves. For example, Walmart and Kroger, which are competitors in the retailing industry, have joined the food supply chain system enabled by blockchain technology developed by IBM [511], thereby forming a coopetition relationship.

Coopetition theory investigates how organizations decide to be involved in a coopetitive relationship, how they take measures to protect themselves in such a relationship, and how a coopetitive relationship is related to organizational performance [528-530]. For example, organizations may need to decide what information should be shared or protected in systems enabled by blockchain technology. Therefore, coopetition theory can be used to understand how organizations use formal and informal control mechanisms to manage tensions related to information sharing in the coopetition network enabled by blockchain technology.

Disruptive Innovation Theory: Disruptive innovation theory (DIT) has caught the attention of the public and business practitioners since Christensen popularized it in 1995 [531, 532]. DIT has been widely used to predict and explain how new and disruptive technologies can outperform dominant technologies, business models, or practices [533, 534]. Moreover, DIT provides guidelines for practitioners on enabling disruptive innovation [534]. Given that blockchain is a potentially disruptive innovation [535], practitioners need a theory to guide them on what to do with blockchain to seize new business opportunities and avoid disruption. However, given that DIT has seldom been empirically studied [533], researchers in the future may need to conduct empirical studies to develop DIT and help it provide meaningful managerial implications to practitioners in the blockchain context.

Process Virtualization Theory: Process virtualization theory (PVT) offers researchers a unique perspective for analyzing whether a process is amenable or resistant to being conducted virtually based on an examination of the following factors: sensory qualities, relationships, synchronism, and identification and control requirements [536, 537]. PVT is a promising avenue in blockchain research because integrating blockchain into business processes or enabling innovative business models based on blockchain would lead to virtualizing business processes [87, 166, 538]. Moreover, blockchain is usually categorized as a virtual asset [41, 539]. Therefore, PVT may shed light on whether individuals or organizations would accept blockchain-enabled virtual assets. Moreover, researchers may use PVT to investigate the factors determining whether an organization can effectively manage blockchain-based virtual assets.

Beyond the theories discussed previously, we should identify other promising theories for investigating blockchain-related issues. We also expect there to be more attempts to develop new theories for inquiries into blockchain-related issues. Thus, we propose the following future research question:

FQ2: *What theories can be applied to studying blockchain-related issues?*

6.3 System Design

Blockchain is an architectural-based innovation because it can act as a fundamental technology for further IT innovations supporting different activities and business processes [10, 507]. Our literature review identified numerous attempts to use blockchain as a fundamental technology to develop solutions to existing problems because of its unique qualities (i.e., decentralization and immutability) [4, 7, 10]. We are convinced that considering how blockchain's unique qualities can make it the fundamental technology for developing innovative solutions to existing problems is a good starting point for system design development. The reason is that "demand-pull," which refers to the motives to adoption innovations to adopt innovations to fulfill organizations' needs [540], is a powerful force driving innovation [541, 542]. Thus, we propose the following future research question:

FQ3: *What are the existing problems that blockchain's unique qualities can solve?*

We observed that most of the blockchain system design studies validated their systems based on modeling and simulation and secondary data analysis rather than an experiment or case study, which would have required the researchers to deploy their systems fully or partially in the real world. We believe that the costs involved in deployment may have been an obstacle. However, because the assumptions or settings made in modeling and simulation may not be realistic, solely relying on either modeling and simulation or secondary data analysis for validating a blockchain-based system might be risky. Because deploying a blockchain-based system in the real world is costly, using more than one methodology to validate a blockchain system design may be a feasible solution. However, the best combination of methodologies is unknown. Thus, we propose the following future research question:

FQ4: *What are the appropriate combinations of research methodologies for validating blockchain system design studies?*

From our systematic literature review, we identified many base innovations in blockchain, innovations in system development, and services enabled by blockchain from blockchain system design studies. In the ideal case, the three groups of blockchain innovations should affect each other. For example, it would be interesting to understand how blockchain-based digital twins can be used to reinvent the blockchain-based supply chain. Improving the data manipulation and efficiency of blockchain may enable the development of a blockchain-based data warehouse. Thus, we propose the following future research question:

FQ5: *How can the system design studies belonging to the three types of blockchain-based innovations inform each other?*

Our systematic review of blockchain studies belonging to the phases of blockchain innovation other than system design can provide useful insights for future studies of blockchain system design. For example, the IT design artifacts investigated in blockchain adoption studies could provide valuable information for improving the design of blockchain-based systems. Moreover, these blockchain studies can provide insights by highlighting the limitations of the current blockchain architecture. For example, a blockchain study under the "implementation" category revealed the immutability (i.e., irreversibility) of the data stored in the blockchain. This could be a severe problem because it violates GDPR.

Some limitations of blockchain architecture were considered trivial until some blockchain-based innovations were extensively implemented [22, 543]. For example, given that an increasing number of people are using Bitcoin, its scalability has been questioned because of the proof-of-work mechanism [510]. Therefore, studies of the implementation of blockchain-based systems may reveal the shortcomings of blockchain technology. Accordingly, this situation may trigger the improvement of blockchain technology because the discrepancy creates "demand-pull" forces [544]. Consequently, the focal technology will be improved to meet the demands of consumers [531]. However, our observations indicate that the identified blockchain system design studies seldom incorporate insights from blockchain studies from other categories. Thus, we propose the following future research question:

FQ6: *How can blockchain studies belonging to other phases of blockchain innovation inform blockchain studies belonging to the system design category?*

6.4 Adoption

Although numerous blockchain adoption studies have been identified from the IS literature, these studies have seldom considered the design artifacts of blockchain-based systems. For example, the literature has shown that some perceptual factors, such as perceived usefulness, competitive advantage, and complexity, affect organizational decision-makers' intention to adopt blockchain-based systems in their organizations [119, 178]. However, the design artifacts of blockchain-based systems that led to those perceptual factors were not investigated. Given that a major aim of the adoption study is to contribute to the improvement of system design [545], we propose the following future research question:

FQ7: *What design artifacts of blockchain-based systems should be included in adoption studies?*

We found that majority of the identified blockchain adoption studies at the organizational level either focused on blockchain-based systems for SCM or did not state the application sectors and types of blockchain-based innovations. However, we should not expect that factors driving blockchain-based systems would be identical across different industries, given the technological, organizational, and environmental differences [546]. Moreover, blockchain-based system features are expected to differ across industries based on observations from blockchain system design studies. Therefore, details of blockchain-based systems in blockchain adoption studies should be articulated. In summary, we propose the following future research question:

FQ8: *What factors drive the decisions to adopt blockchain-based systems in other industries?*

6.5 Implementation

Once organizational decision-makers have decided to adopt blockchain-based systems or technologies, they must choose how to implement them. There are two main models for implementing blockchain-based systems, other than developing a blockchain-based system from scratch. The first is to use open-source blockchain platforms, such as Ethereum, Eris, or HydraChain. The second is to adopt enterprise blockchain solutions and services provided by IT vendors, such as Amazon, IBM, or Samsung. Both models have their advantages and disadvantages. For example, although development based on open-source software may save setup costs and become vendor-independent, it requires IT knowledge and may have hidden costs [547, 548].

The model of blockchain-based system implementation that will be most popular in the future is unclear. Unlike other IS widely adopted by organizations with open-source alternatives, such as browsers, email clients, and enterprise resources planning systems, blockchain technology emphasizes decentralization and freedom from third-party control [549]. Therefore, developing blockchain-based systems using open-source blockchain platforms may match the nature of blockchain technology better, because it allows organizations to become vendor-independent. To understand the selection of a model of blockchain-based system development, researchers may conduct empirical research to investigate the main factors affecting the decision. However, existing studies of blockchain implementation did not investigate this issue. Therefore, we propose the following future research question:

FQ9: *What will be the dominant model of blockchain implementation?*

Our literature review shows that studies of blockchain implementation have covered only limited application sectors and types of blockchain innovation. Furthermore, given that the technological, organizational, and environmental contexts differ across industries (Chiasson & Davidson, 2005), we should not expect organizations in different industries to encounter the same challenges when implementing blockchain-based systems. Moreover, we should not expect them to share the same success factors. Thus, we propose the following future research question:

FQ10: *What are the challenges and success factors for blockchain-based systems implementation in different industries?*

Our literature review shows that the prevalence of blockchain may serve as a shock to IT and corporate governance and even laws and regulations. For example, implementing blockchain-based systems may violate GDPR and result in unclear data ownership [191, 228]. On the one hand, system designers and organizations may have to develop new solutions, designs, or policies to deal with these challenges and capture opportunities. On the other hand, given that the invention of blockchain technology has created some ethical and legal gray areas, authorities and governments should also take the initiative to consider the impact of blockchain on society and make amendments to existing laws and regulations to handle the new ambiguities caused by blockchain. We can observe evidence of the amendment of laws and regulations triggered by new technologies [550]. Therefore, we propose the following future research question:

FQ11: *What are the implications of blockchain for laws and regulations?*

Although blockchain is often categorized in the literature as a challenge to IT and corporate governance, its unique features could also be valuable for developing IT and corporate governance solutions. For example, we identified several studies that attempted to design blockchain-based systems to fight fraud, taking advantage of the immutability and transparency of blockchain [374, 443]. Therefore, based on the potential of blockchain to become part of the solution for IT and corporate governance, we propose the following future research question:

FQ12: *How can blockchain be a solution for IT and corporate governance?*

6.6 Impacts

We did not identify significant attempts to develop new metrics for the impacts of blockchain-based systems. Such metrics are indispensable for two reasons. First, individual and organizational adoptions of innovations often involve evaluating the costs and benefits [551, 552]. The metrics to measure blockchain's positive and negative impact (i.e., benefits and costs) must be articulated to facilitate the cost-benefit analysis of blockchain technology. The metrics should cover the impact of blockchain from the perspectives of financial, nonfinancial, strategic, tactical, and operational impact [553]. Because blockchain implementation in the business context should involve business networks [554], the metrics covering blockchain's overall positive and negative impacts on business networks that adopt a blockchain system should also be established.

Second, metrics covering the externalities of blockchain system implementation should also be developed. Externality is "the impact of an economic agent's actions on the well-being of a bystander" [555]. A classic example of an externality is pollution, which is an issue of major concern in connection with blockchain technology [556, 557]. Blockchain may also create positional externalities that are significant to society. Positional externality refers to the impact of a new object on the context in which other positional objects are evaluated [558]. As the emergence of blockchain is expected to alter the current ecosystems of different industries [559], some businesses, practices, and business models will inevitably be affected by blockchain. For example, several studies have predicted that blockchain may transform the ecosystem of the banking industry [e.g., 11, 315]. Given that the three pillars of sustainability (i.e., environmental, economic, and social sustainability) have attracted increasing public attention and are considered to be indispensable for human beings' future development [560-562], we suggest that researchers should develop more metrics to measure the externalities of blockchain. Therefore, we propose the following future research question:

FQ13: *What are the metrics to measure the impact of blockchain-based systems?*

Over the years, new industries have continually emerged. Consequently, the standard industrial classification system, which had been used for a half-century, has been replaced by the North American Industry Classification Standard system. The reason for this change was that standard industrial classification was incapable of categorizing the new industries that emerged after its establishment, which accounted for half of the industries covered in North American Industry Classification Standard [563]. New technologies are the driving force behind the emergence of new industries [564]. For example, the invention of the satellite fueled the creation of the satellite communications industry. Following this rationale, we expect that blockchain will also lead to the emergence of new industries in the future. To help business practitioners seize new business opportunities enabled and created by blockchain, researchers may need to investigate the types of new industries and business models that blockchain is likely to help. However, the current identified blockchain literature has seldom investigated this issue. Thus, we propose the following future research question:

FQ14: *How will blockchain enable the emergence of new industries?*

The emergence of new technologies does not only create new industries. They may also eliminate and marginalize some industries [565]. For example, the emergence of search engines on the Internet has marginalized companies that make a profit from publishing telephone directories of businesses [566]. Blockchain may similarly eliminate or marginalize certain industries. Given that blockchain can remove the role of intermediaries [4, 325], organizations that serve as middlemen in transactions may be significantly affected. These organizations may need to modify or transform their business models to survive. Organizations that cannot adjust their business models may be eliminated or marginalized by blockchain or the services and business models enabled by blockchain. Although blockchain may not cause disintermediation, it may replace existing intermediaries with new intermediaries [163]. To help organizations and specific industries overcome this future challenge, researchers may need to investigate and predict the types of industries and organizations that would be marginalized or eliminated by the emergence of blockchain. Therefore, we present the following future research question:

FQ15: *What industries will disappear as a result of blockchain?*

7 Conclusions

The amount of blockchain research will undoubtedly increase in the future, given past publication rates and the increasing popularity of blockchain technologies and their applications. Studies that investigate blockchain-related issues from the IS perspective could help ensure that blockchain generates value for organizations and society. Such studies could suggest ways of incorporating blockchain into business or reveal the potential impact of blockchain technology [e.g., 140, 182]. Studies from other perspectives, such as computer science and software engineering, do not typically address these issues. Therefore, investigations of blockchain-related problems from the IS perspective should be promoted. However, a systematic review summarizing the current status of blockchain studies in the IS discipline is lacking. Therefore, it is critical to establish a timely and holistic reference collection of relevant literature.

This study identified 443 blockchain studies published in 77 representative IS journals. We first conducted a descriptive statistical analysis of the identified studies and then offered a conceptual framework to identify the major research areas in blockchain studies. We articulated 15 research questions waiting to be answered to highlight directions for future blockchain research from the IS perspective.

The main contributions of this systematic literature review are as follows: it summarizes the current situation and limitations, highlights undeveloped areas, and articulates the relationships between the dispersed pieces of blockchain literature in the IS discipline. Although our literature review is by no means exhaustive, we are convinced that it will be a valuable resource for IS researchers interested in blockchain-related issues and stimulate further research on blockchain technology. Moreover, we developed a conceptual framework that can serve as a basis for future academic studies that will generate more practical implications. We likewise highlighted potential future avenues by proposing 15 future research questions related to blockchain.

The main limitation of this research is that it focused exclusively on English-language academic IS journals. Textbooks, dissertations, and conference proceedings were also excluded. Furthermore, we did not cover all IS journals. Nevertheless, we are convinced that the selected IS journals represent the population of IS journals. Last, keyword searches may not be sufficiently exhaustive to cover every possible blockchain paper in IS journals.

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