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Review

Unfolding the blockchain era: Timeline, evolution, types and real-world applications

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ABSTRACT

Blockchain technology is based on a series of time-stamped and decentralized immutable records without third-party involvement. Since the infancy of the term, it has attained attention from academic researchers and industrial contributors, globally. The extensive characteristics of blockchain have created new investigation domains in multiple industries including finance, medical, education, governance etc. In this study, we have conducted the systematic literature mapping to collect all relevant research in the field of blockchain since the inception of this exclusive paradigm and presented a comprehensive assessment and analysis on the extracted research papers in a systematic manner. We have rigorously reviewed the relevant research papers found in the literature for understanding the state of the art techniques, methodologies and, applications of using blockchain in different industries. Moreover, we also have presented the evolution and future insights on the use of blockchain in several real-world applications and also consolidated the blockchain into different high level technical and applied perspectives.

1. Introduction

Blockchain is an electronic distributed ledger, that stores the list of ever-growing data verified by all nodes of the network (Wattenhofer, 2017). It contains history and a list of all transactions ever completed within the network. The decentralized nature of blockchain eliminates the need for a third-party and makes records visible to all nodes on the network (de Leon et al., 2017). Thus, to construct a transparent blockchain require extraordinary effort than centralized ledgers. These ledgers require third-party involvement and also require much effort in order to retain security and privacy (Lin and Liao, 2017). This concept was first coined in a white paper that focused on a decentralized cash flow system and introduced the first-ever cryptocurrency 'bitcoin' (Nakamoto, 2008) and extraordinary features of blockchain have led to the development of more than 1600 cryptocurrencies until 2021 (Härdle et al., 2019).

However, Cryptocurrency is not the only application of state of the art blockchain technology. The applications are far and beyond including healthcare, E-government, Insurance, Internet of Things (IoT), decentralized application (DAAPS), games, supply chain, real estate, communication, social welfare, security, privacy, etc., and the list is still growing with time (Pilkington, 2016). Thus, any domain that deals with transactional data can be mapped on blockchain technology making blockchain a very searing research topic. Besides the financial applications, blockchain has started emerging with other fields such as high technology and traditional industries (Duy et al., 2018). Our Study shows that the inclination of blockchain in IoT is 28%, services industry 15%, manufacturing industry 11%, media 10%, education, and scientific institutions 16%, retail inductor 4%, and in other industries it is about 16%, respectively.

Blockchain and related core technologies have become a very pertinent area of investigation as it is being envisaged as a disruptive technology comparable to the scale of the Internet. However, in order to make this technology scalable, secure, and dependable numerous system-level tools and applications are being developed. Similarly, there is a need for identifying new areas of investigation by clarifying the existing state of research (Petersen et al., 2015). To address this gap, we have piloted a systematic literature survey to study and identify the relevant work on blockchain technology. In this study, we have retrieved relevant research papers from well-reputed scientific repositories to prepare an in-depth comprehensive survey on the blockchain. Blockchain evolution, commonly used consensus algorithms, blockchain types, and real-world applications are the prominence of this study. The general characteristics of blockchain technologies are presented in Table A.15.

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The novelty of this work is to summarize and integrate effort compiled by other researchers rather than only focusing on the aforementioned technical and applied areas. Furthermore, apart from the conventional research articles, we have also included papers published by well-known organizations and institutions to cover the broader contribution from market contributors as well.

The rest of the paper is organized as follows. Section 2 describes the related work, Section 3 describes the research methodology to perform this systematic literature mapping study, Section 4 presents the structured methodology, the process of study selection, selection results, quality assessment criteria, a synthesis method of selected studies, finding and discussion on research questions. Section 5 represents the key findings of this study, the section includes advice to new researchers and future directions. The extortion to the validity of the selected research is also part of this section of the study. Finally, Section 6 concludes this literature mapping study.

2. Related work

As a promising paradigm, blockchain has gained interest from academic and market researchers all over the world. These teams have explored and shared their research in the said domain and also have shared several review papers and surveys. In this section, we have presented and summarized the respective research papers. Our systematic mapping presents a concise summary for readers in the context of blockchain. However, this is also an open paradigm and new researchers may add more surveys and reviews in new directions.

Macrinici et al. (2018) prepared a systematic mapping study based on smart contract-based applications. The authors have presented the problems and their respective solutions, trends and future directions on smart contracts. According to this study they have concluded that security, scalability and programmability are major issues in this domain. However, this study is limited to smart contracts that are just a part of blockchain implementation.

Moreover, Yli-Huumo et al. (2016) conducted a systematic mapping study to collect relevant research on blockchain technology. The core focus of the study was about identifying the challenges and limitation of domain. Scalability, throughput and latency are recognized as the significant challenges. Thus the authors has presented the future directions to resolve these issues. Even so, it is a comprehensive evaluation of research but the research was published in 2016. But the rapid changes in the technologies, theories, and applications have encouraged us to investigate and compile another state-of-the-art literature survey.

Another work by Calvaresi et al. (2018), presented a systematic literature review on using the blockchain technology for Multi-Agent System (MAS). The core focus of the study was to establish the scientific relationship among both of the technologies and also have addressed the requirements, motivation and assumption of this state of the art association. Initially they have presented the general research roadmap to explore this topic and introduced the association of MAS and blockchain with the help of several application scenarios. However, the focus of the study is limited to the MAS only.

Another study by the same author Calvaresi et al. (2019) has presented a systematic literature survey on the use of blockchain technology in the field of tourism. They have emphasized that the tourism services are truly dependent on trust factor and how their repute is among peers whose have used their services. Thus, blockchain is the appropriate solution to manage the reliable reputation for tourism applications. In this study, they have provided the in-depth study for using blockchain in tourism further the stakeholders, requirements and challenges have been analyzed. However, the only focus of the study is to present the association of Blockchain with tourism management.

Furthermore, Yumna et al. (2019) piloted a systematic literature review to highlight the challenges and issues in institutional blockchain-based solution. Though, these issues and challenges are described on the surface level as in the digital, physical, and financial aspects and need to be probed further to deeply understand the problem and solution mapping.

Phan the Duy et al. (2018) also have surveyed to discuss adoption, influence, and challenges faced by the blockchain technology. However, the main focus of the study is to discuss the challenges and real-world applications of blockchain.

Chen et al. (2018) provided a summary of organizations and individuals, interested in blockchain. The covered domains of the study were cryptocurrency, insurance, advertising, healthcare copyright protection, society, and energy applications. But focusing only on these domains does not provide a comprehensive evolution of all domains as blockchain is expanding the capabilities to almost every transaction-based domain.

Ban et al. (2019) described empirical research to describe the properties of Hyper-ledger fabric. The main purpose was to show the advantages and disadvantages of the public and private blockchain. However, the study could have been extended to other blockchain and applications.

Similarly, some other articles Ban et al. (2019), Wang et al. (2019d), Li et al. (2020), Feng et al. (2019), Kuperberg et al. (2019), Tavares et al. (2018), Imeri et al. (2019), Cui et al. (2019), Lazarenko and Avdoshin (2018), Ghandour et al. (2019) and, Qi et al. (2017) have provided detailed surveys, covering the different domains and applications of the blockchain. Moreover the details comparison of previous studies and this study is presented in Table 1. Nevertheless, the domains and applications are discussed on the surface level and need to be explored in depth to define a clear future direction. The above discussion shows that there have been many efforts to explore, understand, and compare the different aspects of blockchain technology, yet, there is not any comprehensive solution to bird view for its evolution. This situation urges a need to evaluate previous and current research on blockchain to study the growth over time.

The blockchain industry is flourishing rapidly and the structure of blockchain has encouraged scientific community for state-of-the art real time applications. Consequently, there is need for extensive and in-depth analysis of this domain to formalize the several aspects of blockchain. Thus, this study presents the comprehensive analysis on blockchain research, challenges and future aspects as well. The novelty of this work represents the growth of blockchain applications over time rather than the systematic mapping, only. We have not only focused on a specific domain but explored all possible dominions and applications of blockchain. This effectively helps us to define new research directions and identifies the research gaps as well. Moreover, state of the art quality assessment protocol have designed for in-depth analysis of selected studies. Journal and conference ranking is also considered as a parameter for quality assessment thus each selected study is scored independently and rigorously.

3. Research methodology

Systematic literature mapping has been used as a research methodology to conduct this research presented by Petersen et al. (2008) and illustrated in Fig. 1 and, Fig. 2. This adapted methodology divides the process of SLR analysis into three phases. (i) planning (ii) conducting, and (iii) reporting. Each phase has well defined sub-processes from identification, protocol designing, selection and result formulation. We have adapted this methodology in order to present the comprehensive and in-depth analysis of blockchain technology. Moreover, the guideline method was adapted to search the relevant papers for the systematic literature mapping by Petersen et al. (2015). The core objective of this study is to comprehend the blockchain literature to summarize the existing context along with their timeline since Nakamoto (2008) and, to identify the research evidences, gaps, and presents the future direction and presented in Fig. 4 (see Fig. 2).

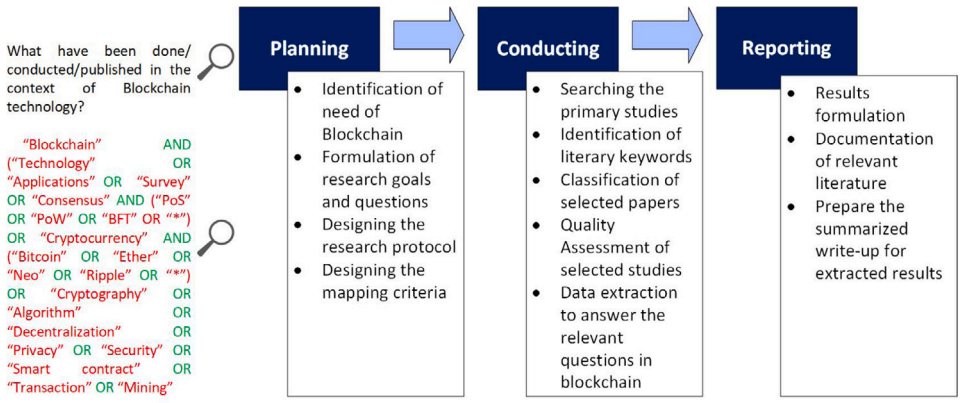

Fig. 1. Description of phase by phase systematic literature mapping process.

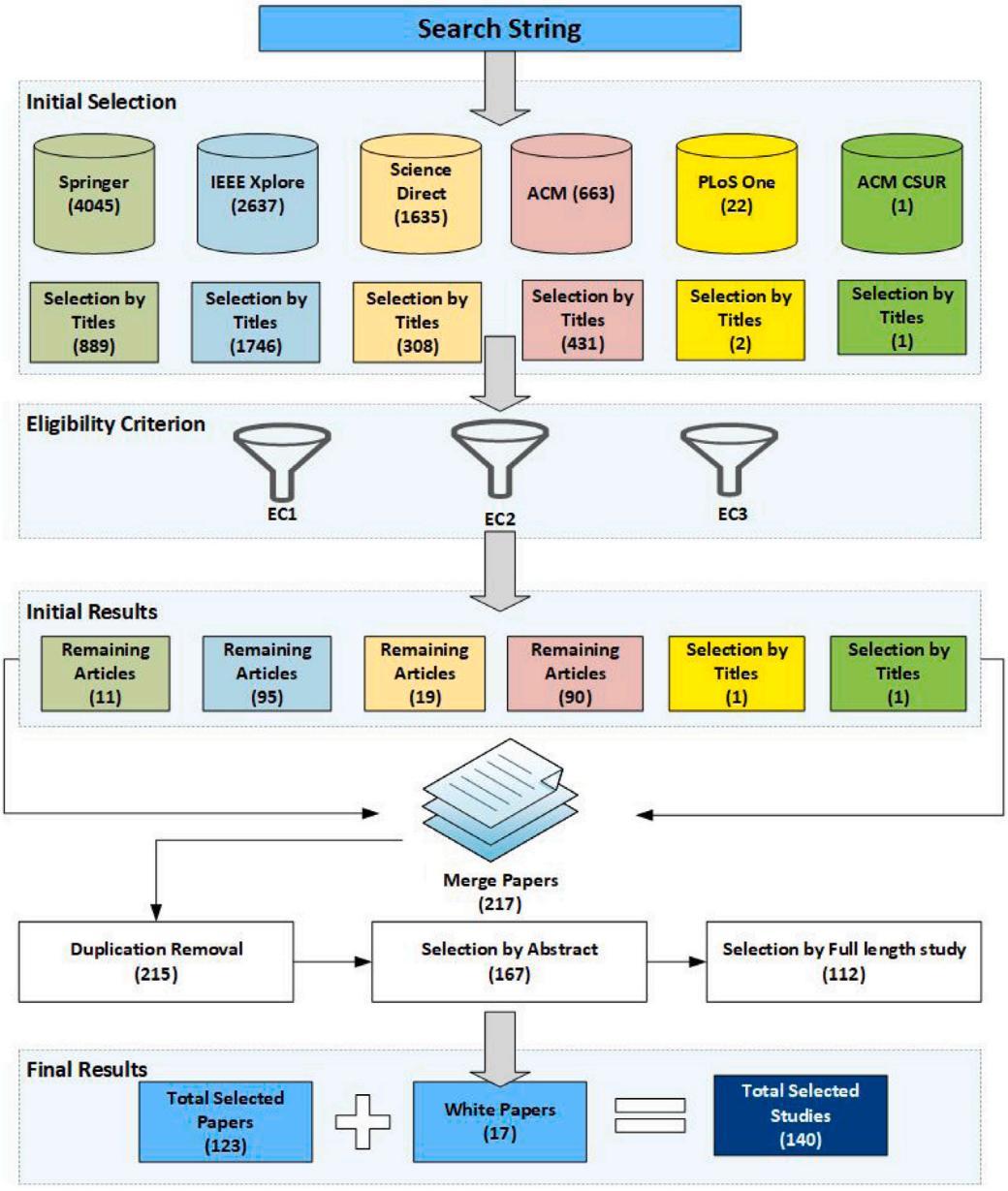

Fig. 2. Mapping process: An illustration to form the synthesis method to collect, analyze, select and presents answers to the research questions.

Table 1
Comparison with other studies.

Description	Macrinici et al. (2018)	Yli-Huumo et al. (2016)	Calvaresi et al. (2018)	Calvaresi et al. (2019)	Yumna et al. (2019)	Duy et al. (2018)	Chen et al. (2018)	Ban et al. (2019)	This paper
Smart contracts	✓	✓	X	X	✓	X	X	X	✓
Timeline	X	X	X	X	X	X	X	X	✓
Blockchain types	X	✓	X	✓	X	X	✓	X	✓
Consensus	✓	X	X	X	✓	X	X	✓	✓
Challenges	X	X	✓	✓	✓	X	X	X	✓
Year	2018	2016	2018	2019	2019	2018	2018	2019	2022
Applications	Several	Several	MAS	Tourism	Physical, Digital, Financial	Several	Transaction solution	Hyper-ledger fabric	Several

3.1. Research questions

To conduct systematic literature mapping and clarify the scope of the study we have defined the following research questions.

RQ1: Which publication channels target blockchain?

The main purpose of this question is to classify the most common channels that have shown interest to publish research on blockchain technology. This helps the researcher to target channels for future publications to better understand the gaps of the research against each publication channel.

RQ2: How blockchain technology is emerging over time?

This question addresses the publication trends of blockchain technology. Although cryptocurrency was the first application of blockchain the general characteristics of this technology have made it very extensible to map it on other domains as well. This is very important to find how researchers diverted their interest over time. And this research question benefits the new researchers to understand the timeline and evolution behavior of blockchain.

RQ3: What are the research types of blockchain technology?

This question explains the research types and categories in literature adopted by researchers, for instance, experience paper, evaluation paper, experiment paper, evolution paper and, review papers. This question explains the main strategies of research adopted by researchers to deal with blockchain technology and its applications.

RQ4: What type of blockchain are commonly used?

The goal of this question is to identify commonly used types of blockchain for different problem domains such as data access and, user privileges. Public, private, consortium, and, hybrid blockchain are notable blockchain types however, several alternatives have also been seen in the literature for managing the complexity and scalability issues. And this question helps researchers to get familiar with different types of blockchain and to analyze frequently used blockchain against best use case scenarios.

RQ5: What consensus algorithms are generally used in blockchain?

Consensus algorithms are the main feature of blockchain technology which makes sure that the blockchain is tamper-proof and decentralization. This question identifies the generally used consensus algorithms including Proof-of-work (POW), Practical Byzantine Fault Tolerance (PBFT), Proof of Capacity (POC), Proof-of-Stake (POS), etc. The in-depth overview of this question helps researchers to classify commonly used consensus algorithms along with suitable use cases. Most commonly consensus algorithms are presented in Fig. 6.

RQ6: What are the main application domains of blockchain?

As stated in RQ2 Cryptocurrency was the first application domain introducing blockchain technology however blockchain is much more capable besides cryptocurrency. Any domain that deals with the transaction can be mapped on the blockchain. Several application domains are health care, E-government, Insurance, Internet of Things (IoT), decentralized application (DAAPS), Games, Supply chain, Real estate, Communication, social welfare, and security, etc. This question categorizes research domains of blockchain technology and helps researchers to identify new domains that still need research consideration. And also provides guidelines to researchers to establish new research on the niche of existing. The research questions with motivation are presented in Table 2.

Table 2
Research questions and motivation.

No	Research questions	Motivation
RQ1	Which publication channels target blockchain?	To identify the channels focus on blockchain technology and target the best channels for publications.
RQ2	How blockchain technology is emerging over time?	To prepare the evolution and trends summary of blockchain technology
RQ3	What are the research types of blockchain technology?	To develop a comprehensive summary of all the types of research conducted in the blockchain.
RQ4	What types of blockchain are commonly used?	Consolidate the frequently used blockchain types i.e., public, private, etc.
RQ5	What consensus algorithms are generally used in blockchain?	To identify commonly used consensus algorithm based on application.
RQ6	What are the main application domains of blockchain?	To specify all the related domain applications and state of the art solution in blockchain for future research directions.

3.2. Conducting research

The second step of systematic research methodology is collecting all relevant papers to the targeted research questions. The method we used to collect relevant paper is defined in Petersen et al. (2015). We have created a search protocol to search for well-known repositories. The term used for research against all databases has been selected after multiple pilot searches and testing different keyword. Although it has been explored that cryptocurrencies are the main topic of blockchain so far and very considerate as a search term. However, the results against cryptocurrency were mostly related to the economical aspect rather than blockchain technology. Therefore, we have eliminated the term cryptocurrency and used blockchain as the main search term to satisfy the main aspect of our study. Because, the main goal of this mapping is to discuss the technical aspects of blockchain, not only the financial aspect. Furthermore, using blockchain as the main search string many cryptocurrencies related papers were also retrieved i.e. Bitcoin, Ethereum, etc. as well. Thus, we have reviewed and included only those that have satisfied our research questions.

The following search string was used to search relevant papers in selected digital libraries.

"Blockchain "AND "Technology" OR "Applications" OR "Survey" "Consensus" AND ("PoS" OR "PoW" OR "BFT" OR "*") OR "Cryptocurrency" AND ("Bitcoin" OR "Ether" OR "Neo" OR "Ripple" OR "*") OR "Cryptography" OR "Algorithm" OR "Decentralization" OR "Privacy" OR "Security" OR "Smart contract" OR "Transaction" OR "Mining". After testing and designing the research protocols, we selected only highly ranked computer science digital libraries to identify the research articles consulting the sources below. However, Google Scholar and

Table 3
Channel types and Publication percentage.

	Number of publications	Percentage
Journal	59	42.2%
Conference	81	57.85%

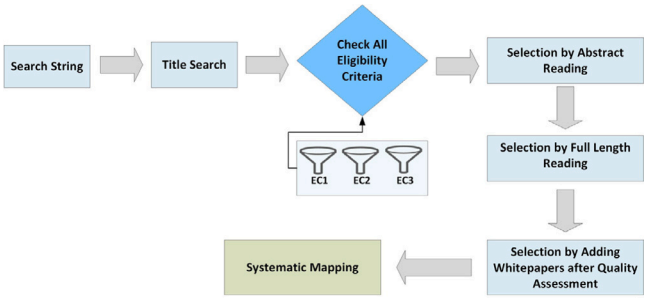

Fig. 3. Building classification scheme: Presents the selection technique and criteria from abstract reading to full length reading and assessment of papers for optimal systematic mapping.

Google Search Engine were used to collect grey literature such as white papers and useful articles of authentic web portals.

- Springer link
- IEEE Digital Library
- ACM Digital Library,
- ACM computing survey
- Science direct
- PLOS

3.3. Study selection

After applying the search string to the digital libraries results retrieved against the query are not necessarily relevant. All papers needed to be assessed based on relevance criteria (Petersen et al., 2015). The next stage is to screen paper, the technique we used is inspired by *T* Dyba (Petersen et al., 2008). In the first phase of screening, we reviewed all retrieved results based on titles. We only included paper that has blockchain in their title. For example, against query there was a tremendous amount of papers those have blockchain term in the text as exemplary content, these paper are evidently out of the scope of our systematic literature mapping, this is a very valid reason to exclude them. However, for some studies, it was difficult to determine either it falls under the criteria or not to deal with this situation. We passed the studies to the next stage of further reading.

In the second phase, we read the abstract of the studies that have been approved based on the titles selected in the previous stage. We used the kappa coefficient for the final agreement for the selection of most relevant research papers, it was 0.95 which is a perfect state of agreement according to Landis and Koch (1977). Furthermore, we defined exclusion criteria to verify the relevancy of the papers. We decided to exclude papers according to the following exclusion criteria (EC) presented in Table 6.

After passing all stages of inclusion and exclusion criterion such as title, abstract, the papers are considered as relevant to the blockchain. Besides these digital libraries, we have also considered the white papers presented by well-known organizations and web portals. This complete classification scheme is presented in Fig. 3 (see Table 10).

3.4. Search and selection results

Against search query total of 9003 papers have been retrieved from well-reputed digital libraries. All of these studies are not significant and appropriate with respect to the research questions of our study and also include the repetitive copies in several repository. Thus this primary research require the re-assessment, filtering and screening based on the criteria we have presented in Table 4. The initial research was on keywords, those were presented in Section 3. After primary search, the next step is to exclude papers based on the title of the paper. All titles of papers were examined carefully and that led to the selection of 3377 papers. The reason behind the exclusion of a huge amount of papers was relevancy issues. For example, many papers just focused on cryptocurrency from an economical perspective rather than blockchain. Therefore, we did not include those papers in our study. On the other hand, there were also retrieved papers on other scientific areas, for instance, Mathematics or Chemistry.

The term blockchain has other meanings in these areas rather than the computer science field. After applying all ECs, as described in Section 3, the resultant papers were eligible for the next step of the study. After the selection of 217 papers, we have removed duplicates and moved to the next step. We have screened abstracts of all selected papers that have to lead to exclusion of several more papers. If the paper did not satisfy the main research questions, we have excluded papers from our study. The inclusion decision was also being examined by full length read of paper to include these papers where the abstract was not enough. That lead to the selection of 140 papers, these papers have a technical viewpoint related to blockchain. However, we have passed some papers to the next step for in-depth analysis and review, the summary of each selection phase and result is presented in Table 5. After extensive and rigorous analysis of these selected studies were proceed for succeeding assessment based on the Internal Scoring (I. Score) and External Scoring (E. Score) protocol, presented in 4.

3.5. Quality assessment

To enhance our research, we have defined quality assessment criteria (QAC) of the selected primary papers. To achieve this, we have designed a questionnaire for better quality analysis. Quality assessment is usually carried out in a systematic literature review. For extensive quality assessment we have classified into two major scoring protocol as Internal Scoring (I. Score) and External Scoring (E. Score) presented in Table 4. Internal scoring addresses the relevance of study by abstract, literature review, blockchain frameworks, models or, architecture etc. all the key findings with respect to the research questions of this study.

External Score (E. Score) was to ensure the JCR and CORE ranking of selected study. However, this is the best way to contend the systematic literature mapping as well. The quality assessment was led by the authors of this study based on the following questions. The standards to write a questionnaire was inspired by Fernandez et al. (2011).

1. Was the abstract well defined? Possible answers were “Yes (1)”, Intermediate (0.5) or, “No (0)”
2. The literature review is explained clearly? Possible answers were “Yes (1)”, Intermediate (0.5) or, “No (0)”
3. The Study presents Types of blockchain were used for framework, model or architecture and clearly defined Possible answers were “Yes (1)”, Intermediate (0.5) or, “No (0)”
4. Types of Consensus algorithm are clearly described, classified and discussed? Possible answers were “Yes (1)”, Intermediate (0.5) or, “No (0)”
5. Are there any application domains being discussed? Possible answers were “Yes (1)”, Intermediate (0.5) or, “No (0)”
6. APIs, Websites, or any other repository is available for data set or solution sharing? “Yes (1), “No (0)”
7. Was conclusion are effectively presented and align with abstract of the study “Yes (1)”, Intermediate (0.5) or, “No (0)”
8. The study was published in a well-reputed journal? JCR (Journal Citation Ranking) based ranking classification is presented in Table 4.

Table 4
Summary of quality assessment criteria.

Sr No.	Assessment questions	Expected response	Score
Internal scoring			
1	Was the abstract well described?	a-Yes b-Intermediate c-No	a-1 b-0.5 c-0
2	Was literature review was described?	a-Yes b-Intermediate c-No	a-1 b-0.5 c-0
3	Types of blockchain were used for framework,model or architecture and clearly defined.	a-Yes b-Intermediate c-No	a-1 b-0.5 c-0
4	Types of Consensus algorithm are clearly described,classified and discussed?	a-Yes b-Intermediate c-No	a-1 b-0.5 c-0
5	Are there any application domains being discussed?	a-Yes b-Intermediate c-No	a-1 b-0.5 c-0
6	APIs, Websites, or any other repository is available for data set or solution sharing?	a- Yes b-No	a-1 b-0
7	Was conclusion are effectively presented and align with abstract of the study	a-Yes b-Intermediate c-No	a-1 b-0.5 c-0
External score			
8	A study published in JCR ranked journal	a-JCR Q1 Rank b-JCR Q2 Rank c-JCR Q3/Q4 Rank d- No Rank	a-4 b-3 c-2 d-0
9	Are Study is published in CORE ranked conference,proceedings or, Conference?	a-CORE Rank A b-CORE Rank B c-CORE Rank C d- No CORE	a-2 b-1.5 c-1 d-0
Methodological quality			
High quality Total quality ≥ 7	Moderate quality Total quality = 6	Low quality Total quality ≤ 6	

Table 5
Selection phases and result.

Phase	Process	Selection criteria	Springer	IEEE Xplore	Science direct	ACM	PLOS	ACM CSUR
1	Initial search	Keywords	4045	2637	1635	663	22	1
2	Selection	Title	889	1746	308	431	2	1
3	Screening	Duplication removal	170	100	112	90	1	1
4	Screening	Abstract	53	69	71	43	1	1
5	Inspection	Full length	43	53	22	20	1	1

Table 6
Exclusion and Inclusion criteria.

Inclusion criteria	Exclusion criteria
IC1: Studies that focused on Blockchain Technology and blockchain based applications	**EC1:** Studies discussed the blockchain but not in computer science domain
IC2: Full-text articles	**EC2:** Papers do not meet any of the research questions
IC3: Paper written in English language	**EC3:** Papers not published in a complete form or the form of a book, tutorial, presentation, or an essay.
	EC4: Papers not presented in the English language.

9. The study was published in a CORE ranked Conference? CORE ranking classification is presented in Table 4.

The quality criteria of papers published in journals are higher than conferences. It is a common understanding that the publication of the paper in journals especially Q1 and Q2 ranked journals is much more difficult than other publication channels. The summation of all quality assessment criteria is the final score of the paper which is an integer between 0 to 12. We also have developed the methodology for quality assessment into three levels and scores of quality assessment are the sum of ranked score for each paper. These levels are classified as High Quality, Moderate and Low Quality respectively. Each paper is scored independently and summarized in Tables 7 To 11.

3.6. Synthesis method

The synthesis method was based on extracting information relevant to the research question.

RQ1: To answer the first research question, publication channels and sources are identified against each question. The possible channels that are retrieved against each paper are well-reputed Journals and, conferences. All channels and sources are presented in Table 3.

RQ2: To deal with the second research question, the publication year of each paper are presented in Tables 7 to 11.

RQ3: To answer the third research question, the research types of each paper were extracted as follow:

Table 7
Pertinent meta information and classification of the selected articles (I).

Ref #	Classification	Year	Research type	Type	Consensus algorithm	Application domain	I. Score	E. Score	Total score
Nakamoto (2008)	Conference	2008	Framework	Public	PoW	Cryptocurrency	5	2	7
Pricewaterhouse Coopers- PWC Copyright (2018)	Conference	2018	Technical report	Public	None	Cryptocurrency	5	2	7
Yli-Huumo et al. (2016)	Journal	2016	Literature review	Public & Private	PoS & PoW	Other	6	3	9
Huckle et al. (2016)	Journal	2016	Experience paper	Public & Private	None	IOT	3	0	3
Ali et al. (2019)	Conference	2019	Solution proposal	Public	PoW	IOT	3	0	3
Vukolić (2017)	Conference	2017	Solution paper	Private	BFT	Other	2	0	2
Li et al. (2017)	Conference	2017	Architecture	Private	PBFT	Industry	3	0	3
Nygaard et al. (2019)	Conference	2019	Architecture	Hybrid	PoC & BFT	Data storage	5	2	7
Jha et al. (2019)	Conference	2019	Framework	Private	PoW	E-government	5	2	7
Xu et al. (2019b)	Conference	2019	Solution paper	Public	PoW	Supply chain	5	2	7
Pedrosa and Pau (2018)	Conference	2018	Solution paper	Public	PoW	Transportation	3	0	3
Wang et al. (2017)	Conference	2017	Solution paper	Private	PBFT	Communication	2	0	2
Wang et al. (2018a)	Conference	2018	Framework	Public	PoW	Security	2	0	2
Ibba et al. (2017)	Conference	2017	Solution paper	Hybrid	None	IOT	2	0	2
Zhao and O'Mahony (2018)	Conference	2018	Framework	Public	PoW	Security	3	0	3
Han et al. (2019)	Conference	2019	Framework	Public	PoW	Crowd sourcing	3.5	1.5	5
Şahan et al. (2019)	Conference	2019	Framework	Private	BFT	Data security	3	0	3
Bahri and Girdzijauskas (2018)	Conference	2018	Framework	Public	PoT	Energy	2	0	2
Androulaki et al. (2018)	Conference	2018	Solution paper	Hybrid	SIEVE	OS	3	0	3
Labouseur et al. (2019)	Journal	2019	Experience paper	Public	PoS & PoW	Education	4	2	6
Coblenz (2017)	Conference	2017	Solution paper	Public	PoW	Education	2	0	2
Wood et al. (2014)	Conference	2018	Architecture	Public	PoW	E-commerce	4.5	1.5	6
Esposito et al. (2018)	Journal	2018	Review	Public & Hybrid	PoW & BFT	Health care	7	4	11
Wang et al. (2019b)	Conference	2019	Solution paper	Private	BFT	Industry	2	0	2
Suchaad et al. (2018)	Conference	2018	Solution paper	Public	PoW	IOT	3	0	3
Luu et al. (2016)	Conference	2016	Solution paper	Public	PoW, BFT, PoS	Education	4	2	6
Kim et al. (2018)	Conference	2018	Review	Public	PoW	Cryptocurrency	3	0	3
Sinclair et al. (2019)	conference	2019	Framework	Hybrid	SIEVE	Supplychain	3	0	3
Han et al. (2018)	Conference	2018	Architecture	Public	PoW	Education	2	0	2
Chen et al. (2017)	Conference	2017	Solution paper	Public	PoW	Cryptocurrency	3	0	3
Bello and Perez (2019)	Conference	2019	Case study	Public	PoW	Finance	2	0	2
Alharby and van Moorsel (2019)	Conference	2019	Framework	Public	PoW	IOT	3	0	3
Dinh et al. (2017)	Conference	2017	Framework	Private	BFT, PoS	Other	2	0	2
Karame (2016)	Conference	2016	Review	Public	PoW	Cryptocurrency			
Bhuiyan et al. (2018)	Conference	2018	Review	Hybrid	BFT, DBFT	Health care	5	2	7
Kalra et al. (2018)	Conference	2018	Architecture	Public	Peer Consensus	Game	3	0	3
Wang et al. (2018c)	Conference	2018	Architecture	Hybrid	PBFT	Health care	3	0	3
Khalil and Gervais (2017)	Conference	2017	Solution paper	Public	PoW	Finance	3	0	3
Wu and Du (2019)	Conference	2019	Framework	Hybrid	BFT	Health care	2	0	2

- Framework/Architecture: Selected papers provide a framework or architecture to a particular domain including methodology, implementation, and results with architectural layers.
- Review: Some papers from the selected collection of this study are review papers that provide an analysis of the existing work such as comparison, research gaps, and possible theoretical solutions.
- Solution Paper: Provides a solution based on blockchain technology. These papers provide solutions to problems in multiple domains and also covers the solution for revamping existing solutions.
- Technical Report/Analysis: There are some technical reports and analysis studies published by high impact factor channels to show the current situation of blockchain technology.
- Other research types with fewer ratios have been retrieved from well-reputed channels are experience paper, case studies, and overview.

RQ4: The fourth research question is to identify the types of blockchain used in the selected paper. There are four main blockchain classifications as classified in the following categories:

- Public: Public blockchain is fully decentralized, anyone can join the network and no signal entity or node controls the network. The decision is made on the consensus of each node in the network and transactions are recorded with the timestamp. There are rewards and incentives for participants of the network (Zheng et al., 2017).
- Private: Private blockchain is a partially centralized network than public blockchain. Nodes cannot directly enter the network they require consent. Transactions are not public and only authorized authorities can interact with data. A consortium blockchain is also a private blockchain that is governed by a group of authorities rather than a single entity (Pongnumkul et al., 2017).

Table 8
Pertinent meta information and classification of the selected articles (II).

Ref #	Classification	Year	Research type	Type	Consensus algorithm	Application domain	I. Score	E. Score	Total score
Deshpande et al. (2018)	Conference	2018	Framework	Public	PoW	Other	5	2	7
Raikwar et al. (2018)	Conference	2018	Solution paper	Hybrid	BFT	Finance	2	0	2
López and Farooq (2018)	Conference	2018	Framework	Public	PoW	Transportation	3	0	3
Kiš and Singh (2018)	Conference	2018	Experience paper	Public	PoW	Security, Finance	2	0	2
Aich et al. (2019)	Conference	2019	Review	Public & Private	PoS & BFT & PoS	Supply chain	2	0	2
Liang et al. (2019)	Journal	2019	Architecture	Private	BFT	IOT	7	4	11
Mora et al. (2018)	Conference	2018	Solution paper	Public & Private	PoS & PoW & BFT	IOT	2	0	2
Helebrandt et al. (2018)	Conference	2018	Architecture	Hybrid	BFT	Industry	3	0	3
Tian (2017)	Conference	2017	Solution paper	Public	PoS	Supply chain	2	0	2
Pussewalage and Oleshchuk (2018)	Conference	2018	Framework	Hybrid	BFT	Health care	3	0	3
Kotsiuba et al. (2018)	Conference	2018	Solution paper	Hybrid	BFT	Energy	2	0	2
Mondal et al. (2019)	Journal	2019	Architecture	Private	dPoS	Supply chain	7	4	11
Barreiro-Gomez and Tembine (2019)	Journal	2019	Framework	Public	PoW	Game	7	4	11
Jun (2018)	Journal	2018	Solution paper	Public	PoS	E-government	7	4	11
Hanifatunnisa and Rahardjo (2017)	Conference	2017	Solution paper	Public	PoS	E-government	3	0	3
Liu et al. (2018)	Journal	2018	Framework	Public	Pow	IOT	7	4	11
Lin et al. (2018)	Conference	2018	Solution paper	Public	PoA (Proof of authority)	Education	2	0	2
Hasan and Salah (2019)	Journal	2019	Framework	Public	PoW	Artificial, Intelligence	7	4	11
Turkanović et al. (2018)	Journal	2018	Framework	Public	PoS	Education	7	4	11
Dasaklis and Casino (2019)	Conference	2019	Framework	Public	PoS	Supply chain	2	0	2
Patel (2019)	Journal	2018	Solution paper	Hybrid	BFT	Health care	6	3	9
Watanabe et al. (2018)	Conference	2018	Framework	Hybrid	PoW & BFT	Cryptocurrency	3	0	3
Gai et al. (2019)	Journal	2019	Architecture	Hybrid	BFT	Security	7	4	11
Shrestha and Nam (2019)	Journal	2019	Solution paper	Public & Private & Hybrid	PoS & PoW & BFT	Security	7	4	11
Lei et al. (2018)	Conference	2018	Architecture	Hybrid	BFT & PBFT	Other	4	1	5
DeCusatis and Lotay (2018)	Conference	2018	Framework	Public	PoW	Security	3	0	3
Krishnaswamy et al. (2019)	Conference	2019	Architecture	Hybrid	PoS & BFT	Communication	3	0	3
Wang et al. (2018b)	Journal	2018	Solution paper	Hybrid	BFT & PoS	E-government	3	0	3
Reyna et al. (2018)	Journal	2018	Review	Public & Private & Hybrid	None	IOT	6	4	10
Pawlak et al. (2018)	Journal	2018	Solution paper	Public	PoS & BFT	E-government	2	0	2
Pustišek and Kos (2018)	Journal	2018	Architecture	Public	PoW	IOT	2	0	2
Badr et al. (2018)	Journal	2018	Framework	Hybrid	BFT	Healthcare	3	0	3
Koshechkin et al. (2018)	Journal	2018	Framework	Private	PoS & BFT	Healthcare	3	0	3
Casado-Vara et al. (2018)	Journal	2018	Case study	Private & Public	PoS & PoW	Supply chain	2	0	2
Wang et al. (2019a)	Journal	2019	Solution paper	Public & Private & Hybrid	None	Cryptography	7	4	11
Helo and Hao (2019)	Journal	2019	Review	Public & Private & Hybrid	None	Supply chain	6	4	10

- Consortium: represents a collaborative effort for sharing the same business goal or need. Several contributors can work together to provide governance and cross-discipline solutions. For instance, Brown et al. (2016) and Lusard et al. (2021).
- Hybrid: Hybrid blockchain use the privacy benefits of private and permissioned blockchain with transparency and security protocols of the public blockchain. Hybrid blockchain inherent transparency from public blockchain to create trust in network and security and privacy from private blockchain making it simple for multiple businesses (Ateniese et al., 2018).

RQ5: To answer the fifth research question, the consensus algorithms against each research paper are identified. There are multiple consensus algorithms but the most commonly used algorithms in selected research papers are listed below:

- Proof of Work (PoW): In the PoW consensus algorithm, miners use computational power to mine a block with newer transactions from mempool and receive an incentive in return.
- Proof of Stake (PoS): In the PoS consensus algorithm, there is no need for any computational power. Rather, an entity with a high number of stakes can add a new block and hold decision power.
- Byzantine Fault Tolerance (BFT): BFT is designed to tolerate a particular number of adversarial nodes in the network for

Table 9
Pertinent meta information and classification of the selected articles (III).

Ref #	Classification	Year	Research type	Type	Consensus algorithm	Application domain	I. Score	E. Score	Total score
Qiu et al. (2019)	Journal	2019	Analysis	Private	Unique node list (UNL)	Cryptocurrency	2	0	2
Wang et al. (2019c)	Journal	2019	Review	Public, Private Hybrid	PoW & PoS	Other	2	0	2
Gramoli (2020)	Journal	2017	Review	Public, Hybrid	PoW & BFT	Other	7	4	11
Prybila et al. (2020)	Journal	2017	Framework	Public	PoW	Cryptocurrency	7	4	11
Otte et al. (2020)	Journal	2017	Framework	Public	Netflow	Data security	7	4	11
Chen et al. (2019)	Journal	2019	Framework	Public	PoW	Healthcare	7	4	11
Kamble et al. (2020)	Journal	2019	Solution paper	Hybrid	BFT	Agriculture	7	4	11
Liu et al. (2019)	Journal	2019	Architecture	Public	PoS & PoW	IOT	7	4	11
Mehedi et al. (2019)	Journal	2019	Solution paper	Public	PoS	IOT	4	2	6
Parino et al. (2018)	Journal	2018	Analysis	Public	PoW	Cryptocurrency	6	4	10
Di Ciccio et al. (2019)	Journal	2019	Technical report	Public	None	Business	4	2	6
Hinterstocker et al. (2018)	Journal	2018	Solution paper	public	BFT & PoS	Energy	3	0	3
Knirsch et al. (2018)	Journal	2018	Solution paper	public	BFT	IOT	6	3	9
Kim and Jeong (2018)	Journal	2018	Solution paper	Hybrid	BFT	Communication	7	4	11
Pappalardo et al. (2018)	Journal	2018	Framework	Public	PoW	Network	7	4	11
Verma et al. (2018)	Journal	2018	Framework	Public	PoW	Energy	2	0	2
Xu et al. (2019a)	Journal	2019	Review	Public	PoW	Finance	6	0	6
Schlund (2018)	Journal	2018	Solution paper	Public	PoS	Energy	2	0	2
Swan (2015)	Other	2015	Book	Public	PoW	Cryptocurrency	3	0	3
Dennis and Owen (2015)	Conference	2015	Framework	Hybrid	BFT	Security	2	0	2
Snow et al. (2014)	Conference	2014	framework	Public	PoW	Business	5	2	7
Buterin (2013)	Conference	2013	Analysis	Public	PoW	Cryptocurrency	5	2	7
Bradbury (2013)	Journal	2013	Analysis	Public	None	Security	5	2	7
Rosenfeld (2012)	Conference	2012	Review	Public	PoW	Cryptocurrency	5	2	7
AidCoin (2018)	Conference	2017	Framework	Public	PoW	Cryptocurrency	5	2	7
Mazet and Wojciechowski (2017)	Conference	2017	Solution paper	Public	BFT & PoS	Charity	5	2	7
Architect (2017)	Conference	2017	Solution paper	Public	PoW	Charity	5	2	7
DHL (2018)	Conference	2018	Architecture	Hybrid	BFT	Logistics	5	2	7
Oracle (2011)	Conference	2019	Framework	Hybrid	BFT	Data storage	5	2	7
Technology and Initiatives (2020)	Conference	2018	Review	Public, Private, Hybrid	None	Other	5	2	7

Table 10
Pertinent meta information and classification of the selected articles (IV).

Ref #	Classification	Year	Research type	Type	Consensus algorithm	Application domain	I. Score	E. Score	Total score
Grealish (2018)	Conference	2019	Technical report	Public	PoW	Cryptocurrency	5	2	7
Task Force (2016)	Conference	2016	Solution paper	Hybrid	PBFT	Charity	5	2	7
Amsden et al. (0000)	Conference	2019	Framework	Public	PoW	Finance	5	2	7
Barrett and Barrett (2017)	Conference	2017	Solution paper	Hybrid	FBFT	Blockchain	5	2	7
Geiger et al. (2019)	Conference	2019	Architecture	Hybrid	BFT	Industry	4	2	6
Miraz and Donald (2019)	Conference	2019	Framework	Hybrid	BFT	Logistics	3	0	3
Alzahrani and Bulusu (2018)	Conference	2018	Architecture	Hybrid	BFT	Supply chain	3	0	3
Foth (2017)	Conference	2017	Overview	Public, Private, Hybrid	None	Human computer interaction	3	0	3
Khan et al. (2019)	Conference	2019	Overview	Public, Private, Hybrid	PoW & PoS	Economics	4	2	6
Taghiyeva-Zeynalova et al. (2019)	Conference	2019	Framework	Hybrid	BFT	Finance	4	2	6
Hepp et al. (2018)	Conference	2018	Solution paper	Hybrid	PoS & BFT	Real estate	2	0	2
Shi and Wang (2018)	Conference	2018	Framework	Hybrid	BFT	Industry	3	0	3
Wessling et al. (2018)	Conference	2018	Review	Hybrid	PoS & BFT & PBFT	DApps	3	0	3
Ehmke et al. (2018)	Conference	2018	Architecture	Hybrid	Proof of Property	Other	2	0	2
Kan et al. (2018)	Conference	2018	Framework	Public	PoW	Blockchain	2	0	2
Khatoon (2020)	Journal	2020	Architecture	Public	none	Healthcare	6	3	9
Tseng et al. (2020)	Journal	2020	Framework	Public, Private, Hybrid	PoW & PoS	IoT	6	4	10
Zhao et al. (2020)	Journal	2020	Architecture	Public, Private, Hybrid	PoS & BFT & PBFT	IoT	7	4	11
Otoum et al. (2020)	Conference	2020	Solution paper	Hybrid	none	Logistics	2	0	2
Franke et al. (2020)	Journal	2020	Framework	Public, Private, Hybrid	PoS & BFT & PBFT	Industry	5	3	8
Everledger (2021)	Conference	2020	Framework	Public, Private, Hybrid	PoS & BFT & PBFT	Finance	5	2	7

Table 11
Pertinent meta information and classification of the selected articles (V).

Ref #	Classification	Year	Research type	Type	Consensus algorithm	Application domain	I. Score	E. Score	Total score
Anon (2021)	Conference	2020	Framework	Public, Private, Hybrid	PoS & BFT & PBFT	Industry	4	2	6
Gerth and Heim (2020)	Conference	2020	Overview	Public, Private, Hybrid	PoW & PoS	Industry	2	0	2
Abidi et al. (2021)	Journal	2021	Framework	Public, Private, Hybrid	PoW & PoS	Supplychain	6	4	10
Alazab et al. (2021)	Journal	2021	Framework	Public, Private	PoW & PoS	Supplychain	4	2	6
Sanka and Cheung (2021)	Journal	2021	Review	Public, Private Hybrid	PoW & PoS	Industry	6	4	10
Alghamdi and Khan (2021)	Journal	2021	Model	Public, Private Hybrid	PoW & PoS & BFT & PBFT	IoT	7	4	11
Alhejazi and Mohammad (2021)	Journal	2021	Model	Public, Private Hybrid	PoW & PoS	IoT & Evoting	7	4	11
Almagrabi et al. (2021)	Journal	2021	Model & Review	Public, Private Hybrid	PoW & PoS	Healthcare & IoT	6	3	9
Bordel et al. (2021)	Journal	2021	Model	Public, Private	none	Security & Industry	6	4	10
Bouras et al. (2021)	Journal	2021	Framework	Public, Private	PoW & PoS	IoT & Security	2	4	6
Carvalho et al. (2021)	Journal	2021	Model	Public, Private	None	Industry	7	3	10
Centobelli et al. (2021)	Journal	2021	Framework	Public, Private	PoW & PoS	Finance, & Security	6	4	10
Chen et al. (2021)	Journal	2021	Model	Public, Private	None	Industry & Security	4	3	7
Das et al. (2021)	Journal	2021	Overview & Framework	Public, Private	None	Industry & Security	4	3	7

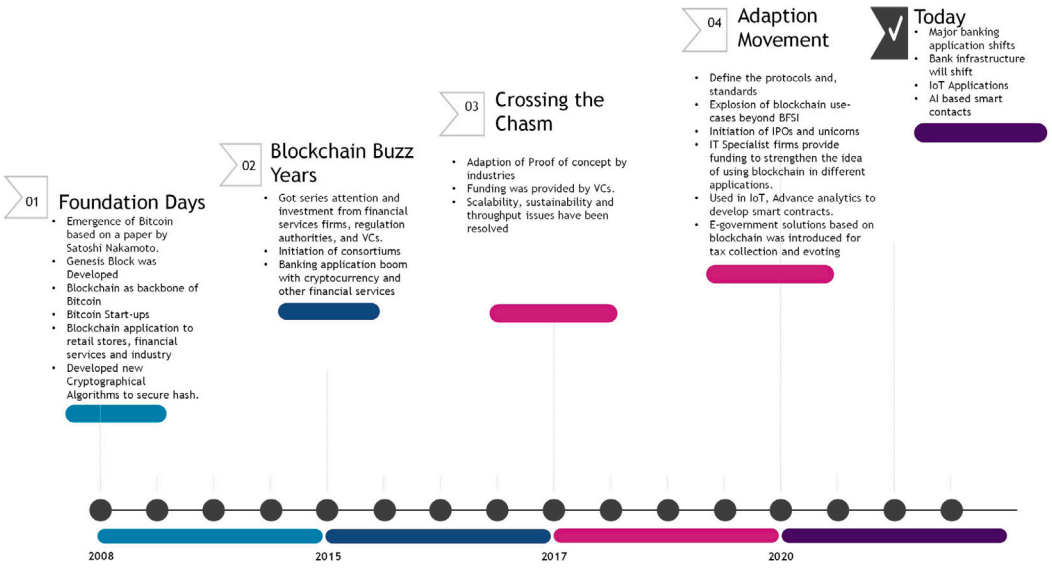

Fig. 4. Evolution of blockchain: Timeline of blockchain from foundation days to buzz years. Describe blockchain emergence and adaption in real-world applications.

verifying and validation process. The actors communicate in an uncontrolled and permission-less contracts thus may be malicious. Therefore PBFT approach is used to remove this deficiency (Zheng et al., 2017).

- Practical Byzantine Fault Tolerance (PBFT): PBFT is based on BFT, a leader is chosen in a round-robin fashion and few nodes are selected as trusted entities. PBFT is best suited for permissioned blockchain.
- Proof of Capacity (PoC): Instead of computational power like PoW, the PoC the miners use storage of the node and entity get stake according to available storage.
- Proof of Authority (PoA): PoA is a consensus technique that consists of a pre-defined validator who acts as a moderator of the system and gives a small number of actors to fasten the transaction validation and network interactions. Moreover, this fast mechanism uses identity as a stake and distributed registry (Zheng et al., 2017).
- Proof of Property (PoP): PoP insert the privacy and consensus at the same time, the proof is used as evidence that a certain entity owns certain property.

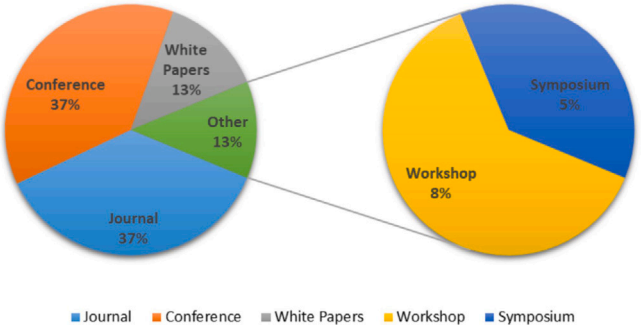

Fig. 5. Publication channels: Graphical representation of journal, conference, white paper and other ratio after selection process of mapping.

RQ6: To answer the sixth question, the research domains of each research paper are identified. Domains are classified as Supply chain, IoT, Cryptocurrency, Education, E-government, Healthcare, Industry,

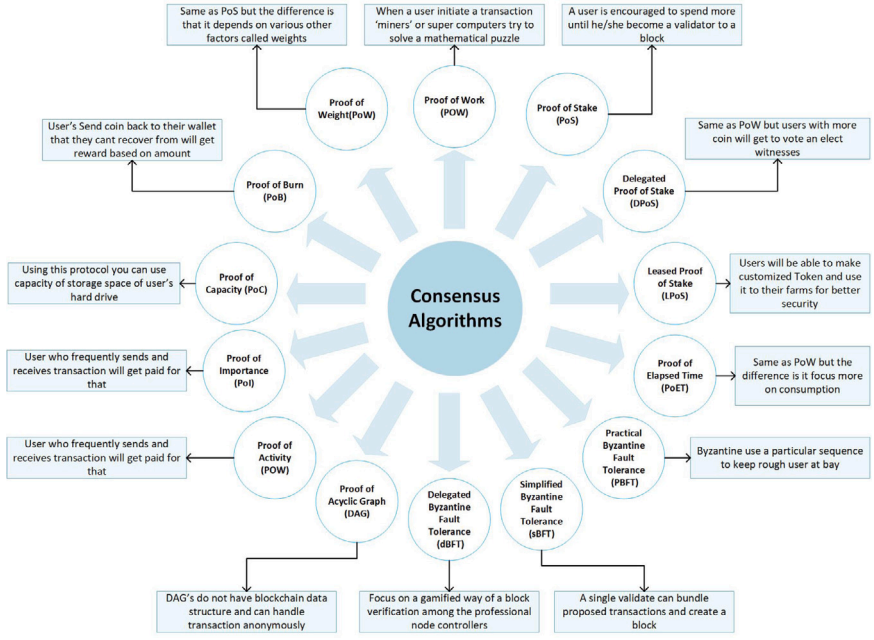

Fig. 6. Types of consensus algorithms: An illustration of comprehensive classification of consensus algorithms for heterogeneous applications.

and Finance, etc. multiple domains are described under IoT to curtail the categories. The synthesis of the data extraction method is used to collect relevant research papers for the research questions, mapping QA criteria on the extracted data & assigning a final score to each selected research paper. Finally, presenting the results on the basis of classification. Several techniques have been used to evaluate and represent results in a graphical manner with a narrative summary.

4. Findings and discussion

This section represents the results based on systematic literature mapping for research questions represented in Table 2. Some research papers are selected to elucidate the example of research question results.

4.1. Search results

After passing the initial retrieved results from different digital libraries to eligibility criteria, 217 papers were rigorously studied and investigated. Preceding the inclusion phase we have added 112 papers after close observation, study, and quality assessment of these studies and strictly mapped these studies on the research questions. Besides these 112 papers, we also added 17 white papers that are relevant to the research topic and have made a significant contribution to the field of blockchain as described in research questions. Tables 7 to 11 represents the pertinent Meta Information and Classification of the Selected Articles. These research papers are from well-reputed repositories and channels and thus individually percentile of journals and, conferences have been illustrated in Table 3. Furthermore, after the inclusion of these studies, we have rigorously evaluated quality assessment standards as described in Table 4. It has been noted that total journal publications are 42.2% and, conference papers 57.8% respectively. Moreover, the quality assessment criterion of systematic mapping scores is presented in Tables 7 to 11. The results of this systematic mapping are 88% concerning all research questions and these scores have shown highly relevant and aligned to the research domain and also show the potential of the domain in all respective application areas.

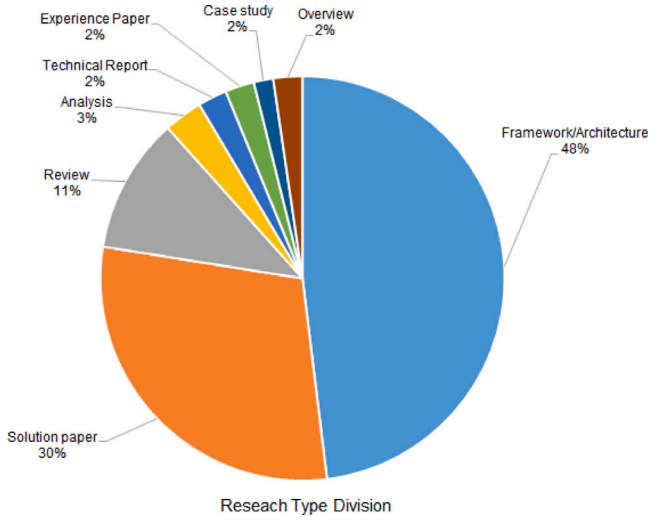

Fig. 7. Research type division: Graphical representation of class distribution of selected papers in framework, review, technical report, solution paper, analysis, experience paper and overview.

4.2. Assessment of research questions

4.2.1. RQ1: Which publication channels target blockchain?

The identical publications channels observed during conduction research are journals and conferences. Tables A.16 to A.19 demonstrate Quantile assessment of publication channels in Blockchain Technology. The summary illustrates as, types of publication channels, the total number of articles in each category, and the percentage of contribution of each study in total research. It is also being noted that a major number of selected research papers were retrieved from journals. Approximately, 42.2% of research papers appeared in journals and 57.85% were published in conferences. The graphical presentation is illustrated in Fig. 5.

4.2.2. RQ2: How is blockchain technology emerging over time?

Fig. 7 demonstrates the publication year distribution of the selected research papers. All selected studies were published after the year 2008 (Nakamoto, 2008). This is not a surprise because the blockchain term was coined the first time in a white paper by Satoshi Nakamoto. This indicates that blockchain is a very recent topic of research. If we look more closely observe the publication year-wise distribution of selected 121 papers, 1 paper (0.78%) was published as a white paper in 2008, 1 paper (0.78%) was published in 2012, 2 papers (1.56%) were published in 2013, 1 paper (0.78%) was published in 2014, 2 papers (1.56%) were published in 2015, 5 papers (3.91%) were published in 2016, 19 papers (14.84%) were published in 2017, 51 papers (39.84%) were published in 2018 and, 38 papers (29.69%) out of 120 were published 2019, and 8 papers in 2020, 12 papers in 2021 respectively. It has been noticed that the number of publications is drastically increasing over time, most publications were in 2018 with 39.84% contribution in this systematic research mapping. Though the number of published papers in 2020 was greater than in 2019. Nonetheless, we have selected 140 papers most relevant to the research questions.

Table 6 and Fig. 7 show the number of publications over time. It has been observed that there is a gap between 2008 to 2012, this could be explained by the fact that research conducted between 2008 to 2012 was mostly established on cryptocurrency. That was not necessarily focusing on the blockchain distinctly but the emphasis was on financial services and economic standpoint. Secondly, during that period, research mainly fixated on introducing state of the art technology rather than providing evidence of the evolution of blockchain. The evolution of blockchain is presented in Fig. 4.

4.2.3. RQ3: What are the research types of blockchain technology?

Research type classification on selected papers is demonstrated and summarized in Table 12 and Fig. 7 as, 56 Framework/Architecture papers, 37 Solution Papers, 14 Review papers 14, 4 Analysis papers, 3 Technical reports, 3 Experience papers, 2 Case studies, and 2 overview papers out of 120 selected papers, respectively. Fig. 7 demonstrates the distribution of research types of selected 140 papers. Approximately, 47% of selected papers have represented the framework/architecture that provides state-of-the-art methods to use blockchain in several domains. 30% of selected research papers were solution papers with identified problems in diverse domains and provide a blockchain-based solution. Roughly, 2% of research papers were review papers and have discussed the existing methods, solution and, also have provided future directions based on included studies. Furthermore, 4% of analysis papers were included, in these studies analysis of existing systems, and comparisons between different methodologies have been presented (Parino et al., 2018). Nearly, 5% were technical reports, and experience papers dealing with different kinds of research domains is also part of this study. We also selected 2 case studies directly mapped on blockchain technology. Lastly, there were around 2% overview papers. The most commonly used blockchain type is a public blockchain, there were 59 out of 140 selected papers have discussed public blockchain that is 49.17% of total selected papers. The most commonly used public blockchain is bitcoin however, Ethereum also has a big share in this percentage. The next prominent blockchain type was the hybrid blockchain. We identified 35 research papers (29.1%) discussed hybrid blockchain. Hybrid blockchain has a closed ecosystem and flexibility to change rules on data access for different authorities. The emerging hybrid blockchain is Cosmo and Smilo. Ethereum is also thriving its way to hybrid implementation in the hybrid blockchain. Moreover, 11 selected research papers (9.17%) have designated private blockchain. Hyper-ledger is on the top of the private blockchain. Besides these research papers with distinct blockchain types, there were also some of the case studies that have discussed a combination of different types such as Yli-Huumo et al. (2016) and Huckle et al. (2016) discussed both Public and Private blockchain. The number of papers that discussed both public and private blockchain was 5 in numbers, 4.17% of total research papers. Similarly, there were two studies Esposito et al. (2018) and Gramoli (2020) discussed the combination of public and Hybrid blockchain to provide a review of the research in a particular domain. Furthermore, 8 research papers (6.67%) have discussed all four types of blockchain such as Shrestha and Nam (2019), a solution paper based on security to avoid 51% attach for all types of blockchain, and Reyna et al. (2018) provided a review of IoT based solution using different types of blockchain. Interestingly, the selected studies have shown no evidence to use a combination of private and hybrid blockchain.

4.2.4. RQ5: What consensus algorithms are generally used in blockchain?

Many consensus algorithms are used to make blockchain immutable and transparent for the whole network. The number of consensus algorithms is still growing with the evolution of blockchain. During conducting our research, we have witnessed many consensus algorithms but for this study, we have selected 14 consensus algorithms based on the expansion and usage of these algorithms in several domains. These algorithms summary is illustrated in Fig. 8.

The most commonly used consensus algorithm was PoW, we have identified 40 research papers using PoW as a consensus algorithm, 33.33% of selected research papers. PoW most commonly used in cryptocurrency applications and solutions i.e. Nakamoto (2008), Parino et al. (2018) and Kim et al. (2018). In fact, Nakamoto (2008) is the first research ever conducted on blockchain provided a peer-to-peer distributed cryptocurrency solution using PoW as a consensus algorithm. In later years most researchers used PoW as a consensus algorithm. Although with time researchers introduced a new consensus algorithm named BFT. BFT is not particularly a blockchain-based consensus algorithm also vastly used in other domains. BFT is adopted by hybrid and private blockchain such as Şahan et al. (2019) and Wang et al. (2019b) used PoW as a consensus algorithm with a private blockchain network. Furthermore, Geiger et al. (2019), Miraz and Donald (2019) and Taghiyeva-Zeynalova et al. (2019) also have used PoW as a consensus algorithm based on Hybrid blockchain. We also have observed that there were also extended forms of BFT as FBFT (1 research paper (0.83%)), PBFT (3 research paper (2.5%)) and DBFT discussed in the selected research papers. During our research, we have identified 24 research papers using BFT as consensus algorithms, 20% of the total selected research papers. PoS is another major consensus algorithm that is frequently used in the blockchain. There were a total of 7 papers (5.83%) in our selected research that has used PoS as a consensus algorithm. We also have observed that many research papers discussed and used more than one consensus algorithm, collectively. The most frequently discussed combination was PoS and BFT consisting of 8 research papers (6.67%). They also have identified other combinations such as PoS and PoW (7 research papers (5.83%)), PoS, PoW and BFT (4 papers (3.33%)), PoW and BFT (3 papers (2.5%)), PoC and BFT (1 research paper (0.83%)), BFT and PBFT (1 research paper (0.83%)), BFT and DBFT (1 research paper (0.83%)), BFT, PoS and DBFT (1 research paper (0.83%)), respectively. SIEVE is another consensus algorithm used in hyper-ledger, 2 research papers were using the SIEVE consensus algorithm. On the other hand, Ripple uses UNL as a consensus algorithm and there was 1 research paper (0.833%) discussing Ripple and UNL. We also have observed, some researchers have introduced their consensus algorithm for possessing better performance and scalability. They also have implemented the proposed solutions on the use case such as Bahri and Girdzijauskas (2018) They have proposed a framework to reduce energy consumption by using the PoT consensus algorithm instead of the PoW (1 research paper (0.83%)) (Bahri and Girdzijauskas, 2018). In Otte et al. (2020), a new blockchain model using Netflow has been introduced as a consensus algorithm (1 research paper (0.83%)). Further, Kalra et al. (2018) have introduced a new game based on peer consensus as a consensus algorithm to ensure robustness (1 research paper (0.83%)). Additionally, Lin et al.

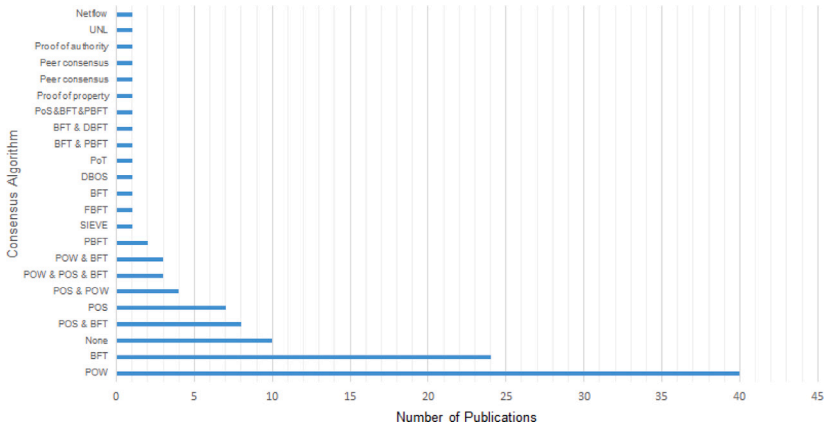

Fig. 8. Consensus algorithms: Quantile presentation of consensus algorithms in blockchain, concerning to selected collection of papers.

Figure 11: Research Domains of Blockchain

Fig. 9. Represents the veracity and variety of blockchain application. Multidimensional presentation of research domains of blockchain in real-world applications.

(2018) have introduced a community for coders and introduced the PoA consensus algorithm. Lastly (1 research paper (0.83%)), Ehmke et al. (2018) used proof of property as consensus algorithm (1 research paper (0.83%)). We also perceived that 10 selected research papers (8.83%) did not discuss any consensus algorithm. Most of these papers have proposed the framework and solutions mentioning the consensus algorithm but did not propose the algorithm. Table 14 represents the multiple consensus algorithms against the number of papers that discuss them and the percentage of each consensus algorithm.

4.2.5. RQ6: What are the main research application domains of blockchain?

The first domain introduced by blockchain technology was cryptocurrency by Satoshi in 2008 (Nakamoto, 2008). Later on, blockchain makes its space in almost every field that deals with transactions. During our research we came across a huge number of the domain, however, our selected research papers discussed 30 unique domains that are mapped on blockchain technology which are presented in Fig. 9 and Table 13.

Table 12
Blockchain research types in different domain applications.

Research type	Number of papers	Percentage
Framework/Architecture	62	48.06%
Solution paper	38	29.45%
Review	14	10.85%
Analysis	4	3.10%
Technical report	3	2.33%
Experience paper	3	2.33%
Case study	2	1.55%
Overview	3	2.33%

Table 13
Blockchain application domains.

Domain	Number of papers	Percentage
Cryptocurrency	16	33.33%
IoT	15	10.83%
Healthcare	9	7.5%
Supply chain	9	7.5%
Industry	8	4.17%
Security	7	5.83%
Finance/Economics	7	5.83%
E-Government	5	4.17%
Education	5	4.17%
Energy	5	4.17%
Communication	3	2.5%
Game/DApps	3	2.5%
Charity	3	2.5%
Logistics	3	1.67%
Data storage	2	1.67%
Data Security	2	1.67%
Blockchain	2	1.67%
Transportation	2	1.67%
Real estate	2	1.67%
Operating systems	1	0.83%
Crowdsourcing	1	0.83%
E-commerce	1	0.83%
Security & finance	2	0.83%
Other	8	6.67%

(i) Cryptocurrency: Cryptocurrency was the first application domain it is still dominating; we have identified 16 research papers discussed cryptocurrency that is 33.33% of the total selected research. For instance, Chen et al. (2017) discussed a new secure method of cryptocurrency-based solution,Karame (2016) have added the scalability and security of blockchain technology. Chepurnoy et al. (2017) has discussed a cryptocurrency based on two consensus algorithm PoW and PoS. Similarly, Swan (2015), Buterin (2013) and Grealish (2018) have also provided extensive cryptocurrency-based solutions.

(ii) Internet of Things (IoT): IoT is another prominent domain use blockchain technological-based solutions. 15 papers have discussed IoT application using blockchain with 10.83% of all selected research papers. There are different applications under the IoT umbrella for example Ateniese et al. (2018) discussed multiple applications of the sharing economy like cultural heritage, digital rights, and exchanges that adore the benefits of blockchain technology and also have made it decentralized and available globally. Additionally, there were also some studies those have provided IoT based solutions for other subdomains for instance, Ali et al. (2019) and, Tseng et al. (2020) have described secure trusted network based on IoT blockchains. Ibba et al. (2017) has described a concept of smart cities and how public data can be collected from different IoT devices and can be secured and become immutable using blockchain technology. In addition, Liu et al. (2019) has introduced a cost-effective data carrier for better execution of smart contracts under the IoT environment.

(iii) Supply-Chain: Supply chain is also one of the noticeable application domains of blockchain technology. We have identified 9 research papers (7.5%) on the supply chain out of 120 selected research papers. The supply chain shares the direct nature of blockchain and can very easily be mapped on it. In Xu et al. (2019b), the authors have proposed a framework for high-value assets to tracking using blockchain technology through its supply chain process and, Sinclair et al. (2019) have provided a solution to the secure supply chain process of drugs, they used Hyper-ledger blockchain for secure permissioned network. Similarly, Helo and Hao (2019) has discussed the multiple possibilities to make the supply chain immutable using blockchain techniques of the immutable electronic ledger. Interestingly, we also have retrieved 9 papers (7.5%), applied the blockchain in healthcare-based solutions specifically, for healthcare transactions and record management.

(iv) Medical: Esposito et al. (2018), Bhuiyan et al. (2018) and Badr et al. (2018) have discussed solutions to secure medical data by using blockchain technology. It has been noted that using blockchain for medical applications, privacy and security were some of the major concerns, and Koshechkin et al. (2018) have proposed the data security solution for electronic health records along with staff training and education.

(v) Security: One of the main traits of blockchain technology is to provide security and privacy to the applications and solutions. We have identified 7 research papers (5.83%) in the security domain. For instance, Wang et al. (2018a) have proposed the security aspect of blockchain technology by improving and discussing multiple hash functions like SHA256 and, Gai et al. (2019) have presented the privacy preservation of smart grid networks. Similarly, in Shrestha and Nam (2019) a solution to secure data transmission in a local vehicular network has been proposed.

(vi) E-Government: Blockchain has also disrupted the E-government sector the total number of identified papers is 5 (4.17%) of total selected papers. These papers have proposed solutions on blockchain technology for instance, Jha et al. (2019) have proposed a framework for citizenship record keeping and management and, Jun (2018) have discussed the nature of blockchain that how it can be best suited for government-based applications and they also have suggested that democratic government should use blockchain technology for consensus, data disclosure, statute law, and in short a decentralized autonomous government. Lastly, Hanifatunnisa and Rahardjo (2017) and Tan et al. (2020) have proposed an e-voting solution using blockchain technology.

(vii) Economics and Finance: Beside Cryptocurrency blockchain also provide services to the economics and finance domain. We have identified 7 research papers (5.83%) addressed these two domains. For instance, Wood et al. (2014) have implemented an e-commerce solution using Ethereum blockchain and smart contracts and, Bello and Perez (2019) have discussed multiple standards in blockchain technology to make financial data more secure and trustworthy. Similarly, Khalil and Gervais (2017), Xu et al. (2019a) and Khelifi et al. (2021) have discussed the economic and financial aspect of blockchain technology while in Raikwar et al. (2018) a complete framework has been proposed for insurance processes.

(viii) Industry: Blockchain is also widely used in several industries, we have recognized 8 research papers (4.17%) on different industries such as Li et al. (2017) and Franke et al. (2020) discussed different consensus protocols and industrial blockchain to make blockchain standards suitable for industrial purposes and, Wang et al. (2019b) proposed a secure blockchain protocol for metering systems, Helebrandt et al. (2018) and Geiger et al. (2019) also discussed industrial applications of blockchain technology.

(ix) Education: The education domain is also under the high impact of blockchain technology its decentralized nature makes it suitable to make the learning process decentralize and easy. During our research, we identified 5 research papers, have discussed the use of blockchain technology for the educational purpose such as Labouseur et al. (2019) discussed how we can use blockchain technology to improve the educational process of computer science, Coblenz (2017) introduced a new blockchain programming language, Luu et al. (2016), Han et al.

Table 14
Consensus algorithms adopted in blockchain.

Consensus algorithm	Number of papers	Percentage
POW	40	33.33%
BFT	24	20%
None	10	8.33%
POS & BFT	8	6.67%
POS	7	5.83%
POS & POW	7	5.83%
POW & POS & BFT	4	3.33%
POW & BFT	3	2.5%
PBFT	3	2.5%
SIEVE	2	1.67%
FBFT	1	0.83%
PoC & BFT	1	0.83%
DBOS	1	0.83%
PoT	1	0.83%
BFT & PBFT	1	0.83%
BFT & DBFT	1	0.83%
PoS & BFT & PBFT	1	0.83%
Proof of property	1	0.83%
Peer consensus	1	0.83%
Peer consensus	1	0.83%
Proof of authority	1	0.83%
UNL	1	0.83%
Netflow	1	0.83%

(2018) and Lin et al. (2018) also discussed the educational solution using blockchain technology.

(x) Energy: After Satoshi introduced the PoW algorithm that raised an energy consumption issue because miners used electrical power to solve a mathematical problem that requires massive energy. The researchers have picked this topic for research as well thus, we have identified 5 research papers (4.17%) discussed energy concerning blockchain technology. For instance, Bahri and Girdzijauskas (2018) have proposed a new algorithm PoT to overcome the energy consumption issue raised due to the PoW consensus mechanism and, Kotsiuba et al. (2018) have introduced a blockchain-based smart grid-based application for a secure infrastructure. Likewise, Hinterstocker et al. (2018), Verma et al. (2018) and Schlund (2018)also have discussed the energy consumption issues and provide a solution to that.

(xi) Communication: Another research domain of blockchain technology is communication. 3 research papers in this area (2.5% of the total selected research) have addressed this application of blockchain. For instance, Wang et al. (2017) have introduced a blockchain router for secure communication protocol similar is the case with Krishnaswamy et al. (2019), Kim and Jeong (2018) and, Vistro et al. (2020).

(xii) Decentralized Applications (DApps): Another application of blockchain technology that addresses to use of blockchain for decentralized data and resources management. We have identified 1 white paper (Wessling et al., 2018) (0.83%), have discussed the importance of blockchain technology to develop hybrid decentralized applications. DApps also includes game development 2 research papers (1.67%) have used a decentralized blockchain-based game. For example, Kalra et al. (2018) has proposed a robust cheat prevention strategy in a multiplayer game, and Barreiro-Gomez and Tembine (2019) discussed the token economy from the perspective of a game.

(xiii) Charity: One of the prominent blockchain application domain. The decentralized and transparent nature of blockchain has made it very much suitable for the charity collection process. It can help to gain donors' trust whereas they can track their donation as well. We encompassed three white papers AidCoin (2018), Mazet and Wojciechowski (2017), Task Force (2016) and Farooq et al. (2020) have introduced charity collection platforms to gain donor trust.

(xiv) Storage: Researchers also have introduced blockchain-based for data storage solutions. 2 research papers (1.67%) discussing the data storage domain. Nygaard et al. (2019) have provided a distributed data storage solution and Oracle (2011) have introduced a new blockchain-based data storage and management system as an oracle for blockchain applications.

(xv) Data security: Another domain of blockchain research 2 research papers (1.67%) from retrieved and selected papers have discussed data security. One of them is Şahan et al. (2019), which introduced secure access of blockchain-based application using multi authentication factors for secure data access and, Otte et al. (2020) have proposed a temper proof permission-less data structure to transfer data without any central control.

(xvi) Business Domain: We also have identified 2 research papers (1.67%) against the business domain for instance Di Ciccio et al. (2019) have proposed a collaborative blockchain base model for secure information exchange between untrusted entities and Snow et al. (2014) introduced Factom, a framework to build a business model on bitcoin blockchain rather than just cryptocurrency.

(xvii) Logistics and Transportation: Blockchain also provides services to logistics and transportation application domains. 3 research papers against each category have been selected for this study. For instance, Pedrosa and Pau (2018) introduced a blockchain-based framework for autonomous vehicles and its management system, López and Farooq (2018) and, Otoum et al. (2020) also have proposed a blockchain-based smart mobility framework.

(xviii) Other Domains: We also have identified research papers against the following domains: blockchain-based logistics (DHL, 2018; Miraz and Donald, 2019), new blockchain-based network (Barrett and Barrett, 2017; Kan et al., 2018) these paper do not focus on the specific domain but discuss multiple blockchain-based factors that are why we have put them under the category of blockchain. real estate (1 research paper (0.83%)), OS (1 research paper (0.83%)), crowdsourcing (1 research paper (0.83%)), E-commerce (1 research paper (0.83%)), Artificial intelligence (1 research paper (0.83%)), security and finance (1 research paper (0.83%)), network (1 research paper (0.83%)), HCI (1 research paper (0.83%)), cryptography (1 research paper (0.83%)) and agriculture (1 research paper (0.83%)) respectively. There were 8 research papers (6.67%) that have not discussed any particular domain but provide an overview of multiple domains or just provided an overview of the methods that can improve blockchain methods and performance. For instance, Vukolić (2017) has discussed the infrastructure of permissioned blockchain, Dinh et al. (2017) proposed a new framework to analyze and improve the performance of the private blockchain network. Similarly, Deshpande et al. (2018) has discussed a framework to simulate the Ethereum blockchain and, Lei et al. (2018) discussed how BFT is the best fit for the Consortium blockchain. Also, Wang et al. (2019c) has provided an overview of blockchain-based research conducted on intellectual property. Table 11 provide a consolidated summary of multiple domains discussed for this study.

5. Major key findings of systematic literature mapping

The main goal of our research was to conduct systematic literature mapping on the evolution of blockchain technology. To conduct this research, we have selected 105 research papers from multiple digital repositories and 15 white papers focusing on blockchain technology from different well-reputed channels. We have divided our research into six major categories which we defined as research questions in the following order: publication channels, the evolution, research type, blockchain type, commonly used consensus algorithms, and major research application domains of blockchain technology. The following are the code findings of our systematic mapping.

(a) While conducting the research we have observed that the blockchain research inception was in 2008 with a white paper presented by Nakamoto (2008), but it has found that the major boasted was after 2017. Though the concept of cryptocurrency was under discussion from 2005 based on a centralized system however the Satoshi's vision of decentralization made it worthy of worldwide attention. Meanwhile, besides cryptocurrency, DApps and smart contracts

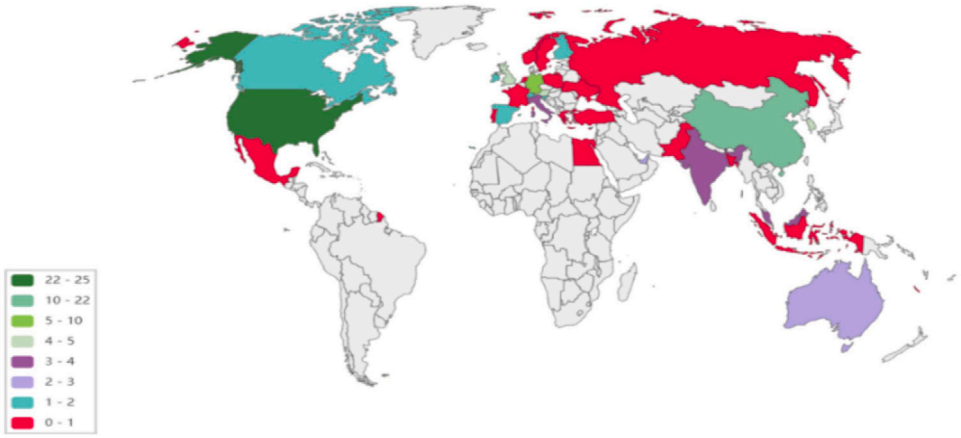

Fig. 10. Geographical distribution of selected research papers: Presentation of Collaboration analysis of selected papers with respect to geographical distribution and share of publication.

Table A.15
Characteristics of blockchain technologies.

Characteristics	Bitcoin	Ethereum	Hyperledger	Ripple	R3 Corda	Quorum
Industry focus	Financial	Cross-Industry	Cross-Industry	Financial	Financial	Financial
Permission restriction	Permissionless	Permissionless	Permissioned	Permissioned	Permissioned	Permissioned
Consensus mechanism	PoW	PoW	PBFT	PoW & PoS	Several	Quorum-Chain
Hashing algorithm	SHA-256	ETHash	TLS	Ripple Protocol Consensus Algorithm (RPCA)	SHA-256	SHA3-512
Scalability	High node, low performance	High node, low performance	Low node, high performance	High node, low performance	Low node, high performance	Low node, high performance
Description of platform	Generic	Generic	Modular	Generic	Specialized distributed ledger	Generic
Governance	Several	Ethereum developers	Linux	Ripple labs	R3 consortium	Ethereum developers & JP Morgan chase

were other revolutionary concepts introduced by Vitalik Buterin in 2013. These solutions have encouraged researchers to not only use blockchain for cryptocurrency rather but also to utilize the spectacular characteristics for a decentralized solution in almost every domain, for instance, computer science (Labouseur et al., 2019), industry (Li et al., 2017), business, IoT (Wang et al., 2020), and supply chain (Tian, 2017) etc.

(b) Another very important aspect that we have noticed during our research was the geographical distribution of the publication. Mostly published research papers were from America and China. We have explored that 25 research papers were from American institutes and 22 research papers were written by Chinese researchers. Another observation was that the selected research papers were from 37 countries although the number of publications was not higher as America and China. Germany and the United Kingdom also have a significant number of research publications. Importantly, we have identified 9 research papers from German institutes and 5 research papers from United Kingdom institutes. Moreover, some research contribution was from researchers belonging from different countries and institutes for instance Parino et al. (2018), Liang et al. (2019), Pawlak et al. (2018), Casado-Vara et al. (2018), Qiu et al. (2019), Prybila et al. (2020), Chen et al. (2019), Kamble et al. (2020), Liu et al. (2019) and Pappalardo et al. (2018). But for sake of clarification, we have considered the country of the first author for this study. Fig. 10 represents the geographical distribution of selected research papers.

(c) There were around 38% papers published in journals, this has revealed that the researchers mostly target journals for their research publication. On the other hand, the impact factor of journals is not very high for some papers such as Labouseur et al. (2019), Jun (2018) and Mehedi et al. (2019). Most of the studies are not mature enough to discuss the whole topic but only focuses on one aspect.

(d) Approximately, 37% of research papers were published in conferences and thus make this channel as important as journals. Though these conferences held under highly ranked digital libraries but still the impact factor was not very good, we have found only one A* ranked conference (Şahan et al., 2019).

(e) Nearly, 49% of selected research papers were discussing public blockchain rather it was framework or solution papers. The probable reason may that blockchain ensures the trust of data between untrusted parties and entities. For instance, cryptocurrencies commonly work on the public blockchain and open-access coin offering needs full transparency on every node. Every node needs to have equal authority over data and networks. Thus, we have noticed that most of the selected research papers were based on the cryptocurrency that easily explains the popularity of public blockchain. On the other hand, Hybrid blockchain is the next popular blockchain, that has enhanced the limits of blockchain capabilities (Ateniese et al., 2018). For instance, for an organization different levels of authorities are responsible for decision making yet they want to make the decision-making process transparent to everyone which can be easily mapped on hybrid blockchain and increase the need for hybrid blockchain.

(f) Another finding of this study was that PoW is one of the most commonly used consensus algorithms. This also relates to the fact that cryptocurrency is the major application of blockchain and bitcoin is the most popular cryptocurrency so far which uses PoW as a consensus algorithm. Although in PoW, high energy consumption is reported as a major drawback of this technology. However, many efforts have been made to overcome this issue such as Bahri and Girdzijauskas (2018) have provided a possible solution to replace PoW with PoT. Some other consensus algorithms such as Androulaki et al. (2018), Mondal et al. (2019), Lin et al. (2018), Otte et al. (2020) and Ehmke et al. (2018) were also introduced based on multiple scenarios but PoW is

Table A.16
Quantile analysis of publication channels for research publication in blockchain technology (I).

Publication source	Reference	Channels	No	%
White papers	Nakamoto (2008), Pricewaterhouse Coopers- PWC Copyright (2018), Snow et al. (2014), Buterin (2013), Rosenfeld (2012), Architect (2017), DHL (2018), Oracle (2011), Technology and Initiatives (2020), Grealish (2018), Task Force (2016), Amsden et al. (0000), Barrett and Barrett (2017), Anon (2021) and Everledger (2021)	Other	19	14.8%
Procedia computer science	Huckle et al. (2016), Wang et al. (2018b), Pawlak et al. (2018), Pustišek and Kos (2018), Badr et al. (2018), Koshechkin et al. (2018), Casado-Vara et al. (2018), Qiu et al. (2019) and Wang et al. (2019c)	Journal	9	6.9%
Future generation computer systems	Reyna et al. (2018), Gramoli (2020), Prybila et al. (2020), Otte et al. (2020), Chen et al. (2019) and Liu et al. (2019)	Journal	6	4.65%
White papers	Nakamoto (2008), Pricewaterhouse Coopers- PWC Copyright (2018), Snow et al. (2014), Buterin (2013), Rosenfeld (2012), Architect (2017), DHL (2018), Oracle (2011), Technology and Initiatives (2020), Grealish (2018), Task Force (2016), Amsden et al. (0000), Barrett and Barrett (2017), Anon (2021) and Everledger (2021)	Other	19	14.8%
Procedia computer science	Huckle et al. (2016), Wang et al. (2018b), Pawlak et al. (2018), Pustišek and Kos (2018), Badr et al. (2018), Koshechkin et al. (2018), Casado-Vara et al. (2018), Qiu et al. (2019) and Wang et al. (2019c)	Journal	9	6.9%
Future generation computer systems	Reyna et al. (2018), Gramoli (2020), Prybila et al. (2020), Otte et al. (2020), Chen et al. (2019) and Liu et al. (2019)	Journal	6	4.65%
ACM workshop on blockchain, Cryptocurrencies, and Contracts	Vukolić (2017), Li et al. (2017), Wang et al. (2018a) and Chen et al. (2017)	Workshop	4	3.1%
ACM SIGSAC conference on computer and communications security	Luu et al. (2016), Karame (2016), Khalil and Gervais (2017) and Wu and Du (2019)	Conference	4	3.1%
IEEE access	Barreiro-Gomez and Tembine (2019), Hasan and Salah (2019), Turkanović et al. (2018) and Shrestha and Nam (2019)	Journal	4	3.1%
Workshop on cryptocurrencies and blockchain for distributed systems	Wang et al. (2017), Alzahrani and Bulusu (2018) and Hepp et al. (2018)	Workshop	3	2.32%
IEEE International Conference on Internet of Things (iThings) and IEEE Green Computing and Communications (GreenCom) and IEEE Cyber, Physical and Social Computing (CPSCom) and IEEE Smart Data (SmartData)	Kiš and Singh (2018), Pussewalage and Oleshchuk (2018) and Watanabe et al. (2018)	Conference	3	2.32%
Energy informatics	Hinterstocker et al. (2018), Verma et al. (2018) and Schlund (2018)	Journal	3	2.32%
ACM international conference on blockchain and secure critical infrastructure	Jha et al. (2019) and Xu et al. (2019b)	Conference	2	1.55%
International conference on blockchain technology and applications	Zhao and O'Mahony (2018) and Wang et al. (2018c)	Conference	2	1.55%
International conference on agile software development: Companion	Coblenz (2017) and Tonelli et al. (2018)	Conference	2	1.55%

still prevalent. Blockchain technology is evolving so fast, it is evident that new applications and solutions of blockchain have been published every day.

This study could be a great help to researchers who are exploring blockchain technology as the first draft to understand the evolution and emergence of blockchain. For clear understanding and consolidation, we have divided our research into two parts: firstly, we have discussed the research papers of online digital libraries including journals, conferences, and workshops, etc. Secondly, we also have included white papers published by well-known industrial projects. This emergence has kept the balance between two domains and give researchers insight into current research on the blockchain.

5.1. Advises to new researchers

The main audience of this study is new researchers focusing on blockchain as a research domain. This systematic mapping will enable them to find the current methodologies in the research concerning blockchain and to endeavor joined methodologies in the blockchain. In addition, the selected empirical studies can give an insight into the efficiency of each approach. Thus provide an open paradigm to find solutions to improve blockchain research. The review papers presented in the related work section Nakamoto (2008), Macrinici et al. (2018), Yli-Huumo et al. (2016), Calvaresi et al. (2018), Calvaresi et al. (2019) and Yumna et al. (2019) have identified many issues and future direction in this area that could also be used as a pioneer to conduct research.

- Researchers should identify the main research channels like journals or conferences to target for their publication based on digital libraries presented in this study. They can identify the publishers which have a lower number of publications. This approach will help them to target for new research. Moreover, the low number of publications also indicate the tough criteria for publication so researchers should keep those standards in mind while conducting research.
- Researchers should identify the geographical distribution of selected research which shows that American institutes focus on the blockchain more than any other country. There are chances that studies from American institutes will be mature enough to be followed. We have also noticed that china is also greatly focusing on blockchain. Therefore, for blockchain research initialization,

Table A.17
Quantile analysis of publication channels for research publication in blockchain technology (II).

Publication source	Reference	Channels	No	%
International Conference on Advanced Communication Technology (ICACT)	Aich et al. (2019) and Dennis and Owen (2015)	Conference	2	1.55%
IEEE transactions on industrial informatics	Liang et al. (2019) and Liu et al. (2018)	Journal	2	1.55%
IEEE internet of things journal	Mondal et al. (2019) and Gai et al. (2019)	Journal	2	1.55%
IEEE international conference on Hot Information-Centric Networking (HotICN)	Lin et al. (2018) and Kan et al. (2018)	Conference	2	1.55%
IEEE International Conference on Blockchain and Cryptocurrency (ICBC)	Dasaklis and Casino (2019) and Krishnaswamy et al. (2019)	Conference	2	1.55%
EPJ data science	Parino et al. (2018) and Pappalardo et al. (2018)	Journal	2	1.55%
ACM 1st International Workshop on Emerging Trends in Software Engineering for Blockchain (WETSEB)	Wessling et al. (2018) and Ehmke et al. (2018)	Workshop	2	1.55%
PLOS one	Yli-Huumo et al. (2016)	Journal	1	0.76%
International conference on omni-layer intelligent systems	Ali et al. (2019)	Conference	1	0.76%
ACM/SIGAPP conference on applied computing contracts	Nygaard et al. (2019)	Conference	1	0.76%
International conference on informatics, environment, energy, and applications	Wang et al. (2017)	Conference	1	0.76%
Scientific workshops	Ibba et al. (2017)	workshop	1	0.76%
International conference on management of data	Han et al. (2019)	Conference	1	0.76%
International conference on computer and technology applications	Şahan et al. (2019)	Conference	1	0.76%
The web conference 2018	Bahri and Girdzijauskas (2018)	Conference	1	0.76%
EuroSys conference	Androulaki et al. (2018)	Conference	1	0.76%
The journal of computing sciences in colleges	Labouseur et al. (2019)	Journal	1	0.76%
IEEE cloud computing	Esposito et al. (2018)	Journal	1	0.76%
International conference on internet of things design and implementation	Wang et al. (2019b)	Conference	1	0.76%
International conference on machine learning and machine intelligence	Suchaad et al. (2018)	Conference	1	0.76%
International conference on Cloud Computing and Internet of Things, CCIOT 2018	Kim et al. (2018)	Conference	1	0.76%
International conference on cryptography, security, and privacy	Sinclair et al. (2019)	Conference	1	0.76%
Annual SIG conference on information technology education	Han et al. (2018)	Conference	1	0.76%
ACM southeast conference	Bello and Perez (2019)	Conference	1	0.76%
ACM SIGMETRICS performance evaluation review	Alharby and van Moorsel (2019)	Conference	1	0.76%
ACM international conference on management of data	Dinh et al. (2017)	Conference	1	0.76%

the research from these countries should keep in their evaluation list.

- Researchers should also keep in mind that the research domains of blockchain are increasing day by day so they should focus on diverse applications rather than cryptocurrency. This may lead to other research types for instance developing new algorithms, proposing privacy, the security standards or applications for blockchain, and mapping blockchain on other areas such as IoT, data storage, decentralized operating systems, transportation and even in telecommunications, banking and military etc.

5.2. Extortions to validity

There could be four threats to validity mentioned by Ouhbi et al. (2015) and describing here under:

(a) Construct Validity: This threat to validity is associated with the identification of selected research (Ampatzoglou et al., 2013). To make certain that as many applicable major studies as feasible were being included. We have identified and proposed a realistic search string in several iterations. The search was conducted via Springer link, IEEE Digital Library, ACM Digital Library, ACM computing survey, Science direct, and PLoS. According to the systematic mapping of blockchain research (Yli-Huumo et al., 2016), we have agreed that most of the lookup on the blockchain can be located in these digital libraries. We believe that the inclusion of research papers from low-impact journals or conferences may reduce the score of primary research. However, it signifies that the representativeness of the selected research is increased. Moreover, certain research papers may additionally have not been noted as the result of the subscription limitations of our university library and, another threat concerns the feasible mishandling of duplication. That may have slightly altered our results but we have double-checked and verified the research in final alteration and not duplication have been detected.

(b) Internal validity: This validity threat is relevant to data extraction and data validation (Ampatzoglou et al., 2013). To avoid this threat, we have carried out research based on search string first and then reviewed the final results as a second step. The selection of research papers inclusion and how to classify these papers are dependent on the judgment of the main authors conducting this systematic literature mapping. Authors who have a distinct mindset such as student and associate professors carried out specific classifications for consistency purposes (Brereton et al., 2007). We used the Kappa coefficient for the study section and agreement was 0.95 which indicates a high degree of agreement between the authors.

(c) Conclusion validity: This validity threat is concerned with the identification of flawed relationships which may also lead to fallacious conclusions. In the case of a mapping study, this hazard refers to elements such as missing relevant research paper and irrelevant data extraction (Ampatzoglou et al., 2013). The purpose is to manage these factors so that a systematic mapping can be performed by way of different researchers Elberzhager et al. (2012) and Garousi et al. (2013) who will draw equal conclusions (Portillo-Rodríguez et al., 2012). The

Table A.18
Quantile analysis of publication channels for research publication in blockchain technology (III).

Publication source	Reference	Channels	No	%
International conference on data processing and applications	Bhuiyan et al. (2018)	Conference	1	0.76%
International conference on emerging networking experiments and technologies	Kalra et al. (2018)	Conference	1	0.76%
IACR cryptology ePrint archive	Chepurnoy et al. (2017)	Journal	1	0.76%
International middleware conference	Deshpande et al. (2018)	Conference	1	0.76%
IFIP international conference on New Technologies, Mobility and Security (NTMS)	Raikwar et al. (2018)	Conference	1	0.76%
IEEE 9th Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON)	Helebrandt et al. (2018)	Conference	1	0.76%
International conference on service systems and service management	Tian (2017)	Conference	1	0.76%
		Conference	1	0.76%
IEEE international conference on Big Data (Big Data)	Kotsiuba et al. (2018)	Conference	1	0.76%
Journal of open innovation: Technology, Market, and Complexity	Jun (2018)	Journal	1	0.76%
International conference on Telecommunication Systems Services and Applications (TSSA)	Hanifatunnisa and Rahardjo (2017)	Conference	1	0.76%
Health informatics journal	Patel (2019)	Journal	1	0.76%
International Conference on Parallel and Distributed Systems (ICPADS)	Lei et al. (2018)	Conference	1	0.76%
IEEE international conference On Trust, Security And Privacy In Computing And Communications /12th IEEE International Conference On Big Data Science And Engineering (TrustCom/BigDataSE)	DeCusatis and Lotay (2018)	Conference	1	0.76%
Journal of network and computer applications	Wang et al. (2019a)	Journal	1	0.76%
Computers & Industrial engineering	Helo and Hao (2019)	Journal	1	0.76%
International journal of information management	Kamble et al. (2020)	Journal	1	0.76%
Iran journal of computer science	Mehedi et al. (2019)	Journal	1	0.76%
Informatik spektrum	Di Ciccio et al. (2019)	Journal	1	0.76%
Computer science-research and development	Knirsch et al. (2018)	Journal	1	0.76%
Human-centric computing and information sciences	Kim and Jeong (2018)	Journal	1	0.76%
Financial innovation	Xu et al. (2019a)	Journal	1	0.76%
Computer fraud & security	Bradbury (2013)	Journal	1	0.76%
ACM/SIGAPP conference on applied computing	Geiger et al. (2019)	Conference	1	0.76%
International conference on information system and data mining	Miraz and Donald (2019)	Conference	1	0.76%

Table A.19
Quantile analysis of publication channels for research publication in blockchain technology (IV).

Publication source	Reference	Channels	No	%
Australian conference on computer–human interaction	Foth (2017)	Conference	1	0.76%
International database applications & engineering conference	Khan et al. (2019)	Conference	1	0.76%
International conference on blockchain and secure critical infrastructure	Taghiyeva-Zeynalova et al. (2019)	Conference	1	0.76%
Asia-Pacific conference on intelligent medical 2018 & International conference on transportation and traffic engineering 2018	Shi and Wang (2018)	Conference	1	0.76%
MDPI-Electronics	Khatoon (2020)	Journal	1	0.76%
IEEE-Networks	Tseng et al. (2020)	Journal	1	0.76%
Springer-Science direct	Zhao et al. (2020)	Journal	1	0.76%
GLOBECOM 2020–2020 IEEE global communications conference	Otoum et al. (2020)	Conference	1	0.76%
MDPI-Sustainability	Franke et al. (2020)	Journal	1	0.76%
Proceedings of the 5th international conference on Economics, Management, Law and Education (EMLE 2019)	Cheng and Huang (2020)	Conference	1	0.76%
Proceedings of the ACM on measurement and analysis of computing systems	Gopalan et al. (2020)	Journal	1	0.76%
Journal of network and computer applications	Hewa et al. (2021)	Conference	1	0.76%

traceability between the information extracted and the conclusions was strengthened via statistical packages like graphs and plot. We believe slight variations based on selected research choice bias and misclassification would now not alter the fundamental conclusions drawn from the 120 articles identified in our systematic literature mapping study.

(d) External validity: External validity of systematic mapping is to apply the conclusion of the study to the generalized domain (Ampatzoglou et al., 2013). The results of this study are relevant to blockchain technology and validity was based on defined research questions. There is not any time restriction besides the fact that the blockchain concept was first coined in 2008, so the representativeness of selected research was not affected. This threat is no longer present in this context. The search string and the classification plot presented in this paper may serve as a starting point for blockchain analysts, and professionals can look for and categorize additional papers appropriately.

6. Conclusion

Blockchain is a distributed electronic ledger where all the transactions are recorded publically and visible to all members or nodes of the network. Blockchain concept was first coined by Satoshi in 2008 and after that, it got attention of scientists from all around the world. This new area of research lead to open new doors of investigation including new research domains and solving issues in the existing blockchain network.

The main purpose of this study is to highlight the evolution of blockchain technology using systematic literature mapping. We have prepared research questions to clarify the scope of our research, included the research year, popular publication channels of blockchain-based research, types of research used to investigate this field, types of blockchain, most commonly used & newly introduced consensus algorithms, and finally the research domains of blockchain technology. We have selected 140 studies to investigate the research questions. Out of 140 selected research papers. We also did a quality assessment of

selected studies and assigned a score to every study based on relevancy and impact factor of publication channel.

The results indicate that after the 2013 conception of a smart contract was introduced that drastically increased the research on this topic and continuously expanding as well. The publication channels that are mostly focusing on this state-of-the-art technology were journals. In this study is has been identified that the most commonly used blockchain type so far is a public blockchain, and PoW is the most commonly used consensus algorithm. We also identified several unique research domains in selected studies related to blockchain. Thus, it has revealed the potential of the study in future endeavors.

This investigate might be a beginning point to explore better ways in blockchain-based research. Moreover, the Blockchain approaches displayed in this research may offer assistance to new researchers to recognize new methods that can be embraced in new researches. For future studies on blockchain, more prominent presence in highly ranked journals should be considered and more consideration ought to be paid to the quality research. Particularly, more specific measure should to be carried out to assess existing consensus algorithms. The future research is based on conducting a systematic literature reviews to evaluate the blockchain-based research on the ground results of this systematic literature mapping.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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Appendix

See Tables A.15–A.19.

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