

## SURVEY

# An Extensive Blockchain Based Applications Survey: Tools, Frameworks, Opportunities, Challenges and Solutions

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**ABSTRACT** Many security standards and cryptographic solutions exist for different applications such as agriculture, aircraft, banking systems and etc. but a more effective and efficient solution can be given by combining existing technologies with blockchain. This work addresses the problems of previous works such as scalability, immutability, robustness, network latency, auditability, and traceability. Satoshi Nakamoto introduced Blockchain (BC) to tackle the Address Resolution Protocol (ARP) spoofing attacks, Distributed Denial of Service (DDoS), phishing problems and various security issues. Blockchain is a technology that stores the data using a chain of blocks in an encrypted form with hashing algorithms. It uses the decentralized architecture to store the information that helps users and customers to have transparency on records. The data is stored in a distributed ledger that is tamperproof and immutable. To amalgamate the research done so far, this paper presents a systematic review of ten different applications and tools used in blockchain. The applications include academics and education, agriculture, aircraft, banking, car sharing, e-voting, healthcare, Internet of Things (IoT), Intellectual Property Rights (IPR), and Supplychain (SC). Moreover, this paper presented a taxonomy for these applications and analyzed the implementation of tools used in different domains. Different open issues and challenges and key takeaways of blockchain technology were also highlighted. Hence, this paper helps give a new insight into working with blockchain and deciding on appropriate tools and approaches for a particular application.

**INDEX TERMS** Blockchain, ethereum, security, privacy, trust, banking, e-voting, agriculture, healthcare.

## I. INTRODUCTION

With the technological advancement and increasing uses of the internet, online communication systems are becoming a priority for different users. As the flow of data is continuous, the threats to privacy and security have increased tremendously [1]. Hackers and attackers usually attack the communication channel to disrupt or steal the information. Hence, it is required to consider security and privacy concerns actively along with data integrity, heterogeneity, and

redundancy. Security and privacy are the important concerns to be taken care of in any organization [2], [3]. The information leakage and unauthorized data breaching lead to financial losses and wastage of resources. In the absence of a secure and robust model, the system faces many attacks such as data rate alteration, DDoS, manipulation, ARP spoofing attacks, network congestion, config threats, noise interference, and phishing. These attacks affect confidentiality and harm the integrity of data. With the increasing cyber-attacks, confidentiality, access control, integrity, authorization, and data availability are the primary concerns to deal with. Many client-server and centralized-based architectures were

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introduced to mitigate the aforementioned threats. But, the problem with these architectures was that when the central server fails to survive cyber-attacks and failures, the entire system used to crash down. Advanced Encryption Standard (AES) and Data Encryption Standard (DES) security mechanisms were also used to secure the system, but they faced high communication overhead and significant computation power.

The revolution came up with the introduction of the blockchain (BC) and bitcoin concept [4]. Unlike the usual traditional models, the decentralized and secured BC technique enables peer-to-peer (P2P) transference of digital assets without the support of any intermediate party [5]. Initially, BC was developed to help and support the bitcoin cryptocurrency. In the year 2008, the concept of BC was proposed for the first time, and later, it was implemented by Nakamoto in the year 2009. The decentralized BC is a technology of connected blocks or nodes chained together that stores all the committed transactions in a public ledger [6]. As the transactions increase, the new blocks are created and thus appended to the chain, thereby increasing the chain growth. The decentralized technology of BC comprises several cores and important technologies such as cryptographic hash, digital signatures, and distributed consensus algorithms. The decentralization property of BC thus removes the need for any intermediate party to verify and validate the transactions [7]. A few important BC key characteristics are transparency, trustworthiness, decentralized, auditability, and immutability [8]. Because of its trust and secured societal impact, BC is applied to various applications worldwide.

#### A. COMPARISON OF SURVEY WITH EXISTING SURVEYS

The possibility of dealing and integrating BC with different domains such as academics and education, agriculture, aircraft, banking, car sharing, e-voting, healthcare, IoT, IPR, and SC has always been a topic for investigation and analysis. Many researchers have investigated applications and frameworks of BC, but it lacks comprehensive and concrete work in different domains. The recent surveys such as [9], [10], and [11] have reviewed different application domains and architecture of BC such as healthcare, IoT, IPR etc. However, the papers lack the in-depth analysis, tools used and taxonomies of BC. Motivated by the aforementioned facts, in the proposed survey, this paper reviews various applications of BC and their taxonomy, tools, and frameworks used for BC applications and deals in-depth analysis of various open issues and challenges of BC. TABLE 1 shows the comparison of the proposed survey with the existing surveys that various researchers carried out. It highlights the year, primary objective, key contributions, applications, taxonomy, tabular discussion, tools and limitations, and open issues of the paper, which ought to be useful for beginners interested in doing research in this emerging field of BC. The survey deals with the ten different applications of BC and their taxonomy, along with a detailed description of the tools and frameworks used. It also analyzes various open issues and challenges faced by different applications and their related taxonomy.

The authors in [9] discussed the evolution of blockchain architecture and details of consensus protocols but lacked a tabular discussion of applications. Papers [10] and [11] presented a classification of BC-based applications across diverse sectors. However, papers have shortcomings and lack taxonomy for open issues and challenges faced. The authors in [11] had only discussed eight applications and lacks the details of different tools and frameworks that are used in BC applications.

The authors in [12] carried out a systematic literature review of 69 articles and discussed current BC issues of scalability, incentivization, privacy, and regulations as future opportunities. The authors in [13] analyzed the tradeoffs of blockchain and explained the concept of architecture and taxonomy of blockchain. However paper lacks an in-depth analysis of many applications. Authors of [14] discussed the following applications of healthcare records management, verifiable electronic voting, decentralized notary, identity management systems, access control systems, and supply chain management. Authors in [15] discussed the concepts of confidence and trust for BC. However, both the papers lack the details of tools used for BC. The authors in [16] showed the usage of BC for healthcare data management and discussed various features of BC with the significant benefits in the healthcare department, major opportunities offered, case studies, open research challenges, and future recommendations. Reference [17] suggested possible opportunities related to the future of IP law that BC offered and discussed the impact on the management, registration, and enforcement of intellectual property rights. However, the paper lacks taxonomy and discusses only the IP law. The authors in [18] presented a comparative analysis of BC consensus algorithms with respect to different type of applications. Different challenges faced as well as platforms are also discussed. However paper lacks taxonomy for different applications and the relative comparison of BC applications.

#### B. PROBLEM STATEMENT

For every business relationship, trust is the basic foundation to be laid down. After trust, success is built on it. Different intermediaries participate in business and create trust among stakeholders such as banks help to ensure the correct transactions for the correct amounts. But these traditional systems led to a very costly, time-consuming, and insecure system. These systems develop trust using intermediary service platforms that demand fees. Hence trust demands a price. Therefore BC technology came into existence that helped improve trust and security in different business relationships. For example, in the supplychain management system earlier, it wasn't easy to track products. But BC allowed it to follow the process and store each detail in BC. Many creative works of various musicians often travel through a complicated path from an artist to the buyer. Various intermediaries involved want their cut in this complete process. In addition, there are licenses and various complex rights management

TABLE 1. Comparison between existing surveys with proposed survey.

Related Surveys	Year	Objective	Key Contributions	1	2	3	4	5	Limitations and Open issues
Ismail <i>et al.</i> [9]	2019	Review of blockchain-based architecture and consensus mechanism	The authors focused on the use-cases, challenges and their solutions for blockchain consensus protocols and architecture	✓	✓	X	✓	✓	Lacks tabular analysis on the BC applications.
Casino <i>et al.</i> [10]	2018	Review of BC applications	The authors provided the study of the BC applications with the current status, open issues and classifications	✓	✓	X	X	✓	Taxonomy for open issues and tools details were not discussed.
Zou <i>et al.</i> [11]	2020	Survey on Academic and industry	The authors provided a comprehensive survey on BC with the detailed discussion on BC projects, issues faced and research trends	✓	X	✓	X	✓	Not included the taxonomy and tools details for BC applications
Vu <i>et al.</i> [12]	2021	A systematic review of peer reviewed articles and implementation proposed framework for FSCs.	The authors provided a systematic literature review of 69 articles that captured details about FSCs. They also identified blockchain issues and developed a three-stage conceptual framework for BC implementation in FSCs.	✓	✓	✓	X	✓	Discusses only about SC and FSC and lacks in-depth analysis of tools used in BC.
Monrat <i>et al.</i> [13]	2019	Survey of BC and opportunities	The authors provided a comparative study about BC and discussed its applications, opportunities and challenges.	✓	✓	X	X	✓	Less number of BC applications were considered
Maesa <i>et al.</i> [14]	2020	Survey on BC 3.0 applications	The authors carried out a survey on BC 3.0 applications	✓	X	✓	X	✓	Lacks taxonomy and BC tools details.
Filippi <i>et al.</i> [15]	2020	BC as confidence machine to be trusted	The authors carried a discussion on BC to be trusted and used confidently for work by researchers and learners.	X	X	X	X	✓	Lacks BC applications and tools details
Yaqoob <i>et al.</i> [16]	2021	Comprehensive analysis on adoption of blockchain for healthcare data management system	The authors discussed the blockchain features, advantages, opportunities, challenges and future research aspects for adoption of blockchain in healthcare system.	✓	X	X	X	✓	Lacks in the proper real-time implementation and have not discussed about the tools used for implementation in detail.
Gürkaynak <i>et al.</i> [17]	2018	Comprehensive study on adoption of BC for IP law.	The authors discussed the possible opportunities that BC offered to the future of IP law and discussed its potential impact on the registration, enforcement and management of IPR.	✓	X	X	X	✓	Lacks taxonomy and discussed only IP law.
Johar <i>et al.</i> [18]	2021	Applied and Research perspective to BT	The authors presented a comparative analysis of BC consensus algorithms with respect to different type of applications.	✓	X	X	✓	✓	Lacks taxonomy and detailed relative comparison of BC applications.
The proposed survey	2022	Comprehensive study on BC application in ten different domains and tools used	The authors discussed in depth about the BC, proposed solution taxonomy for 10 different applications adopting BC, tools/frameworks used for decentralized system, open issues, challenges and key takeaways.	✓	✓	✓	✓	✓	-

1: Applications, 2: Taxonomy, 3: Relative comparison of BC applications, 4: Tools, 5: Open issues and challenges

of online platforms. But BC helps build trust through a direct connection between consumer and artist, reducing the fee. In academics and the education system, BC builds trust by securing data from any attack and thus provides transaction transparency. This helps in providing a reliable and

cooperative working environment. In the e-voting system, BC helps to secure the ballot system and the count of votes that helps to build trust among people. Motivated by the aforementioned facts, the authors review ten different applications that use BC technology to help build trust among them.

### C. MOTIVATION

In 2008, various business parties faced an economic crisis due to the lack of trust among stakeholders. Due to the heavy losses, there was an urge to bring the businesses back on track. This need resulted in the evolution of bitcoin and BC. From 2008 to 2018, BC was used for cryptocurrency. In 2018, BC started being used for different applications such as academics and education, agriculture, aircraft, banking, car sharing, e-voting, healthcare, IoT, IPR, and SC systems. Many surveys have been carried out on BC and its applications, but not a single paper has covered all the significant applications and tools used in BC. The existing research focused on the particular application, while the need was to get an end-to-end solution for different domains that use blockchain technology (BT). Motivated by these facts, this paper reviews all the possible ten applications that adopt BC and discusses the various tools used in different applications.

### D. SCOPE OF THE SURVEY

This paper provides taxonomy solutions for different applications. This survey identifies ten different applications: ride-sharing system, IPR management, SC management, agricultural system, aircraft system, IoT, e-voting system, academics, education system, healthcare system, and banking system. It also provides a relative comparison of different state-of-the-art approaches to these applications. It highlights different tools and frameworks used for research, open issues, challenges, and future trends of BC to help beginners finalize their research domain and application. The articles reviewed so far are summarized as follows.

Kim et al. [19] showed the usage of BC technology to design a decentralized car-sharing system that ensures the data integrity, security, and decentralized nature for the legitimate users. Zhu et al. [20] introduced BC architecture to protect the originality effectively and also enhance the information trackability. The proposed architecture used the core functions of BC technology that included consensus mechanisms, encryption algorithms, distributed data storage, and peer-to-peer transmissions. Ahmad et al. [21] proposed a decentralized BC-based answer for computerized forward supplychain network measures for the Coronavirus disease (COVID)-19 clinical gear and empowered data trade among every one of the stakeholders engaged with their waste administration in a way that is completely secure, straightforward, detectable and reliable. Liu et al. [22] reviewed literature from years 2011 to 2020 on BC Technologies (BTs) and Information and Communications Technologies (ICTs) in agriculture.

Kuhle et al. [23] analyzed the shortcomings of methods and operational processes in the aircraft industry. Based on the analysis, mapping the BC capabilities and commercial aircraft leasing. The authors in [24] introduced distributed knowledge graph problem in IoT 5G setting. They solved the problem and developed an end-to-end solution by exploring intelligent method and the blockchain management for better matching of the relations knowledge graphs set.

Pasha et al. [25] addressed and identified GST implementation and proposed, GSTChain, as a solution using blockchain network technology. The main objective behind such innovation was to make tax collection transparent and efficient for the government. Huo et al. [26] presented a comprehensive survey on blockchain technology using industrial IoT. Authors discussed benefits, motivations and explored the technical requirements of different BC platforms in industrial IoT applications. Panja et al. [27] proposed a secure technique for an end-to-end verifiable, authenticated and secret ballot election. The proposed system provided a verifiable and secure voter registration and authentication framework. Jaramillo et al. [28] proposed a proposal for academic certification in Higher education and showed different applications of BC technology. The features of BC, such as immutability and traceability, helped track various steps performed during each transaction, thereby making it more secure. Iqbal et al. [29] used machine learning techniques and smart contract and proposed a BC-based Reliable and Intelligent Veterinary Information Management System (RIVIMS).

Cucari et al. [30] discussed a BC related case study on the problems faced by Italian banking sector. They showed the Interbank Spunta project's relevance to interbank processes to provide faster execution, greater data visibility, transparency, etc. The reason why the BC is being used and adopted was because of certain features like decentralization, transparency, immutability, irreversibility, anonymity, open-source, etc. [31]. With wide variety of features in BC and their importance, the authors in [32] presented survey of Blockchain technology's architecture, evolution, security issues and development frameworks. They provided an analysis of various security risks and cryptographic primitives that have been used in BC for safety measures. Despite BC's great potential and advantages, it faced technical constraints too. In Bitcoin, the major concerns for scalability included the frequency of the blocks and the limited size with the total transactions that the network can handle and process were considered to be the problem of scalability [33]. In bitcoin, the network throughput was constrained by the mean block development time of 10 minutes, and the size of a block up to 1 megabyte was considered [34]. Bitcoin's scalability varied with the node's size and was limited to the mathematical puzzle complexity in the network, which was not dependent on the nodes. Hence the transaction processing capacity for bitcoin lies between 3.3 to 7 transactions per second [35]. However, the efficiency and throughput were affected due to the increased size of generated blocks. Different issues of BC, such as congestion problems and transaction delays, etc., had led to the result that BC could not be effectively used for big business trading.

BC faces various challenges regarding privacy, interoperability, selfish mining, energy consumption, security and regulation policy [13] etc. Also, an algorithm such as Proof of Work (PoW) consumes a large amount of electrical energy due to the ability of miners to solve a complex mathematical problem for creating blocks [36]. In Proof of Stake (PoS),

the rich become richer as the winner strategy depends on the highest stake made by the miners [37]. Another drawback includes selfish mining, where miners keep the block private with themselves to gain better revenue [38]. Also, the chain sometimes suffers from a 51 percent attack, where some node gains the majority in the network and then works accordingly. Also, as believed, the BC technology may not be accepted on a large scale by various stakeholders due to the uncertainties with government regulations [39]. Hence, to eradicate such issues related to BC, certain steps need to be taken to make it efficient and be utilized all around the work.

### E. RESEARCH CONTRIBUTION OF THIS SURVEY

This research paper reviews more than 150 papers that discuss the BC technology used in ten different domains. This research mainly focuses on the previous five-year developments done in BC applications to give readers a brief overview. Moreover, this paper also highlights the limitations and the future scopes for each paper. The major contributions of this paper are:

- A detailed taxonomy for BC-based application is presented along with tools used, objectives, limitations, and future scopes.
- Ten different BC-based applications such as academics and education, agriculture, aircraft, banking, car sharing, e-voting, healthcare, Internet of Things (IoT), Intellectual Property Rights (IPR), and Supplychain (SC) are covered in detail. To the best of our knowledge, no survey has covered all the ten applications to date.
- The tools and frameworks used for various researches are also explained and explored with graphical representation using a piechart. The percentage of the papers that uses different simulation tools for their work is also evaluated.
- A detailed taxonomy of BC-based applications' open issues and challenges is shown. In addition, the key takeaways are also discussed so that the readers can get a deeper insight into the technology and carry the further investigation.

### F. ORGANIZATION AND READING MAP

TABLE 2 lists the abbreviations used in this paper. FIGURE 1 shows the definite structure of survey. This survey paper deals with the different state-of-art approaches and is further organized in different sections. Section II deals with the details of BC and its architecture. Section III gives details of different sources of information collection and the selection criteria. Section IV gives information about the different BC applications present around the world. Section V details different tools/frameworks used to build up decentralized systems. Section VI discusses open issues and challenges faced by BC and its applications. Section VII briefs about the key takeaways with a conclusion and future scope.

FIGURE 2 provides a reading map for better understanding of this research paper. Readers interested in the basics of

BC and its overview can focus on Sections I, II, and VIII. Section III gives the in-detail knowledge of steps taken for writing a research paper. The solution taxonomy proposed by the authors for adopting BC in different applications is given in Sections I and IV. Moreover, the details of different tools used in BC are given in Sections IV and V. Finally, Sections I, II, VI, VII, and VIII are recommended for further knowledge about the topic and include open issues and key takeaways too.

## II. BLOCKCHAIN OVERVIEW

BC technology came into existence much later after developing a centralized and decentralized system. Initially, the centralized system provided storing the data on one node, big data management, large network access, processing, availability, and on-demand self-service. But the main disadvantage was that if the data storing node gets corrupted, then full data gets lost [40]. Hence to overcome the disadvantage of a centralized system, the decentralized system came into existence. FIGURE 3 highlights various features of decentralized system. Thus with the advancement of a decentralized system, the need for a secure distributed system also led to the evolution of BC technology.

### A. BLOCKCHAIN

BC is a technology that consists of a chain of blocks. The data cannot be tampered with and is stored in a safe noncentral ledger, which helps to synchronize the environment, thus helping to invalidate all the transactions and making them traceable [41]. It creates a decentralized environment, thereby helping all network users to interact securely. BC is a series of connected blocks where all the history related to transactions can easily be traced using previous nodes, making it trustworthy and transparent. Each node has its unique Identification and the previous block's hash [42]. All transactions are time-stamped and are arranged chronologically to the previous node. Consensus algorithms make BC secure, trusted, and transparent. These algorithms help in adding a new node to the noncentral BC system [43]. FIGURE 4 shows brief BC architectural perspective used for different applications.

### B. BLOCKCHAIN ARCHITECTURE

BC architecture has five modules [43], [44] and a brief description of all of these is as follows:

- Data module: It is used for creating the BC system in the "shared and distributed databases.
- Transaction module: It manages and monitors the transactions in the BC system.
- Block creation module: Blocks are developed by miners and contain a description of transactions present all over the network nodes.
- Consensus module: Consensus algorithms example, PoS, and PoW helps to validate and maintains the consistency of the transactions.

TABLE 2. List of abbreviations.

Acronym	Explanation	Acronym	Explanation	Acronym	Explanation	Acronym	Explanation
5G	Fifth generation	DDoS	Distributed Denial of Service	IPR	Intellectual Property Rights	PoV	Proof of Value
5G NR	5G New Radio	DEMATEL	Decision making trial and evaluation laboratory	IV	Intelligent Vehicle	PoW	Proof of Work
ABVS	Auditable BC Voting System	DISV	Decentralized IoT Solution for Vehicles	IVTP	Intelligent Vehicle Trust Point	PPE	Personal Protective Equipment
ACM	Association for computing machinery	DL	Deep learning	ISI	Institute for Scientific Information	PPM	Provenance-Provided data sharing Model
ACP	Artificial systems + Computational experiments + Parallel execution	DPoS	Delegated Proof of Stake	JPEG	Joint Photographic Experts Group	QC	Quantum Computing
ADAS	Advanced Driver Assistance Systems	DRE-ip	Direct-Recording Electronic with integrity and enhanced privacy	JSON	JavaScript Object Notation	QoS	Quality of Service
AI	Artificial intelligence	DTC	Distributed Time-based Consensus	JVM	Java Virtual Machine	R2	R-squared
Amazon EC2	Amazon Elastic Compute Cloud	DTM	Distributed Throughput Management	L5GOs	Local 5G Operators	RDF	Resource Description Framework
AMOS	Analysis of a MOment Structures	EBRC	Efficient Byzantine Reputation based Consensus	LDB	Local Dynamic BC	RFID	Radio-Frequency Identification
ANTLR	ANother Tool for Language Recognition	ECC	Elliptic-Curve Cryptography	LL	Left-to-right, leftmost derivation	RIVIMS	Reliable and Intelligent Veterinary Information Management System
API	Application Programming Interface	ECDLP	Elliptic Curve Discrete Logarithm Problem	LoRaWAN	Long Range Wide-Area Network	RMSE	Root-Mean-Square Error
ARP	Address Resolution Protocol	ELM	ELMarket	LSB	Lightweight Scalable BC	RTT	Round Trip Time
ASPM	Aircraft Spare Parts inventory Management	ELS	ELStone	LTE	Long Term Evolution	SAMPL	Secure Additive Manufacturing Platform
ASP.NET	Active Server Pages Network Enabled Technologies	EHRs	Electronic health record	MaaS	Mobility as a Service	SC	Supply Chain
ATLB	Authentication mechanism based on Transfer Learning empowered Blockchain	ETH	Ether	MAE	Mean Absolute Error	SCS	Social Credit System
AVISPA	Automated Validation of Internet Security Protocols and Applications.	EVM	Ethereum Virtual Machine	MATLAB	MATrix LABoratory	SDK	Software Development Kit
AWS	Amazon Web Services	FL	Federated Learning	MENA	Middle East and North Africa	SHA256	Secure Hash Algorithm 256-bit
BAAAs	Blockchain Application Areas	FS-ANFIS	Feature Selection based Adaptive Neuro-Fuzzy Inference System	MICMAC	Cross-Impact Matrix Multiplication Applied to Classification	SLR	Systematic Literature Review
BaaS	Blockchain as a Service	FSCs	Food Supply Chains	MV	Mean-Variance	SPSS	Statistical Package for the Social Sciences
BBVS	Blockchain Based Voting System	Geth	Go Ethereum	ML	Machine learning	SSI	Self-Sovereign Identity
BC	Blockchain	GLAM	Galleries, Libraries, Archives and Museums	NIZK	Non-Interactive Zero-Knowledge	SIR	Signal to Interference Ratio
BCMs	Blockchain Mechanisms	GPS	Global Positioning System	NMI	Normalized Mutual Information	SNR	Signal to Noise Ratio
BFT	Byzantine Fault Tolerant	GUI	Graphical User Interface	NS2	Network Simulator Version 2	TISM	Total Interpretive Structural Modelling
BLESS	Blockchain Enabled Social credits System	HBM	Health Belief Model	OCT	Overall Communication Throughput	TPC-C	Transaction Processing Performance Council Benchmark C
BMSCS	Blockchain -based Maritime Supply Chain System	HTML	HyperText Markup Language	OLTP	OnLine Transaction Processing	TPS	Transaction Per Second
BSs	Base Stations	IATA	International Air Transport Association	OPNET	Optimized Network Engineering Tools	TSR	Transmission Successful Rate
BT	Blockchain Technology	ICTs	Information and Communications Technologies	OWL	Web Ontology Language	TTBNCP	Trusted Trade BC Network Cloud Platform
BTs	Blockchain Technologies	IDE	Integrated Development Environment	PBFT	Practical Byzantine Fault Tolerance	UAS	Unmanned Aircraft System
C Hash	C Sharp	IEEE	Institute of Electrical and Electronics Engineers	P2P	Peer-to-Peer	UAV	Unmanned Aerial Vehicle
CFA	Confirmatory Factor Analysis	IoT	Internet of things	PHP	Hypertext Preprocessor	VAT	Value Added Tax
COVID	Coronavirus disease	IoTSec	IoT Security	PHSs	Parallel Healthcare Systems	VE	virtual Environments
CSS	Cascading Style Sheets	IoV	Internet of Vehicles	PoC	Proof of Credit	V2X	Vehicle-to-Everything
CTs	Clinical Trials	IP	Intellectual Property	PoET	Proof of Elapsed Time	VOSviewer	Visualization Of Similaritiesviewer
dApp	Decentralized Application	IPFS	InterPlanetary File System	PoS	Proof of Stake	YCSB	Yahoo! Cloud Serving Benchmark

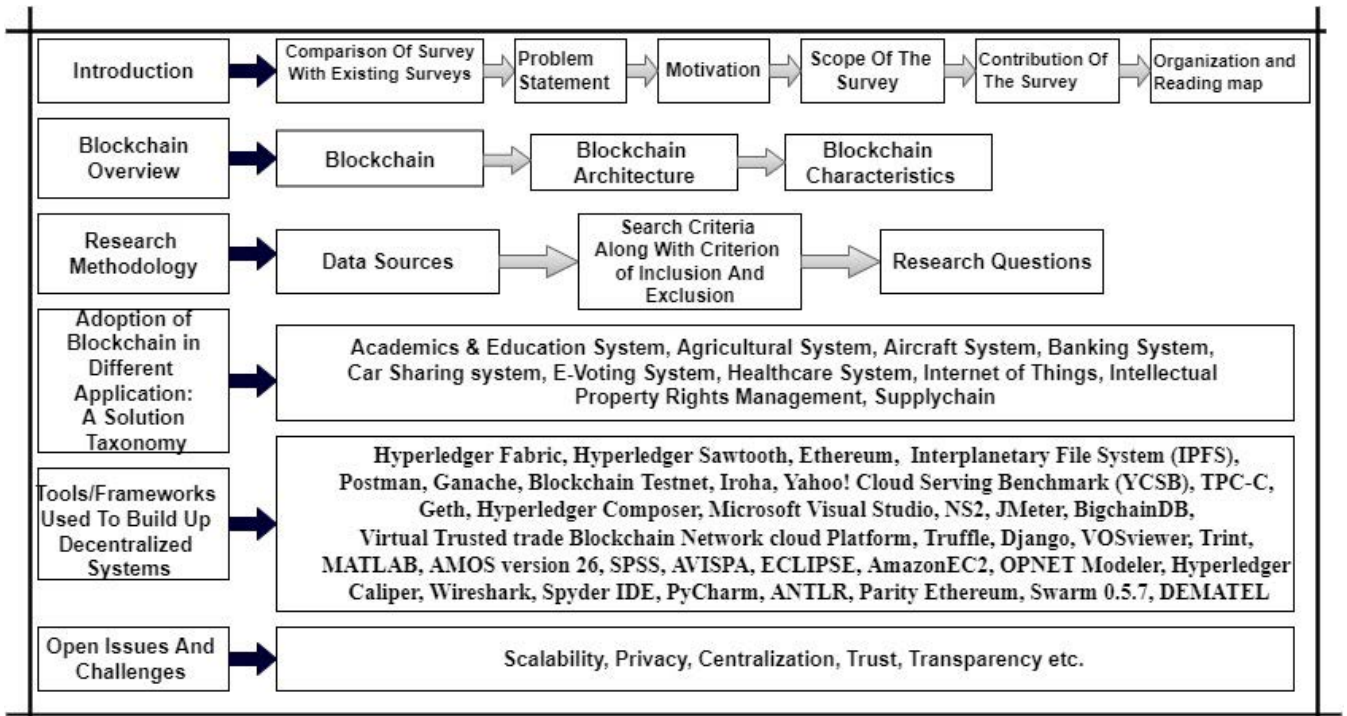


FIGURE 1. Structure of survey.

- Connection and interface module: It tracks the transactions and deals in real-time data on smart contracts.

**C. BLOCKCHAIN CONSENSUS MECHANISMS**

Consensus mechanisms [45] are the procedures used in the blockchain system where different participating nodes conclude about a problem. Different consensus mechanisms used in BC are discussed below:

- Proof of Work: Satoshi Nakamoto, in 2008, suggested Proof-of-Work(PoW), where each participating block solves a given complex mathematical problem. Finally, the node which solves the problem gets the chance to generate the block. However, there is a huge loss of energy and resources here in this process.
- Proof-of-Stake(PoS): It preserves the non-centralized nature of the blockchain system. In the PoS mechanism, the node gets n percent time opportunity for creating a new block only if it has n percent resources. This mechanism saves resources and time for a blockchain system.
- Byzantine Fault Tolerance(BFT): In this algorithm, the validators are present, electing the next node randomly.
- Proof of Authority(PoA): It is designed to designate some set of nodes as the authority that validates the transactions and hence creates new nodes.
- Proof of Space(PoS): It is also known as Proof of Capacity(PoC), an algorithm that gives the nodes proof of their storage and capacity to solve complex problems to generate and validate the next block in a blockchain.

- Practical Byzantine Fault Tolerance(PBFT): This protocol has 3 phases to reach consensus. PBFT algorithms use fewer resources and tolerate big message complexities. Due to this reason, it is used in small networks of blockchain.

**D. BLOCKCHAIN CHARACTERISTICS**

TABLE 3 tabulates different characteristics [43] of non central BC system that are used in different applications. Liu et al. [46] showed the transparency characteristics used in the supplychain management system that helped the customers to track and gain knowledge about the product life-cycle from its manufacture till its distribution. It helped to track the product source as well as any adulteration, if it occurred, in between the process till product supply [47]. Guo et al. [48] used decentralized characteristics of BC in academics and the education system to develop an online education platform of ELMarket (ELM) for better future development and more participation and interaction among students. Garg et al. [49] explored the immutability characteristic in the banking system to keep a check on every transaction with a timestamp to keep a record of every detail. With the advancement in the healthcare sector, Iqbal et al. [29] used the open-source accessibility feature in the healthcare system to provide future prescriptions to patients by saving every detail of previous appointments and prescriptions of patients [50]. Goyal et al. [51] used irreversible nature in e-voting mechanism that helped to save each transaction or vote and cannot be altered by anyone. Smart contracts are the small functions that help in executing small

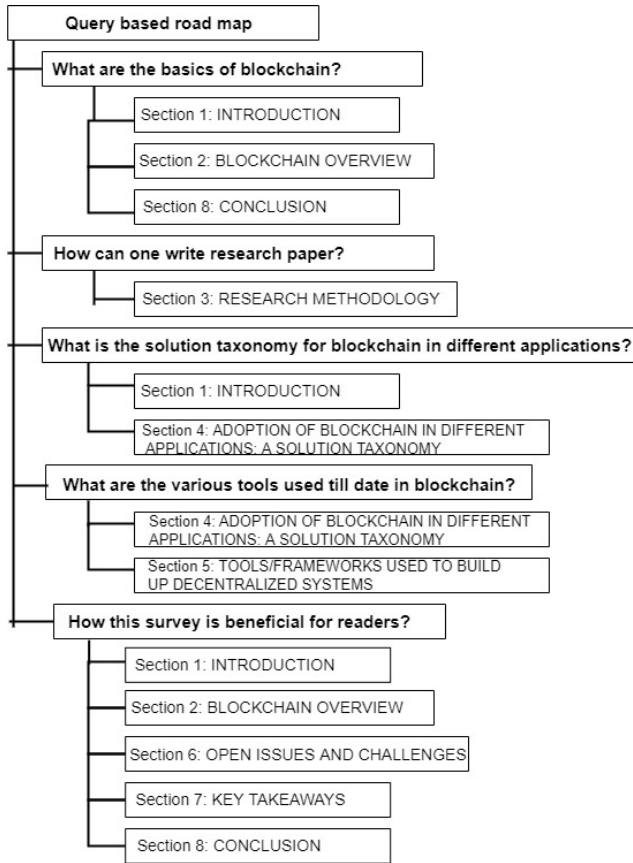


FIGURE 2. Reading map of the proposed survey.

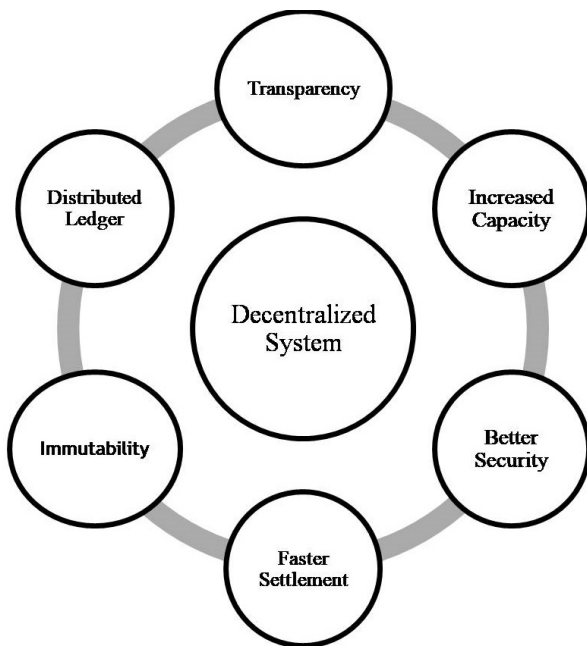


FIGURE 3. Features of decentralized system.

operations. Iqbal et al. [29] in the healthcare management system used smart contracts to operate operations such as scheduling appointments of patients with doctors, paying bills, etc., to ease the burden of healthcare data management.

### III. RESEARCH METHODOLOGY

A systematic study is carried out for the proposed survey, which aims to provide an extensive and systematic literature review of BC adoption in ten different applications. The study proposed the analyses of different state-of-art approaches for ten different applications such as academics and education, agriculture, aircraft, banking, car sharing, e-voting, health-care, IoT, IPR, and SC are carried out. Also, the survey highlights open issues and challenges, along with key takeaways associated with the technology.

#### A. DATA SOURCES

For this research paper, the focus was to include high-quality research and peer-reviewed articles from the reputed databases such as IEEE, Wiley, Elsevier, ACM, Science Direct, Taylor Francis, Google Scholar, etc. The inclusion and exclusion criteria for the selection of papers were chosen from Kitchenham et al. [52], and [53]. Four filtration steps were used to filter 629 articles using the search terms, removing papers published before 2017, exclusion based on title, abstract, and full text to collect 171 papers for this survey.

#### B. SEARCH CRITERIA ALONG WITH CRITERIA OF INCLUSION AND EXCLUSION

The last five year papers were considered to get the current research trend in BC technology. Keywords, title, abstract and full text were the steps considered for paper selection criteria in the proposed work. Extensive work was done in choosing the papers and removing duplicacy from searched items. Many white papers, books about the topic, and websites related to the existing surveys were explored. In this criteria, papers were searched using keywords like BC, SC, and application to collect 629 papers. The first filtration removed publications until 2017, and 415 articles were shortlisted. The second filtration was done based on the title to get the required 367 papers based on BC’s different applications, tools used in BC, open issues, and challenges of BC. While the search still led to many unwanted papers, the third filtration was applied based on the abstract, and a total of 253 appropriate lists of papers were collected. The fourth filtration was applied finally based on full text to include the final list of 171 papers for this research. FIGURE 5 highlights step by step filtration result and study selection procedure that deals with the inclusion of relevant papers for the study and exclusion criteria.

FIGURE 6 explores the year wise distribution of BC based research papers in ten different domains for previous five years. It highlights 18 papers from year 2017, 27 papers from year 2018, 29 papers from year 2019, 27 papers from year 2020, 47 papers from year 2021 and 10 papers from year 2022.

### IV. ADOPTION OF BLOCKCHAIN IN DIFFERENT APPLICATIONS: A SOLUTION TAXONOMY

This section covers work done by researchers in specifically ten different applications, namely academics and education, agriculture, aircraft, banking, car sharing, e-voting,



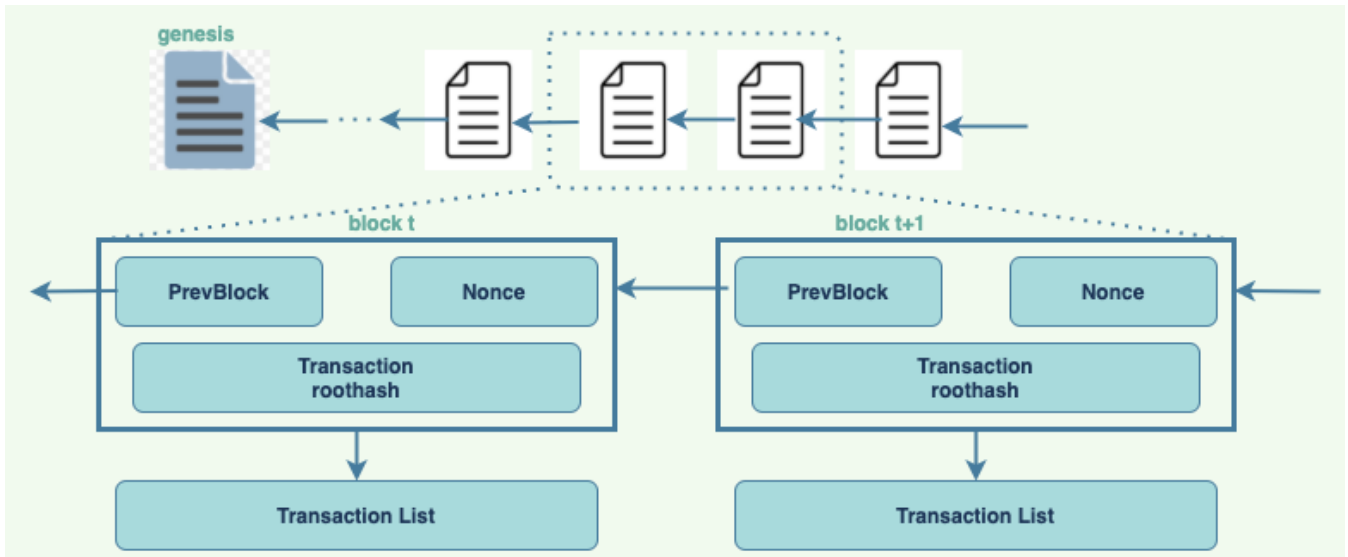


FIGURE 4. A bird-eye blockchain architecture.

TABLE 3. Blockchain characteristics.

Characteristics	Description	Contribution to different Applications
Transparent	Recorded Data on the network is transparent and traceable throughout BC’s lifetime.	BC in supplychain system [47] helps the consumers to track the source of product
Decentralized	The data present in the BC system can be utilized, stored, updated, and monitored on more than one node.	Decentralized online education platform ELM developed in [49] for a better future and more interaction of participants.
Immutable	Due to timestamp facility and controls, it helps record the details.	User’s previous bank transactions with the time stamp helps users and bankers to track all records at any time [50]
Open Source	It provides access to everyone in the network.	Previous checkup records can easily be seen by doctors, and patients [29]
Irreversible	Every transaction that happened to date on the BC system is saved forever and cannot be changed.	The e-voting mechanism developed in [52] cannot be changed without permission.
Smart Contracting	It is a small computer function or program that helps execute contracts in the BC system.	Smart contracts for the healthcare system in [29] helped in executing small operations such as scheduling appointments, paying bills, etc.

healthcare, IoT, IPR, and SC systems. The work done summarized below shows that how BC technology has built trust in these applications and among different stakeholders. Yadav et al. [54] used BC technology as an opportunity to optimize working of land registry records and thus helped built trust. The paper Gupta et al. [45] described the BC mechanism in detail. The article Yadav et al. [55] proposed a framework based on BC that helped in reducing risks related to documents and protected it from any unwanted access. The paper Gupta et al. [56] described the usage of distributed large scale databases that are used to support cloud-based and commercial applications. The paper Yuan et al. [57] aimed at resolving a few problems in the current consensus algorithms such as less transaction per second (TPS) rates, issues related to scalability, and poor node reliability and proposed

an Efficient Byzantine Reputation-based Consensus (EBRC) framework. The paper Kosiba et al. [58] clearly described the usage of smart contracts that allows people to communicate safely and transact without even knowing the third party. Rupa et al. [59] used the Remix platform to create a BC application to manage certificates related to the medical field for Industry 5.0.

Sravan et al. [60] proposed a model that helps in insurance claims validation. Shanker et al. [61] aimed at the development of smart contract and BC network for specific fields of real estate for solving issues of Brokerage service, non-involvement of third-parties, trusty transaction, etc. Han et al. [62] presented a special type of Proof of Stake (PoS) algorithm known as the proof of credit (PoC) algorithm. They explained how the PoC protocol could resist selfish mining

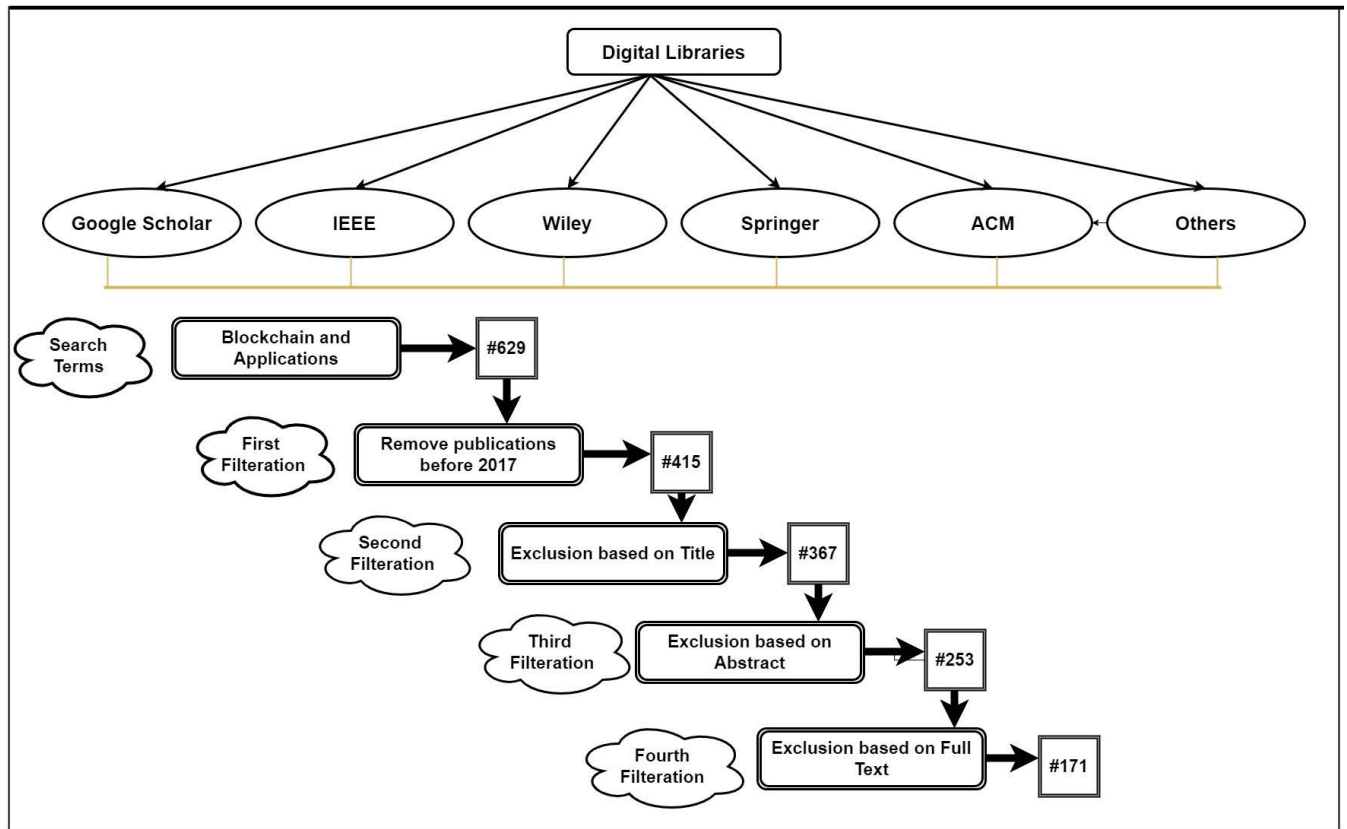


FIGURE 5. Proposed study selection procedure with inclusion and exclusion criteria for papers.

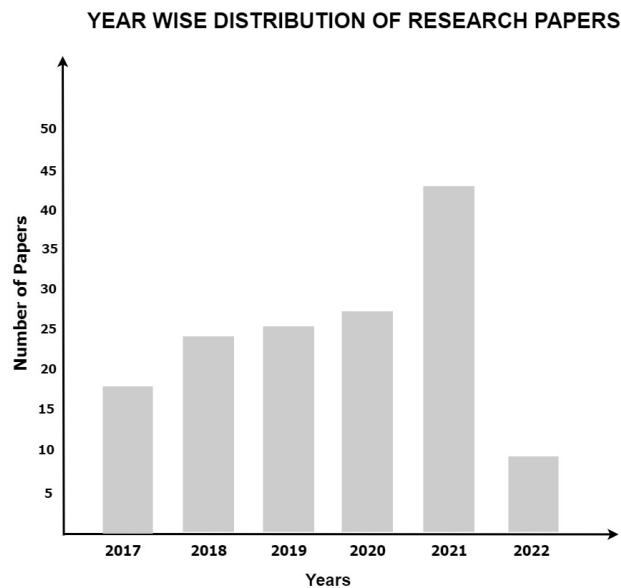


FIGURE 6. Year-wise distribution of research papers.

attacks and double-spending attacks. Xu et al. [63] proposed a BC-based remote arbitrable non-centralized data auditing model for network storage facility. Panja et al. [64] clearly described the problems faced during the e-voting system. The

article proposed an e-voting scheme consisting of two rounds for self-tallying Borda count. Gupta et al. [65] presented a land administration system known as LandLedger, which is based on BC and provided the following characteristics such as transparency, security, accountability, efficiency, and scalability. Alkhodre et al. [66] presented the idea for developing a BC-based Value-Added Tax (VAT) system for Saudi Arabia. Dhall et al. [67] proposed a Bc based framework that helped in reducing vicious news spread on social media platforms. Kaushik et al. [68] elaborates the role of BC in forestalling the pandemics future. Below are discussed a summary of ten different applications that use BC technology. Tables are formulated below to brief about different papers that use the BC for a particular application. FIGURE 7 shows the detailed taxonomy in real-time applications of blockchain deployment in academics and education, agriculture, aircraft, banking, car/ride sharing, e-voting, healthcare, IoT, IPR, and SC.

#### A. ACADEMICS AND EDUCATION SYSTEM

Establishing trust in the academics and education system is one of the major problems faced by the institutions. The involvement of intermediaries often results in data breaches and influences the student’s privacy. In such scenarios, BC is used to prevent tampering with data and build trust among

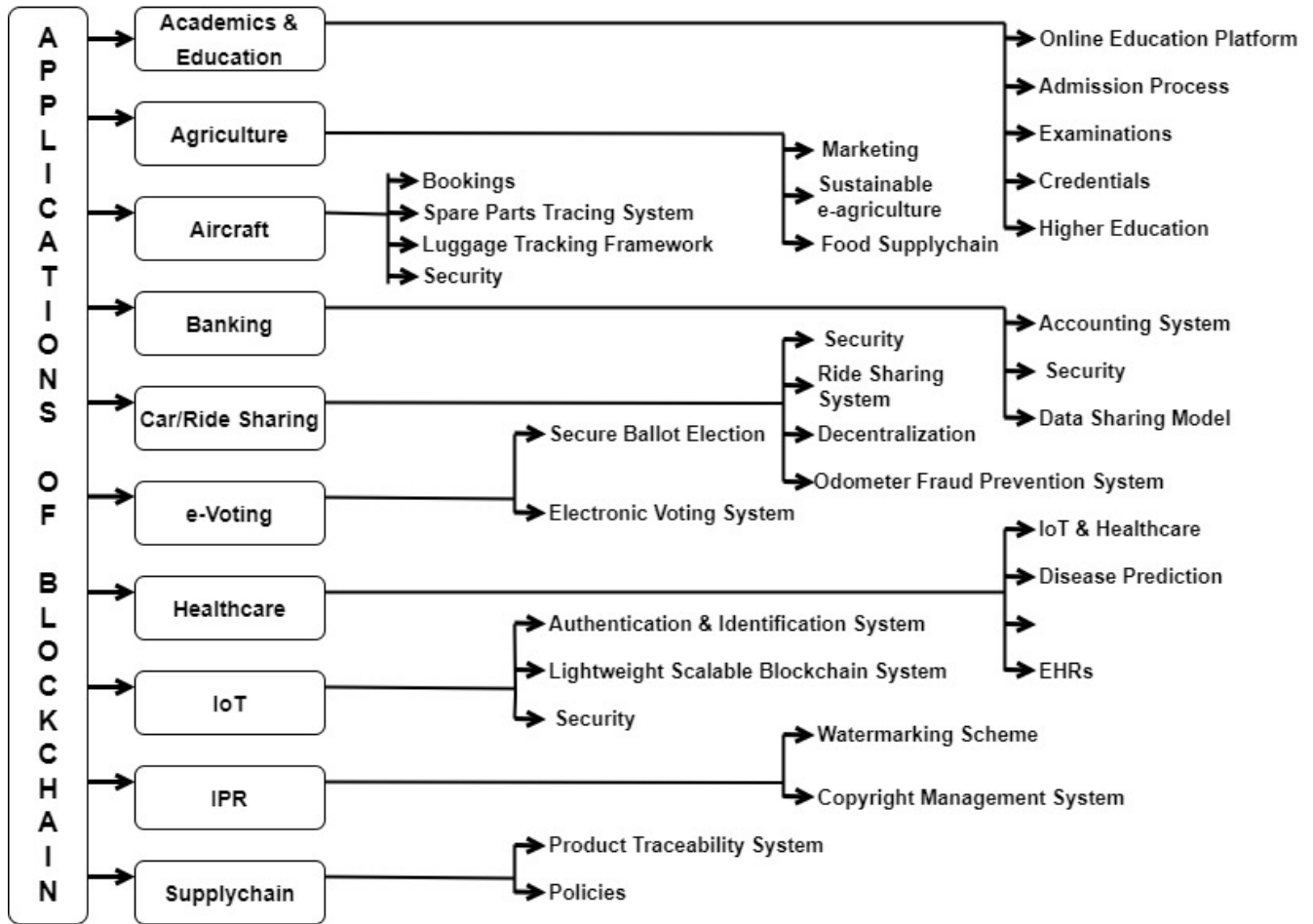


FIGURE 7. Blockchain applications to build trust in society: A solution taxonomy.

the institute, faculty, parents, and students. They help provide distributed storage systems, student data safety, tamperproof data, and accuracy to help students and parents trust the institution. BC removes the involvement of any third party, thus securing the student’s information and hence helps build trust among them. Table 4 shows the relative comparison of state-of-the-art approaches for academics and the education system that helped to build a trusted and secure system. It contains the reputed journals and conferences from the last five years (2017-till date). The summary below elaborates how each paper helped build trust in students and institutions in the academic system by either creating a new proposal for the higher education system or by helping make the system anonymous by not revealing their original identity. Thus all this made the system secure and safe from being attacked or tampered with by malicious users.

Dai et al. [69] proposed a BC-based system architecture and method for student status information management. The model provided an interactive interface for users and the data to complete the query functions. The research provided theoretical and practical results for the application of BC in student status management.

Guo et al. [48] proposed ELM, a decentralized system that aimed to solve the problems of online existing educational platforms. It solved the participant’s non-interaction and protected the educational resources’ copyrights. It used cryptographic measures for safe access of data and distributed storage system along with improved data sharing mechanisms that helps in building trust and efficient collaboration. ELM used Ethereum to build an “Intelligence Chain.” Authors released tokens called ELStone(ELS) on the “Intelligence Chain” to provide an incentive to users. The system also proposed a “Smart Market.” Authors also included several mechanisms of review of users’ behavior, credits exchange, and originality detection. In addition, to store large data, the authors combined relational databases and IPFS. The proposed ELM established a transparent, safe, non-tamper, and efficient online education ecosystem.

Menon et al. [70] presented the paper by explaining the idea of BTs. They expounded on the importance of marketing applications of the technology and the no need for intermediaries in BC that helped in developing trust and reduced cost. They also illustrated with the details of marketing facility that could incorporate the application and concepts in the

**TABLE 4.** Relative comparison of state-of-art approaches for academics and education system.

Authors	Year	Tools Used	Objective	Limitation	Future Scope
Dai <i>et al.</i> [69]	2022	-	Proposed BC based method and system architecture of student status management	Less efficient	Improve efficiency
Guo <i>et al.</i> [48]	2021	Ethereum Inter-planetary File System (IPFS)	Developed ELMarket(ELM), online educational platform	No incentive strategies.	Develop incentive strategy
Menon <i>et al.</i> [70]	2021	-	Enlightened marketing faculty on BC	Verification and transparency in the system is lacking	Manage customer's identity online and transparency
Deenmahomed <i>et al.</i> [71]	2021	Microsoft Visual Studio 2019	Design and implementation of an examination, transcript and certificate system	Less scalable and less secure	Improve efficiency
Jaramillo <i>et al.</i> [28]	2020	Ethereum IPFS	Proposal for Higher Education in academic certification	Not affordable in real time	Improve visual interfaces
Alammary <i>et al.</i> [72]	2019	-	Review of BC-based educational applications	Needs in-depth analysis	Induce partnership between educational institutions
Mohan <i>et al.</i> [73]	2019	-	Summarized academic misconduct problem	Less efficient	Improve efficiency
Arenas <i>et al.</i> [74]	2018	-	Proposed CredenceLedger, for verification of academic credentials	Less secure	Improve privacy and security
Capetillo <i>et al.</i> [75]	2018	-	Review on BC technology	Less in depth analysis	Review more papers
Williams <i>et al.</i> [76]	2018	-	Examined implications in academy by convergence of Artificial Intelligence (AI), data analytics and BC technology	Less in depth analysis	Improve sustainability and efficiency

market. Deenmahomed et al. [71] designed and implemented an examination, certificate, and transcript system using BC. It provided an effective examination and award system that can be used to replace the traditional system. The proposed system is secured, immutable, decentralized, easy to use, provides anonymous trust without revealing his/her identity, scalable and modular. With highly encouraging results, the system faces certain weaknesses too. The proposed system only supports multiple-choice questions. Open-ended and structured questions were not supported. The performance declined with the increasing number of users and smart contracts were more often prone to attacks leading to a decline in the performance of the system.

Jaramillo et al. [28] suggested a proposal for academic certification in Higher education and discussed different applications of BC technology. Due to its decentralized nature, it helped eliminate the involvement of intermediaries, thereby building trust between students and others and make it fit perfectly for digital transformations in various educational firms. The features of BC, such as immutability and traceability,

helped track various steps performed during each transaction, making it more secure. Also, the transactions' encryptions were done to reduce the level of risk. The paper also identified the actors taking part in the process and discussed the process in detail. The benefits and the various challenges regarding the technology used in academic certification were also explained.

Alammary et al. [72] presented a systematic review of 31 articles of educational applications based on BC technology. The paper dealt with the educational applications developed using BC technology. It provided benefits to the educational field using BC features and discussed challenges and limitations in education using BC technology. Detailed analysis and discussion were done for all the topics, respectively. Firstly, it helped in issuing and verifying academic student certificates, shared students' learning achievements and competencies and also helped to evaluate one's professional ability. Secondly, BC brought significant benefits to education, such as lowering costs, secure sharing of students' information, and enhanced transparency and to build

trust among various participants. Third, it showed that BC technology is full of challenges. Before using the technology, policymakers and managers should consider challenges related to security, availability, privacy, scalability, and cost. The review done helped in giving an insight into other educational fields that could progress and benefit from BC technology.

Mohan et al. [73] summarized the extent and nature of the academic misconduct problem. A model is constructed in academia to enlighten the presence of the potential for a Prisoners' Dilemma, where scholars indulge in the academic dilemma. The paper examined the failure of centralized regulatory solutions in the current system and analyzed the features of a decentralized architecture such as anonymity and immutability so as to build trust to use the current system. The paper also highlighted the importance of recent advancements and new technologies in Open Science for misconduct.

The paper Arenas et al. [74] suggested 'CredenceLedger' as a solution to describe the usage of the BC concept on to a specific educational use case using the permission version of BC for non-centralized verification of academic records. The system stores the data related to academics in the BC ledger that can easily be verified by any third party or any of the educational stakeholders. It uses cryptocurrency and without any transaction using BC, the system easily awards a digital version of any student. It allowed other parties, such as employers, and other stakeholders, to privately and independently check the credentials. Secondly, the decentralized part of the permissioned BC made it an effective distribution system for verifying the data in the shared ledger. Also, managing the academic credentials concerning resources consumption, low cost, and high transaction throughputs made permissioned BC an efficient system.

Capetillo et al. [75] discussed the various opportunities for the development of the academic sector. The advancement of BC technology aims to make academic institutions decentralized in nature. Due to the property of ease of access and reliability in BC, innovators wanted to use it for the better upbringing of students and the advancement of the institutions. Few applications had affected "New pedagogy" and "Educational Costs" methods but could not be done due to a lack of technological advancements. Hence many types of research and experiments were being done to use full features of BC technology including trust and safety so as to build an effective and efficient system to protect student's data from manipulating in the educational field.

Williams et al. [76] examined implications in academia by convergence of artificial intelligence, data analytics and BC technology. The system made the universities remain competitive by outsourcing the delivery of courses and assessments. The authors of this paper also examined a mission strategy to move away from narrow academics towards an authentic learning discipline to focus on the overall development of students.

## B. AGRICULTURAL SYSTEM

Earlier, the agricultural system faced many problems in its execution. Due to improper facilities and less knowledge, farmers could not build trust among their consumers. The details regarding product production from scratch and its supply chain were unclear. The involvement of intermediaries often results in increased costs of production and data breaches. In such scenarios, BC is used to protect and store the supply chain data, thus building trust between producer and consumer. They help provide agricultural supply chain data directly to the buyer and also help in reducing agricultural transaction costs. Table 5 shows the relative comparison of state-of-the-art approaches for an agricultural system that helped to build a trusted and secure system. It contains the reputed journals and conferences from the last five years (2017-till date). The summary below for each paper shows each paper's contribution toward building trust in the agricultural sector by either deploying a new system of food supply-chain or by helping make the system traceable and trackable at any point in time. Thus all this made the system secure and safe from being attacked or tampered with by malicious users.

Khan et al. [77] investigated BT for agricultural SC during the COVID-19 pandemic. Many solutions and benefits are identified for the smooth working of agricultural SC. The study used interviews from Pakistan with agricultural companies. The work discovered the seven important benefits of applying BT and four main challenges and their promising solutions. Liu et al. [22] reviewed literature from years 2011 to 2020 on BTs and ICTs in agriculture. The review provided a good basis for learning the combination of BTs and ICTs in agriculture. The review helps to build a sense of security and trust among users to use BC for agriculture purpose as it's distributed storage system and shared ledger helps to find any information of any stage at any time. Mainly the trust in agriculture is build in supplychains where the consumer can verify the details of the product being travelled from different places. The authors in this work had used Institute for Scientific Information (ISI) Web of Science only.

Mavilia et al. [78] analyzed the effect of BC applications in the food supply chain and agriculture by surveying the literature review. They provided key technologies and new tools to different agriculture value chain stakeholders to increase production and improve distribution processes. They demonstrated the importance of BC technology regarding safety and effectiveness in agriculture and also examined South Africa's case. The findings indicated that BC could reshape the agricultural sector by building a sense of security and preventing a food crisis. Moreover, the proposed work also discussed the overall implications, challenges, limitations, and potentials of the applications to be used to build trust in agricultural food supply chains by using BC. Leduc et al. [79] highlighted the importance of the design of digital marketplaces to support the agricultural goods trading between third party stakeholders and farmers. Thus, the authors proposed FarMarketplace, a farming marketplace platform based on BC, to build trust

**TABLE 5.** Relative comparison of state of art approaches for agricultural system.

Authors	Year	Tools Used	Objective	Limitation	Future Scope
Khan <i>et al.</i> [77]	2022	-	Investigated BT for agricultural SC during the COVID-19 pandemic.	less number of interviews conducted	Include other countries for interviews
Liu <i>et al.</i> [22]	2021	-	Review from 2011 to 2020 (ICTs) and BC technologies in agriculture	ISI Web of Science is only used	Include other databases also
Mavilia <i>et al.</i> [78]	2021	-	Analysed agriculture and the food supply chain with BC	Less efficient	Improve efficiency
Leduc <i>et al.</i> [79]	2021	Ethereum	Introduced BC-based farming marketplace, called “FarMarketplace”	Insufficient dataset	Improve accuracy
Bai <i>et al.</i> [80]	2021	-	Based on non-cooperative game proposed a green supply chain framework	Less efficiency	Consider cooperation between greenhouse miners and sensors
Patel <i>et al.</i> [81]	2021	IPFS Remix	Proposed KRanTi, to promote the supply chain of agricultural food	Optimization in overall cost	Evaluate the performance in different heterogeneous environments
Song <i>et al.</i> [82]	2021	-	Investigated relay-aided wireless network for sustainable e-agriculture	Less efficient	Improve efficiency
Orjuela <i>et al.</i> [83]	2020	Jmeter BigchainDB	Designed and developed the platform for agriculture Supply Chain Management	Less efficient	Test again with real productions
Hang <i>et al.</i> [84]	2020	Hyperledger Fabric Hyperledger Composer	Proposed a fish farm platform	Low scalability	Run the Fabric network on a Amazon Web Services (AWS)
Antonucci <i>et al.</i> [85]	2019	-	Review of BC usage in the agri-food sector	Review till 2019	Extend the survey till date
Kamilaris <i>et al.</i> [86]	2019	-	Examined agriculture and food supply chain	Less efficient systems	Improve security and scalability
Lin <i>et al.</i> [87]	2018	virtual Trusted Trade BC Network Cloud Platform (TTBNCP)	Proposed ecological food traceability system	Less efficient	Use script technology of smart contract
Papa <i>et al.</i> [88]	2017	-	Explored the possibilities of BC technology in agribusiness	Less efficient	Improve efficiency

among users to trace and track the food details at any point of time and developed a methodology to help software solution integrates better measure and check the influence of the overall quality of service performance.

Bai et al. [80] designed a Bayesian formula-based scientific game theory model and proposed a green supply chain framework that integrates past experiences with the current scenarios. The model is reliable and trustworthy and inputs data from sensors available. The authors proposed a green data supply chain and developed a trust management system to record the trust values of sensors which improved the trust and transparency of the system. Finally, simulations were conducted to evaluate the performances. Patel et al. [81] proposed a BC-based system, KRanTi, which helped to promote

the supply chain of agricultural food across the 5G network. The authors presented an efficient credit system that helped farmers buy higher-quality raw agriculture products without instant payments. Moreover, a farm-food quality score-based assurance system is also proposed that guarantees optimum quality grading. Transparency, trust and traceability were achieved by creating smart contracts using public ethereum BC. The trust was build by influencing the consumers and buyers to get the knowledge of food product without tampering. The data storage service was facilitated through the usage of the shared storage IPFS that holds all the data from different stakeholders. Thus, results showed that the efficiency of KRanTi was improved from the traditional scheme compared with scalability, Long Term Evolution (LTE) with 5G, packet

failure ratio, cost-quality ratio, BC performance and data storage contrast.

Song et al. [82] presented a relay-aided BC-enabled wireless network for e-agriculture system. It considered signal-to-noise ratio/signal to interference ratio (SNR/SIR) for the best relay selection scheme. Authors evaluated Transmission Successful Rate (TSR) and Overall Communication Throughput (OCT) for the best relay performance. The results showed that OCT and TSR performance ameliorated with the increase in the number of potential relay nodes. Moreover, the correctness of the work was validated with numerical simulations. Orjuela et al. [83] proposed the development and design of a platform using BC technologies to provide a solution for agriculture supply chain management and control by considering the study case of Colombian agriculture negotiation process. The proposed solution eliminated the third-party involvement thus building trust to improve the control over products. The time to time analysis and verification increase more trust among users to use BC for agriculture SC. Also, the developed open platform helped farmers involved and emerging companies to negotiate the goods in an open market. Moreover, the proposed platform was robust, scalable in a horizontal way and could handle a large amount of transactions per second.

Hang et al. [84] proposed a fish farm platform based on BC to provide agriculture data integrity and trust among farmers. The designed platform aimed to provide a tamperproof storage system to fish farmers for storing large amounts of agriculture data so as to reduce the risk of any manipulations for diverse processes of the fish farms by using smart contracts to execute automatically. A proof of concept with the Hyperledger Fabric BC to integrate a legacy fish farm system was implemented on top of the proposed architecture. The usability and efficiency of the proposed system were demonstrated using various metrics through a series of experiments. Antonucci et al. [85] reviewed the BC usage in the agri-food sector. However, the reviewed study mainly focused on architecture and smart contracts that helped to build trust among farmers for BC in agriculture. The study involved in the paper focused on 2019 papers and hence required more in-depth analysis. Kamilaris et al. [86] examined the impact of BC technology in the food supply chain and agriculture and presented existing initiatives and ongoing projects. It discussed overall implications, potential and challenges. The findings indicated that BC is the most promising technology for trusted supply chains for food. However, many challenges and barriers exist, such as technical aspects, policies, education, and regulatory frameworks that hinder the popularity among systems and farmers. Lin et al. [87] proposed an ecological, self-organized, trusted and open food traceability system based on IoT and BTs that involved all parties in a smart agriculture ecosystem. Authors reduced the human intervention by replacing manual verification and recording through the usage of IoT devices for system efficiency. Furthermore, smart contract technology usage helped the law-executor find problems timely thus building trust to get the knowledge or

any detail at any time safely. Papa et al. [88] explored the possibilities of usage of BC technology in agribusinesses. The authors showed that the agricultural sector has a great need for information traceability. Different parameters of BC were also studied on the part of agribusiness.

### C. AIRCRAFT SYSTEM

The aircraft systems are developing daily to comfort their passengers. The aviation industry faced many problems, including inaccurate digital payments and tracking cargo and spare parts. In such scenarios, BC improves the flying experience and prevents data tampering. They help provide distributed storage and safe digital payment systems to help passengers trust aircraft systems. BC removes the involvement of any third party, thus reducing the traveler's expenses and securing the passenger's information. Table 6 shows the relative comparison of state-of-the-art aircraft system approaches that helped build a trusted and secure system. It contains the reputed journals and conferences from the last five years (2017-till date). The summary below for each paper shows the author's contribution towards building trust in the aviation sector by deploying a new platform for airlines or aviation, logistics, helping make the quick credit transaction, tourism, or handling luggage over the cloud using BC. The reviews discussed help researchers gather the overall impact along with features provided by BC in aviation. Thus all this made the system trustworthy to be used for future purposes.

Yadav et al. [89] BT has revolutionised a lot in data storage and encryption systems. The aviation industry has adapted to BT, but still, there is a need for advancement in technology. Yadav et al. [89] discussed various situations related to transaction in the aviation industry using BT. Kuhle et al. [23] analyzed the shortcomings of methods and operational processes in the aircraft industry. Based on the analysis, mapped the BC capabilities, trust and commercial aircraft leasing. The authors analyzed and proposed a BC application design that focused both on the business and regulatory needs and the implementation from a technological perspective. The PoC proposed to help commercial aircraft leasing in asset management.

Ho et al. [90] proposed a BC-based managerial platform using Hyperledger Composer and Fabric that accurately records data about spare parts traceability with organizational validation and consensus to help build trust among users. A data model based on Aircraft Spare Parts inventory Management (ASPM) was determined that help integrate information during transactions. The channel yielded a trustful and useful data-sharing platform to enhance information security and visibility for operational and logistics arrangements between each contracting organization. The BC-based system proposed to improve the quality of traceable and reliable data sharing in the spare parts supply chain. Lopes et al. [91] identified the impact of BC and its various features such as anonymity, trackability and trust on aviation industry. The study presented results from 18 interviews conducted with industry experts. A thematic data analysis and text mining

**TABLE 6.** Relative comparison of state of art approaches for aircraft system.

Authors	Year	Tools Used	Objective	Limitation	Future Scope
Yadav <i>et al.</i> [89]	2022	-	Discussed different transaction situations in the aviation industry	Less efficient	Maximize throughput
Kuhle <i>et al.</i> [23]	2021	Hyperledger Sawtooth Django	Built commercial aircraft leasing of decentralized digital asset management system	Less scalable	Maximize throughput
Ho <i>et al.</i> [90]	2021	Hyperledger Fabric Hyperledger Composer	Recorded spare parts traceability data using managerial platform	physical spaces not used for performance measures	Integrate forecasting algorithms and deep learning (DL)
Lopes <i>et al.</i> [91]	2021	VOSviewer Trint	Studied BC impact on aviation industry	limited generalization of the results	Improve scalability
Yadav <i>et al.</i> [92]	2021	-	Built framework for smart tourism ecosystem	Less scalable	Improve scalability and privacy
Wang <i>et al.</i> [93]	2021	MATrix LABoratory (MATLAB)	Approach to mitigate the threats from accessing the malicious basestations.	Less efficient	Improve efficiency and security
Syed <i>et al.</i> [94]	2020	-	Survey of techniques used for securing Unmanned Aerial Vehicles (UAV) applications	Less secure	Increase security Reduce cost
Alagiah <i>et al.</i> [95]	2020	-	Devised framework for passengers to track their luggage in a live manner over the cloud	Less secure	Increase privacy
Choi <i>et al.</i> [96]	2019	-	Explored global supply chain operations risk with Mean-Variance (MV) approach	No deeper analysis	Improve demand and supply management
Mofokeng <i>et al.</i> [97]	2018	-	Highlighted a future tourism marketing trend through the use of virtual environments.	Less efficient	Can help in growing the tourism wildlife market
Lim <i>et al.</i> [98]	2018	-	Developed Dizistics for new air cargo business flow	Less secure	Increase efficiency in air cargo and transport area
V <i>et al.</i> [99]	2018	-	Detailed description of BC and usage in travel industry	Less descriptive	Include more applications usage
Ebarefimia <i>et al.</i> [100]	2017	-	Investigated the impact of BC technology in enhancing customer loyalty programs in airline business in Nigeria	Research not compared with other developing economies	Research should expanded

concepts were combined to illustrate the likelihood of technology in the aviation industry that affected various stakeholders and replaced current platforms. The overall impact of BC on aviation was analyzed, which helped the industry build trust in BC technology for its users to safeguard the records and distributed data storage facility. The five major topics that determined the adoption of BC by the aviation industry were customer loyalty, specific adoption factors, adoption barriers, the need to replace centralized platforms, and a general lack of awareness. All topics were discussed, and future academic research was also put forward.

The smart tourism concept remained tough to be implemented due to a lack of clarity on the responsibilities and roles of stakeholders. Furthermore, the security of data generated posed huge challenges. Hence, Yadav *et al.* [92] proposed a solution using distributed ledger feature of

BC technology using Ostrom's action arena to examine contractually, information and monetary exchanges between various stakeholders to enable smart tourism and trust. The rapid deployment made the cellular-connected Unmanned Aircraft System (UAS). Severe effects of malicious Base Stations (BSs) depleted 5G New Radio (5G NR). Poor connections between cellular stations and UAS brought unpredictable losses for the public properties. However, Wang *et al.* [93] leveraged BC to detect the malicious BSs that degraded the performance of 5G NR. Authors implemented Practical Byzantine Fault Tolerance (PBFT) to detect malicious BSs in the BC. The approach improved the efficiency of the cellular-connected UAS that access the network efficiently. Authors recommend that they will optimize the efficiency of consensus algorithms and extend the verification efficiency of UAS soon.



Syed et al. [94] provided a survey of optimal techniques that were used for Unmanned aerial vehicles (UAVs) security applications in terms of Machine learning (ML), BC, and watermarking [101]. Furthermore, the authors introduced each technique's advantages and suitability for securing and trusting UAVs applications. Also, the survey discussed various opportunities and challenges of subject applications [102]. The most important activity of the International Air Transport Association (IATA) was to reduce baggage mishandling. Hence smart technologies such as IoT, BC, and cloud were adopted to reduce baggage mishandling. Alagiah et al. [95] designed a system with Radio-Frequency Identification (RFID) tags with proper management reporting systems to deal with the situation to improve the mishandling of baggage. Authors devised a system framework that allowed the passenger to track their luggage over the cloud in a live manner and from any part of the cloud. Thus with trackable efficient system used in aviation the passengers can easily handle their luggage and hence helps to create a sense of trust in passengers.

Choi et al. [96] reviewed on air-logistics and its strategic decisions. The authors explored risk measures of operations disruption and identified the main areas that needed risk analysis to be dealt. They examined different characteristics in the risk management of the mean-variance (MV) theory of air-logistics operations and studied demand management. They highlighted different models related to lead time reduction, explored analytical models, reviewed supply management, explored supply-demand coordination, and discussed the role played by air logistics. Hence for each of the four major areas, the authors discussed the application of BC technology in "demand management," "air-logistics related operations," "supply management," and "supply-demand coordination. Thus authors believed that the paper provided all useful information to both academics and practitioners on MV theory application to conduct risk analysis with air logistics for global supply chain operations.

Tourism destinations seek new ways to increase tourism revenues and market tourism offerings. To highlight a future tourism marketing trend Mofokeng et al. [97] used virtual environments (VE) with BC and provided additional revenue. They suggested that the technology can also be used in the growth of the tourism wildlife market. Lim et al. [98] provided an overview of BC technology applied on Logistics. The authors showed the impact of BC on various air cargo business model through decentralized data and financial transactions, smart contracts, peer-to-peer (P2P) networks, development of trustworthiness for digital records, and real-time data proceeding and exchange.

V. et al. [99] gave an overview of BC with the potential to change the traditional travel industry working. The authors presented a detailed architecture of BC, explaining the working and its key components. Also, they discussed the diverse changes brought in the travel industry in terms of fraud prevention, data protection, and trustful quick credit transactions with the usage of BC. Ebarefimia et al. [100] enhanced

customer loyalty programs by understanding the impact of BC in airline business. A survey was conducted to collect data from the sample population using literature and contextualized based research instruments to achieve the goal. A total of 450 Questionnaires were distributed to managers and customers of surveyed airlines. The respondents had different educational, social, and occupational backgrounds. The research instrument showed positive evidence of validity and reliability. Data were analyzed using percentages, descriptive statistics, and t-test analysis. Hence authors observed the impact on airlines operators in Nigeria, the effective usage of customer loyalty program goals and objectives.

#### D. BANKING SYSTEM

The banking system is one of the most important sectors that constitutes our country's financial development. Banks help people to transfer and save money for the betterment of the future. But initially, the system was unsafe as it involved many intermediaries, often resulting in data breaches and losses. Hence with time, BC came into existence that helped in the easy and safe movement of money among its users. It avoids the need for any middlemen during the transaction and allows people to communicate through a shared ledger directly. This prevents tampering with data and thus builds trust among users. Table 7 shows the relative comparison of the state-of-the-art approaches for a banking system that helped to build a trusted and secure method. It contains the reputed journals and conferences from the last five years (2017-till date). The summary below for each paper shows the author's contribution toward building trust in the banking industry by deploying a new system for safe digital transactions and a reward system for people doing social services. The survey and reviews conducted by authors help researchers gather the overall impact along with features provided by BC in banks. Thus all this made the system trustworthy to be used for future purposes.

Ramchandra et al. [103] assessed the impact of BT in the banking domain. Infrastructure, platforms, channels, and scenarios are the four pillars for successful internet finance. BT ensured a secure and transparent business system. Saheb et al. [104] examined the barriers and organizational values of BC in the banking industry. The authors tried to explain the BC adoption relationships and conducted a mixed-method qualitative study. The study included semi-structured interviews, a two-panel Delphi study, and a systematic literature review to uncover the business values of BC. The study showed that environmental and organizational variables significantly impact the hindrance of adopting BC in the banking industry. The study provided guiding insights to implement BC for managers more effectively in their enterprises to maximize the output. Earlier users remain largely unaware of BC's privacy protection feature. Building on the Health Belief Model (HBM), Raddatz et al. [105] include privacy inertia and concerns to influence consumers' perceptions of BC database benefits. They tried a sample of 304 respondents by incorporating the factors to test the

**TABLE 7. Relative comparison of state of art approaches for banking system.**

Authors	Year	Tools Used	Objective	Limitation	Future Scope
Ramchandra <i>et al.</i> [103]	2022	-	Assessed the impact of BT in the banking sector	Less scalable	More in-depth analysis
Saheb <i>et al.</i> [104]	2021	-	Mixed-method qualitative analysis	Can be extended	Inclusion of more research papers
Raddatz <i>et al.</i> [105]	2021	AMOS version 26	Understood consumer benefits	Privacy concerns	Increase user acceptance
Cucari <i>et al.</i> [30]	2021	-	Addressed case study of real business problems in the Italian banking sector	Limited research	Research can be extended
Garg <i>et al.</i> [49]	2021	SPSS 20 AMOS 26.0	Measured benefits of BC in banking sector	Less efficiency	Optimize the cost
Xu <i>et al.</i> [106]	2020	-	Proposed a provenance-provided data sharing model (PPM) of open banking	Less efficient	Improve security and efficiency
Karajovic <i>et al.</i> [107]	2019	-	Circumspect analysis of the implications of BC in accounting	Less efficient	Improve efficiency
Cai <i>et al.</i> [108]	2019	-	Explored triple-entry accounting	Less in – depth analysis	Triple-entry accounting further examination
Dozier <i>et al.</i> [109]	2019	-	Utilized grounded theory approach to study 12 financial service organizations	Limited sample size	Development of tool to measure Proof of Value (PoV) attributes
Hassani <i>et al.</i> [110]	2018	-	Review of BC's impact on banking	Lack of consensus	Signal extraction techniques in banking
Xu <i>et al.</i> [111]	2018	-	Constructed safe communities based on BC Enabled Social credits System	Less efficiency	Improve transparency
Larios-Hernández <i>et al.</i> [112]	2017	-	BC entrepreneurship opportunity in practices of the un-banked	Less analysis	Needs more in depth analysis

theoretical model. The study revealed that threat susceptibility, threat severity, awareness, and inertia significantly impact the benefits of BC.

Cucari *et al.* [30] discussed a BC-related case study on the problems faced by the Italian banking sector. They showed the Interbank Spunta project's relevance to interbank processes to provide trust, faster execution, greater data visibility and transparency, etc. The authors also discussed new challenges various bankers face and developed several propositions on the topic to guide future research. Garg *et al.* [49] aimed to measure the business benefits in the banking sector of BC technology. Data were collected from 291 respondents, including BC marketing experts, BC consultants, or business heads of banks who advise, consult, or implement BC technology. To check the proposed instrument's validity and reliability, Confirmatory Factor Analysis (CFA) was carried out. The study indicated a good degree of validity and reliability in each construct. The societal and scientific significance of the study based on its theoretical and practical applications was also presented.

Xu *et al.* [106] proposed a provenance-provided data-sharing model PPM for the requirement of open banking. The model employed the programmable smart contracts between

third-party services and users and provided the modifications on the application layer, smart contract layer (logic), and data layer (data content, transaction structure). The proposed PPM model possessed trust, privacy-provided control, transparent authentication, and auditable provenance. The authors showed that the model was an achievable secure system for open banking. Karajovic *et al.* [107] presented the circumspect analysis of BC technology in accounting and its broader industry. The analysis began with a summary of early developers using BC technology to improve business practices. Finally, the paper discussed technology's long-term implications on work. Criticisms were raised throughout the paper to address concerns regarding BC's widespread usage.

Apart from utilizing FinTech and BC, another promising accounting method, triple-entry accounting came into existence. Cai *et al.* [108] explored triple-entry accounting using three case studies. They highlighted that business entities perform a single entry internally and record opposite entries in a shared public ledger for some accounts in the BC ecosystem. Also, triple-entry accounting ensures trust and transparency for current accounting systems. Authors ensured they improved accounting with proper implementation of BC with triple-entry accounting. Dozier *et al.* [109] studied

12 financial service organizations by utilizing grounded theory approach. To create the proof-of-value model, organizations applied a specific process of organizing, understanding, and testing to determine the value of BC. The author's findings had implications for both practitioners and innovation researchers to evaluate BC technology.

Hassani et al. [110] summarized the challenges and opportunities from a banker's perspective and reviewed the impact of BC technology in the banking sector. In addition, the authors also discussed the impact of big data on banking data analytics soon. They showed the importance of signal extraction and filtering for the banking industry. Since selected banks adopted BC technology in small groups or isolation, the authors found the need for extensive research on BC adoption in several aspects of banking to overcome challenges. Xu et al. [111] suggested the construction of trustworthy communities based on a BC Enabled Social credits System (BLESS). The system rewarded residents who committed socially beneficial activities. The BLESS system focused on enhancing the communities and regulating private and business behaviors. The BLESS system leveraged the decentralized nature of the BC network, which allowed individuals in a social credit system (SCS) and provided a tamper-proof network environment. The anonymity in BC records protected individuals from being targeted by powerful enterprises. The usage of smart helped prevent any unauthorized access to the credit system. The BLESS scheme offered a transparent, trustworthy, secure and decentralized SCS. Larios-Hernández et al. [112] studied decentralized BC entrepreneurship opportunity in practices of the unbanked. The authors discussed the importance of BC entrepreneurship for financial inclusion and summarized many results related to the financial and BC-based banking sector.

### E. CAR SHARING SYSTEM

Establishing trust in the car-sharing system is one of the major problems faced by the passengers. The involvement of third parties and intermediaries often results in data breaches and influences the passenger's privacy. In such scenarios, BC is used to prevent tampering with data and build trust [19] among riders by using the P2P protocol. They help provide rental cabs, personal cabs, bike rides, carpooling, and luxury cab services to ease customer life. This protocol allows passengers to book their cabs via an online platform and directly make payments. This removes the involvement of any third party, thus securing the customer's information and hence helps build trust among them. Table 8 shows the relative comparison of state-of-the-art approaches for the car-sharing system that helped to build a trusted and secure system. It contains the reputed journals and conferences from the last five years (2017-till date). The summary below for each paper shows the author's contribution toward building trust in the car-sharing system using BC. Privacy, anonymity or hiding passengers' details, maintaining location privacy, and calculating profit by the drivers of their ride are some of the

significant factors that contribute to the usage of BC in the car-sharing system to build trust among users in society.

Auer et al. [113] explored the effect of BC and IoT together on shared mobility. The authors presented an architecture for a BC-IoT-based platform that combined car leasing and car-sharing. The work also demonstrated that the design of car-sharing platforms depends on the right balance of authenticity, security, privacy, scalability, traceability, reliability, and interoperability factors.

These days, ride-sharing or car-sharing systems have helped urban people resolve their transportation problems [125]. However, the traditional systems were exposed to many security issues earlier due to the unavailability of decentralized systems via a public channel. Kim et al. [19] used BC technology to develop decentralized car-sharing system that ensured the data integrity, security, trust and decentralized nature for the legitimate users. It helped in the authentication of the various participants randomly. The user's privacy was also guaranteed using the user's pseudonym, thereby hiding the real identity and helping develop trust among passengers and users. The car system prevented many attacks and provided authentication and security using automated validation of internet security protocols and applications (AVISPA) simulation, informal analysis, and BAN logic analysis. The proposed rule gave security against offline password guessing, impersonation, replay, and stolen mobile devices. It also provided mutual authentication, anonymity, and confidentiality regarding the information. Finally, the scheme's communication and computation costs were also calculated.

Manjunath et al. [114] proposed a distributed ride-sharing system with a multi-objective optimization problem and solved it with the Ant Colony optimization technique. Authors defined novel performance metrics and analyzed the Spatio-temporal challenges of the ride-sharing system. In-depth experimentation from Chicago showed the proposed solution success rate upto 79.65 percent for ride-sharing. The results were shown better during light traffic hours due to less contention. Furthermore, ride-sharing always reduced the number of taxis available on the road and the total distance traveled by all the taxis. Finally, the results were obtained, and a revenue framework was proposed that analyzed nuances in the operating environment.

Wang et al. [115] proposed a BC-based secure ride-sharing service that not only provided a decentralized structure of ride sharing system but also ensured security, privacy and confidentiality of the information among drivers and riders. It helped in the proper distribution of data among the driver and the customer and kept a check on illegal transfer of the user data. Based on the attributes set for the driver, the proxy re-encryption formula or algorithm was used to depict the correct driver for the passenger, thereby ensuring verifiability, unidirectionality, and confidentiality. This type of system helped in the proper maintenance of data, thereby reducing the risk of customer data leakage. To ensure tamperproof property and data integrity, the improved Delegated Proof of

**TABLE 8.** Relative comparison of state-of-the-art approaches for car sharing system.

Authors	Year	Tools Used	Objective	Limitation	Future Scope
Auer <i>et al.</i> [113]	2022	Hyperledger fabric	Presented a high-level architecture for BC-IoT-based platform for promoting car-leasing and car-sharing	Less scalable	Improve scalability
Kim <i>et al.</i> [19]	2021	AVISPA simulation tool	Modeled decentralized car-sharing scheme	Not applied to real systems	Simulation to a real car-sharing system
Manjunath <i>et al.</i> [114]	2021	-	Proposed multi objective optimization framework based on Ant Colony.	Fail if no taxi present within transmission range of passenger	Apply framework to the Chicago dataset with relations factors
Wang <i>et al.</i> [115]	2020	-	Developed secure ride-sharing system with consortium BC	Less efficient	Propose an attribute-based proxy re-encryption algorithm
Jabbar <i>et al.</i> [116]	2020	Ethereum	Developed an IoT system for Vehicle-to-Everything (V2X) communication challenges	Less efficient	Develop network for users paying for electrical charging through machines transactions
Yu <i>et al.</i> [117]	2020	-	Proposed distributed ride sharing algorithm aiming at addressing the dynamics of taxi topology	Less efficient	Evaluate the Success Rate of nth passenger Model road congestion
Astarita <i>et al.</i> [118]	2019	-	Literature review of application of BC in transportation	Less in depth analysis	More efforts needed.
Baza <i>et al.</i> [119]	2019	Test net of Ethereum	Proposed B-Ride , a decentralized ride-sharing service based on public BC	Less efficient	Improve efficiency
Bothos <i>et al.</i> [120]	2019	-	BC technology for enabling seamless mobility for Mobility as a Service(MaaS)	Less analysis	Needs in-depth analysis
Kato <i>et al.</i> [121]	2018	-	Established a mathematical model of the stationary distribution of drivers	Less efficient	Improve efficiency
Singh <i>et al.</i> [122]	2018	-	Proposed a BC-technology-enabled Intelligent vehicle communication use case.	Less efficient	Improve efficiency
Kanza <i>et al.</i> [123]	2018	-	Introduced cryptotrasnport-a ride-hailing service powered by cryptocurrency and BC	Less efficient	Improve trust an efficiency
Chanson <i>et al.</i> [124]	2017	Ethereum	Presented an odometer fraud prevention system	Less secure	Move the cryptographic part from the application to the dongle itself

Stake (DPoS) consensus mechanism made car-sharing transactions or records stored in the block. The stored data on BC was used for verification if any dispute occurred between rider and driver. The system ensured the credibility of the users and drivers, thus providing a secure and reliable interaction environment. Furthermore, the system's performance measures and the security analysis made it realize that the system was more secure than any other existing system. Hence, the suggested scheme gave certain theories and research value that other researchers could further use to improve the quality of the existing ride-sharing systems.

Jabbar *et al.* [116] suggested new concept named DISV which meant Decentralized IoT Solution for Vehicles

communication. The technique incorporated three basic layers for vehicle communication and BC usage on the Internet of Vehicles (IoV). It also created the smart contracts that were deployed on the Testnet of Ethereum for its feasibility. The study considered several properties like availability, security, and integrity for testing the BC's efficiency and security. The final results displayed DISV as a solution for Vehicle-to-X (V2X) communication challenges such as security, lack of privacy and centralization. It also facilitated the cooperation between cars and their infrastructure and data exchange and involved intelligent transportation system's other actors. Furthermore, DISV also acted as an important part of the Advanced Driver Assistance

Systems (ADAS) that helped improve transportation mobility and safety. Yu et al. [117] proposed distributed ride-sharing algorithm that used asynchronous localized communication and highlighted the dynamics of taxi topology between taxis and passengers. Empirical analysis using Chicago's large-scale single-user taxi ride records showed that the algorithm proposed ensured a success rate of 76 percent in the ride-sharing system and a 97.5 percent as the taxi occupancy rate during peak working hours.

Astarita et al. [118] presented a review about the different applications of BC-based system used in transportation. The important aim of this research was to find the main gaps in the research done so far, current trends and possible future scope. Initially, an analysis was done to overview the topics related to BC and its usage. Regarding the road traffic management and smart cities [126] and the supply chain and logistics, the analysis was done in-depth. Being a new technology, BC found its importance in various fields such as regulatory compliance, supply-demand matching, food track and trace and smart vehicles' security. Moreover, the topic of sustainability with BC was analyzed to reduce exhaust gas emissions, limit the food waste, improve the quality of life and thus favor correct urban development.

Baza et al. [119] proposed a new concept of B-Ride, which was a non-centralized public BC-based ride-sharing service. With the help of BC's feature, B-ride in rideshare service used the property of non-dependency on a third party. Both drivers and riders preserved their journey data in the system, including travel price, arrival/departure date, and pick-up and drop-off location. However, to have a better price and offer for the trip, a customer could make various ride requests and not commit to any single offer, thus making it unreliable. B-Ride used a zero-knowledge set membership proof and a protocol of time-locked deposit by using a smart contract for a ride-sharing system. Hence, both rider and driver had to commit to a booking by sending a deposit to the BC. In this system, a driver must agree upon the departure time that he has arrived at the pick-up location. Using the zero-knowledge set membership proof, the privacy of the data of driver and rider of their pick up location was maintained. Moreover, the pay-as-you-derive method was proposed based on a distance between the rider and driver to ensure fair payment. Also, researchers proposed a trust model that helped the riders to predict the correct driver for their trip by analyzing their past journey details without involving any third party. The system was deployed on the test net of Ethereum to implement the protocol and the results were calculated and summarized.

Bothos et al. [120] presented a progress paper and discussed about BC technology role for enabling seamless mobility for MaaS. The authors provided a brief background on MaaS and BC technology and identified the main contributions of BC in MaaS based on the existed works. Kato et al. [121] showed a scheme that used BC technology for rideshare systems. The paper used a de-centralized authority of BC that matched riders and drivers with the concept that helped the drivers be miners simultaneously. The suggested

system tried to benefit the drivers and find their least probability matching. If a driver mined generously and obtained the least matching probability is less than a matching probability, then the BC rideshare system provided him a great price than does the centralized and conventional rideshare service. Furthermore, the paper used the Markov chain to establish a mathematical formula for drivers' stationary arrangement. It provided the equation that helped the drivers calculate their profit and analyze whether they should be a part of the rideshare system or not.

Singh et al. [122] introduced BC technology to provide trust and security in Intelligent vehicle (IV) similar topologies communication. The authors proposed a BC-enabled IV communication use case. The proposed method comprises the main BC and local dynamic BC (LDB), enabled with a unique and secure crypto ID called intelligent vehicle trust point (IVTP). IVTP ensured the trustworthiness of vehicles. The LDB with IVTP was used by vehicles to communicate with other vehicles. The proposed IV communication was simulated in a common intersection deadlock use case. With an emphasis on real-time traffic, the performance of the traditional BC was evaluated. The authors also introduced LDB branching for IV communication to automate the branching process.

Initially, the trust in the rideshare systems was less due to its less security. Hence to avail trust and secure rides, Kanza et al. [123] introduced cryptotransport, a ride-hailing service along with cryptocurrency and BC service for passengers, which helps passengers to easily and truly choose the origin and destination of their ride by preserving location privacy. Also, the decentralized nature of BC made Cryptotransport riders not rely on any organization and company to manage the system. Chanson et al. [124] presented an odometer fraud prevention system that records Global Positioning System (GPS) and mileage data of cars and saves data on BC. The suggested system users control and own their data with ensured data integrity, thus facilitating data certification. The authors also compared the proposed and the current system and stated the approach's advantages. They also highlighted the limitations of the architecture.

## F. E-VOTING SYSTEM

The traditional voting mechanisms were cumbersome, time-consuming, and lacked trust. The inaccuracy led in these systems often results in inefficiency. Hence for an effective and efficient e-voting mechanism, BC was used to provide accurate outcomes. It mainly helped in end-to-end verification and counting of votes. It does not allow the involvement of third parties, often resulting in data breaches, and prevents tampering with data. It helps provide the facility to vote from wherever the place has an internet connection and reduces the organizational cost. All these characteristics help in building trust in e-voting systems among different users. Table 9 shows the relative comparison of the state-of-the-art approaches for the e-voting system that helped to build a trusted and secure system. It contains the reputed journals and conferences from

the last five years (2017-till date). The summary below shows the paper's contribution toward building trust in an e-voting system using BC. Privacy, anonymity in casting votes, preventing ballot stuffing, end-to-end verification, and casting votes from any place are the major factors that contribute to building a trustworthy and safe e-voting system.

Divya et al. [127] incorporated BC with online e-voting system. The method helped to save the voters' votes into a secure BC. It allowed voters to vote and register for any candidate that they desired. All other voter information, such as the voters' city, name and vote count, was accessible via the website to anyone. The system developed a sense of trust among voters to vote in a safe and secure manner. It also provided a sense of security and denied duplication of votes [141].

The authors in [27] proposed a secure technique for an end-to-end verifiable, authenticated and secret ballot election. The proposed system provided a verifiable and secure voter registration and authentication framework, which thus prevented ballot stuffing attacks. Authors modified the Direct-Recording Electronic with integrity and enhanced privacy (DRE-ip) system so that no adversary can create and post on the public bulletin board a valid ballot without detection. The authors proposed a way of publishing the final tally using non-interactive zero-knowledge (NIZK) proof and secure multi-party computation. Two methods to store these ballots were also proposed using a cloud server and BC. The authors also provided security proofs for the proposed scheme to prove the security properties.

Malkawi et al. [128] presented a BC-based voting system (BBVS) in the country of Jordan for the parliamentary elections system. The proposed system is a centralized and private BC implemented hierarchically, where a voter votes at two levels. The first level is for a group, and the second level is for distinct group members. The authors provided a novel yet secure BC-based e-Voting system that measures the election process's performance, integrity, and accuracy. The research implemented new algorithms to maintain acceptable performance both when creating and casting votes for voters and candidates. Goyal et al. [51] proposed an e-voting system that the Indian Government can use to host the whole election procedure on the digital platform. Authors suggested that all the elections organized by the Election Commission of India would be done through Decentralized Application (dApp). Candidates, too, would file their nominations as per their choice. Organizers had the freedom to accept or reject the request. The voting process's availability made it easier for voters to cast their votes from any place. Also, it allowed voters from other countries to participate, thus increasing the total voting percentage. Since the authors used BC technology for this system, it ensured ease of use, transparency, security, portability, reliability and Trustability.

Huang et al. [129] presented a comprehensive review of voting systems based on BC and classified them based on the consensus approaches used, types of BC and the scale of participants. The authors systematically compared the different voting systems and identified several research opportunities

and limitations. The survey gave an in-depth insight into the utility of BC in voting systems and suggested future research agenda. Khan et al. [130] investigated the BC-based e-voting system to identify the settings for transaction malleability attacks within the system. The authors tried to highlight the conditions that cause an attack on the system to help develop appropriate protection measures. In particular, the successful execution of a transaction malleability attack was presented on a BC testbed hosting an e-voting application. To successfully operate transaction malleability attacks, the experiments identified the significance of block generation rate and network delay and highlighted the directions for future research.

Dimitriou et al. [131] proposed a secure, scalable and practical BC-based voting system that achieved properties expected from large scale elections without requiring much from the voters. Receipt-freeness and coercion resistance were ensured by using a randomizer token for constructing the ballot that acts as a black box for the user. The append-only structure ensured universal verifiability, too, due to BC. Dhulavvagol et al. [132] developed a setup for a private BC network that shares the data among peer blocks within the network. The authors developed a democratic voting application that used BC technology to process and store data and execute transactions; smart contracts were deployed too. Also, the performance analysis of ethereum clients Parity and Geth were carried out by considering consistency, time, and scalability parameters. Electoral fraud has been a major issue for the voting mechanism for ages. E-voting and e-governance are now being used in many countries. Baudier et al. [133] highlighted the major contributions of BC in a trustworthy and secure voting system to provide peace globally. Unfortunately, the technology was tedious and complex and generated conflict between different actors in the election mechanism. Thus, the authors did a qualitative analysis by interviewing BC experts and election observers to identify the technology's weaknesses and strengths. The results depicted the importance of human factors and trust in the voting system.

Abuidris et al. [134] proposed (PSC-B chain), a hybrid consensus model that comprised of Proof of Credibility (PoC) and Proof of Stake (PoS). The proposed model addressed the scalability, efficiency, and latency problems of an e-voting system. Smart contracts were deployed to provide a trustworthy and secure computing environment to ensure the accuracy and safety of the ballot customs. The authors combined the PSC-B chain with the sharding mechanism to ensure the scalable performance of the e-voting system based on BC. Furthermore, discussion on the execution of attacks on the proposed hybrid BC and classical BC were done to analyze the security factor. Pawlak et al. [135] described the use of a multi-agent and intelligent agent system for ABVS, which was based on BC with e-voting process to integrate into a supervised internet non-remote voting system to make it end-to-end verifiable. The system was so developed to enhance safety and security at the polling stations and to generate a sense of non-dependability on client applications for voting.

**TABLE 9.** Relative comparison of state-of-the-art approaches for e-voting system.

Authors	Year	Tools Used	Objective	Limitation	Future Scope
Divya <i>et al.</i> [127]	2022	RemixIDE Ganache	Proposed BC based an online voting system called BlockVoting	Less efficient	Improve efficiency
Panja <i>et al.</i> [27]	2021	IPFS Ethereum	Proposed a cryptographic technique for secret ballot election	Less efficiency	With improved False Rejection Rate design biometric encryption algorithm
Malkawi <i>et al.</i> [128]	2021	Eclipse	Presented voting system for Parliamentary elections in Jordan country	Less scalable for candidate record	Apply mutual exclusion technique for candidates' records
Goyal <i>et al.</i> [51]	2021	Ethereum Remix	Implemented an electronic voting system over digital platform	Less accurate	Combine data with machine learning
Huang <i>et al.</i> [129]	2021	-	Comprehensive review of BC-based voting systems	Less no. of papers surveyed	Extension of survey
Khan <i>et al.</i> [130]	2021	-	Aimed to identify settings for successful transaction malleability attack	Less secure	Develop methods to mitigate against transaction malleability attack
Dimitriou <i>et al.</i> [131]	2020	-	Proposed BC-based voting system for large scale elections.	Less efficient	Security and efficiency can be increased
Dhulavvagol <i>et al.</i> [132]	2020	Ethereum	Proof-of-concept application is developed for E-Voting process	Less security	Improve security
Baudier <i>et al.</i> [133]	2020	-	Investigated the contributions of BC to peace on a worldwide level by securing voting systems	Experts with similar knowledge were interviewed.	More countries should be analysed
Abuidris <i>et al.</i> [134]	2020	MATLAB Amazon EC2 Ethereum	Combined sharding mechanism with the PSC-Bchain hybrid approach to enhance security	Less efficient	Ensure coercion resistance and receipt freeness
Pawlak <i>et al.</i> [135]	2019	-	Used intelligent agents and multi-agent system concept for Auditable BC Voting System (ABVS)	Less efficient	Working prototype to be developed and tested
Suralkar <i>et al.</i> [136]	2019	Ethereum	Developed e-voting system using ring signature and fingerprint authentication	Less scalable	Improve Scalability
Zeadally <i>et al.</i> [137]	2019	-	Explored less focused BC application areas	Sort range analysis	Invest the efforts in ownership, supply chain management
Desai <i>et al.</i> [138]	2019	-	Implemented an electronic voting system for singing competitions	Less efficient	Improve efficiency
Moura <i>et al.</i> [139]	2017	-	Explored using BC for solving transparency and confidence problems in voting system	Needs in depth analysis	Increase efficiency
AboSamra <i>et al.</i> [140]	2017	OPNET modeler	Proposed e-voting scheme to enhance level of ballot security	Less of public acceptance	Real world deployment and testing to be done using SAC e-voting system

Suralkar et al. [136] developed a secure e-voting system by using BC technology with fingerprint authentication and ring signature. The system developed doesn't require too

many individuals at every level, thus making it more verifiable and secured. Zeadally et al. [137] evaluated quantitative perspective of BC's suitability. Zeadally et al. [137] evaluated

quantitative perspective of BC's suitability. Authors explored and considered different applications that didn't receive BC attention. This was done to find the potential of applications to reach the customers for their benefits and market production. With the development of BC, digital services are growing rapidly. BC has gained professional expertise in legal and technical aspects of digital services. Digital services work well, but there has always been a risk to security and privacy. Desai et al. [138] studied this problem of safety and security and resolved it by the usage of BC technology. The availability of the transparent and fair voting system increased only due to BC-based e-voting services. This helped people to transport, cast, and count votes for singing competitions on national television.

Moura et al. [139] explored the possibility of solving confidence and transparency problems of a voting mechanism using BC. First, the authors overviewed BC and elaborated on societal issues and analysis. Then, they analyzed the consequences of adopting BC in the digital government repertoire. They also examined the contribution of technology to matters related to the e-voting mechanism, promoted election transparency and voter confidence, and helped strengthen democracy. Finally, the benefits and potential risks of the technology adoption were also elaborated. AboSamra et al. [140] proposed a secure and auditable cryptographic e-voting system to replace the conventional voting methods of the Middle East and North Africa (MENA) regions to build trust among people and voters towards the voting system. The proposed system is based on a paper ballot Prêt à Voter method e-voting scheme. The scheme used mixed servers to generate anonymous channels. Mixnets needed complex protocols for maintaining shared mix keys. Moreover, Mixnets were vulnerable to corruption and were complex to implement on a large scale. The authors proposed a scheme that eliminated the need to anonymize the votes using anonymous channels in Mixnet-based e-voting. The proposed scheme used paper ballots with strong cryptographic and proven security algorithm features that provided trust, ballot secrecy, security, and verifiability. Threat and security analysis was also conducted to prove the system's resistance to known attacks.

### G. HEALTHCARE SYSTEM

Trust establishment in the healthcare system is one of the important factors to be satisfied. The involvement of third parties often results in data breaches and hacking and influences the patient's privacy. In such scenarios, BC prevents tampering with data and builds trust among hospitals, doctors, and patients. They help provide distributed storage systems, patient data safety, tamperproof data, and accuracy to help patients and doctors trust the healthcare management system. BC helps direct communication among patients and doctors, thus removing the involvement of any third party and hence helps in building trust among them. Table 10 shows the relative comparison of the state-of-the-art approaches for the healthcare system that helped to build a trusted and secure system. It contains the reputed journals and conferences from

the last five years (2017-till date). The summary below for each paper shows the researcher's contribution toward building trust in the healthcare system using BC. Patient data management and storage, clinical trials, privacy, etc., are the significant factors that contribute to a better healthcare system and are protected using BC. The tamper-resistant records and shared ledger helps the hospitals to store data safely and preserve anonymity, immutability, and consensus mechanisms that allow people to trust BC in healthcare. The authors proposed a new architecture for deploying trusted and safe healthcare and reviewed articles to gain in-depth knowledge of BC in healthcare to date.

Azbeq et al. [142] proposed BlockMedCare, a secure healthcare system integrated with BC and IoT. The system helped monitor remote patients and their chronic diseases regularly. The authors ensured three important factors: scalability, security, and system processing time. The security was ensured using the re-encryption proxy and BC, which helped store hash data. IPFS was used to store data in the off-chain database for BC scalability. The data storage process gained speed using Ethereum BC-based PoA. The authors applied the system to diabetes management and showed improved healthcare system results.

Yaqoob et al. [143] showed the usage of BC for healthcare data management. The authors discussed various features of BC, such as immutability, decentralization, data provenance, trust, transparency, distributed ledger and consensus, and programmability, along with the significant benefits in the healthcare department. They also discussed BC's benefits in the healthcare field, such as accuracy, security, interoperability, sharing, handling cost, and global healthcare data audit. The major opportunities offered in the healthcare sector like improved drug traceability, maintaining consistent permissions, patient record management, precision medicine and clinical trials, optimized health insurance coverage, protecting telehealth systems and medical billing systems using BC helped build trust among patients, doctors and hospitals were also discussed. It also discussed several case studies such as the Estonian e-health system, BC for healthcare and pharma data in UAE, permissioned BC for medical device tracking in Swiss hospitals, and patiently DApp solution in healthcare systems. The paper also elaborated on open research challenges like scalability, interoperability, navigation regulation uncertainty, integration of BC with existing healthcare systems, irreversibility and quantum computing, tokenization, ensuring the accuracy of healthcare data, culture adoption, and BC developers. It also outlined several future recommendations like plugging BC technology into legacy healthcare systems, combining BC and artificial intelligence, developing secure smart contracts, IoT-based healthcare systems, and establishing BC policies, latency, and throughput bottlenecks.

Shynu et al. [144] proposed proficient secure medical care services based on BC for prediction of disease using fog computing. For this research, cardio and diabetic diseases were considered. Fog nodes collected patient data and then



**TABLE 10. Relative comparison of state-of-the-art approaches for healthcare system.**

Authors	Year	Tools Used	Objective	Limitation	Future Scope
Azbeq <i>et al.</i> [142]	2022	Ethereum IPFS	Proposed secure BlockMedCare healthcare system	Less efficient	Extend work using Hyperledger Blockchain
Yaqoob <i>et al.</i> [143]	2021	-	Showed BC features and research challenges	Discusses only healthcare applications	BC and AI convergence IoT based health care system
Shynu <i>et al.</i> [144]	2021	-	Fog computing for disease prediction	Only cardio and diabetes diseases considered	Enhance security Hybrid classification models be added
Iqbal <i>et al.</i> [29]	2021	Hyperledger Fabric Hyperledger caliper	Proposed reliable and intelligent veterinary information management system	Only useful for veterinary data	Consider different consensus algorithms Enhance the transaction processing rate
Ray <i>et al.</i> [145]	2021	-	Details of IOT based Healthcare and some usecases	Shows only IOT based healthcare system details	Develop resource-constrained protocol Develop a more compact system
Shuaib <i>et al.</i> [146]	2021	-	Reviewed the applicability of BC-based SSI solution in healthcare	Self-sovereign identity for healthcare is discussed	Can make more secure system for healthcare
Omar <i>et al.</i> [147]	2021	-	Insights of adoption of BC technology in Clinical trials	Low scalable Privacy leakage	Improve Scalability Increase privacy
Tanwar <i>et al.</i> [148]	2020	Hyperledger network Hyperledger Fabric Hyperledger Composer Hyperledger Caliper Wireshark tool Spyder IDE	Explored several solutions for improving current limitations in healthcare system Proposed an Access Control Policy Algorithm	Speed can further be increased	Increase speed
Bhavin <i>et al.</i> [149]	2020	Hyperledger Fabric Hyperledger Caliper	Analysed security architectures for (EHRs) Proposed an architecture for Healthcare	Progress needed	Extend work on heterogeneous environments
Soltanisehat <i>et al.</i> [150]	2020	-	Systematic review on BC-based healthcare systems	Slow speed and latency for frameworks developed	Improve BC based designs
Saha <i>et al.</i> [151]	2020	-	Designed access control scheme for Healthcare security against attacks	Not efficient	Improve efficiency
Alomar <i>et al.</i> [152]	2019	Ethereum	Presented healthcare data management system for patients	Less secure	Handle issues of key-theft/loss mechanisms
Zhang <i>et al.</i> [153]	2019	-	Discussed on some of the main consensus protocols of BC	Less efficiency	Develop better protocols
Agbo <i>et al.</i> [154]	2019	Used bitcoin, Ethereum and Hyperledger Fabric for comparison	Compared the popular general-purpose BC frameworks	Only summary of BC frameworks	Use Hyperledger Fabric for specific healthcare application development
Bhuiyan <i>et al.</i> [155]	2018	-	Proposed a solution to manage individual health data and cross institutional sharing of this information	Less efficient	Knowledge of more real-world usage for implementation
Wang <i>et al.</i> [156]	2018	-	Proposed a framework of parallel healthcare systems (PHSs)	For specific diseases	Build bit patient Improve PHS for more disease treatments.
Sravan <i>et al.</i> [157]	2018	Ethereum IPFS	Proposed efficient and fraud free solution to validate insurance claims	Doesnot evaluate varying trades off between frameworks	Implement on R3 Corda Develop Interoperability protocol
Koshechkin <i>et al.</i> [158]	2018	-	Scope of BC in healthcare of Russian federation	Can provide more details	Details can be extended
Liang <i>et al.</i> [159]	2017	Hyperledger Fabric	Proposed an innovative user-centric health data sharing solution	For specific scenario	Combine both personal health data and medical data together
Raju <i>et al.</i> [160]	2017	-	Briefs data bank using BC technology to govern healthcare and education	Specific for healthcare and education	Develop a proof-of-principle prototype to study the challenges of a real-world implementation

saved it on a BC [161]. To collect the health records of the patients, the clustering algorithm based on the rule was used. Using Feature Selection based Adaptive Neuro-Fuzzy Inference System (FS-ANFIS), cardio disease and diabetics of the patients were predicted. To assess the performance of the work, experimentation and analysis were done on the healthcare data. Normalized Mutual Information (NMI) metrics and Purity helped calculate the results. For predicting the experiment's performance, accuracy was calculated for the work that efficiently predicted the disease.

Iqbal et al. [29] used machine learning techniques and smart contract and proposed a Reliable and Intelligent Veterinary Information Management System (RIMS) based on BC. Using Hyperledger Fabric, a reliable and secure BC-based veterinary clinic system was framed. Secondly, using permissioned - BC technology, predictive analytics modules and smart contract enabled data were developed. To build a prediction model and to uncover the data patterns of the veterinary clinic patient's appointments data, the paper used machine learning algorithms [162]. The prediction helped the veterinary management with future business decisions for better services to their patients. The important tool Hyperledger Caliper was used for working. The overall result of the model was determined by certain machine learning performance measures such as Mean Absolute Error (MAE), R-squared (R2) score, and root-mean-square error (RMSE). Finally, the experimental observations showed the robustness and effectiveness of the designed RIVIMS.

Ray et al. [145] described BC, followed by the discussion on developed consensus algorithms used in BC for e-health. The paper also reviewed different BC platforms for their appropriate use in IoT-based e-healthcare. Finally, the use cases were shown that showed the usage of IoT and BC features in healthcare ecosystems and services. Authors also proposed a data-flow architecture called IoBHealth, which combined BC with IoT, which can be used for storing, managing and accessing e-healthcare data in a more trusted, transparent, secure, and efficient manner. The data stored in shared ledger with tamperproof facility helps in building trust among users. A reliable and secure identity is relevant to providing user services. The traditional centralized identity systems had less security and did not support user control. Thus to provide a secure model for identity, Self-Sovereign Identity (SSI) was proposed. Shuaib et al. [146] reviewed SSI solution based on BC in healthcare, advantages and requirements. Moreover, the authors demonstrated a model use case for SSI applications in healthcare. Omar et al. [147] presented a survey and provided insights for clinical trials (CTs) to adopt BC technology. The authors classified and categorized the literature using taxonomy based on indispensable parameters. Furthermore, the authors provided detailed knowledge of developments toward the deployment of BC in CTs. Finally, the authors discussed several challenges that hindered the implementation of BC in CTs.

Tanwar et al. [148] explored solutions for improving limitations in BC-based healthcare systems that included various

tools and frameworks such as Docker Container, Hyperledger Fabric, Composer, Hyperledger Caliper and the Wireshark capture engine. Furthermore, to improve data accessibility between healthcare members, the paper proposed an Access Control Policy Algorithm using chaincode to implement EHRs sharing system based on hyperledger. Finally, various performance metrics such as throughput, latency, and Round Trip Time (RTT) were also optimized to obtain enhanced results. Bhavin et al. [149] applied Quantum Computing (QC) to the earlier developed encryption systems and studied various security architectures to secure EHRs. Authors proposed architecture based on BC for the healthcare system that allowed users of defined roles to access the database's data easily. Furthermore, during the block creation, the Quantum blind signature was used to protect from quantum attacks of the traditional encryption system using Hyperledger Fabric BC. Finally, results showed the efficacy of resource consumption, transaction throughput and network traffic of the proposed scheme compared to the state-of-the-art schemes.

Soltanisehat et al. [150] conducted a systematic review of 64 articles based on BC healthcare systems. The articles reviewed were published between the years 2016 and 2020. The authors tried to find the different BC applications and challenges faced in the healthcare scheme. The temporal, technical, and spatial aspects of developed BC applications were also found for different healthcare systems. Also, various future research directions in implementing and designing healthcare BC systems were found. Finally, future research directions, such as integrating the BC in cloud-computing solutions, artificial intelligence-based solutions, and parallel BC architecture, were also discussed. Saha et al. [151] attempted to address the need for security for IoT-enabled healthcare applications. The authors designed an access control mechanism to share confidential data using private BC technology within a group of trusted hospitals. The proposed mechanism used the elliptic-curve cryptography (ECC)-based signature. The system's security depended on solving the "collision-resistant one-way hash function" and Elliptic Curve Discrete Logarithm Problem (ECDLP). The proposed scheme protects from different known attacks and preserves "untraceability" and "user anonymity" properties, thus providing a trustworthy system. Finally, the proposed scheme for IoT-based healthcare applications showed better safety and security and required low computational overheads.

The decentralized nature of BC was useful to maintain integrity. But somehow, this feature lacks in maintaining the security of patient-centric systems. Hence, Alomar et al. [152] presented a patient-centric healthcare system to attain security and privacy using BC technology as storage. Various cryptographic functions were used to ensure pseudonymity and encrypt patient data. The authors analyzed the cost-effectiveness and data processing procedures of the smart contracts used in the system. Zhang et al. [153] highlighted a few main consensus protocols belonging to two different categories of the absolute-finality and the

probabilistic-finality consensus protocols. The paper analyzed the strengths, weaknesses, and applicability of consensus mechanisms through comparison and analysis. Finally, the authors concluded and suggested that a good protocol should not only be fault-tolerant but should also be used appropriately for a particular application.

Agbo et al. [154] compared the popular general BC frameworks for healthcare systems that helped health informatics practitioners and researchers to select the viable platform for healthcare applications. The authors highlighted that the Hyperledger Fabric BC framework had complete features for healthcare applications. Also, they suggested testing the framework in terms of latency, scalability, and throughput. Bhuiyan et al. [155] reviewed papers and proposed a solution to manage to share of cross-institutional as well as to maintain the security and privacy of individual health data. The solution was aimed to increase clinical effectiveness and included various stakeholders such as clinics and hospitals, providers, insurance companies, and patients. The system proposed allowed the data owner to be secure and brought trust among different participants.

To increase the effectiveness and accuracy of diagnosis and treatment, Wang et al. [156] proposed a framework for PHS. This system was based on the artificial systems + computational experiments + parallel execution (ACP) approach. The artificial healthcare system was used to model patients' diagnoses, conditions, and treatment processes. The computational experiments implemented parallel execution and evaluated various therapeutic regimens for real-time optimization and decision-making support in healthcare processes. In addition, the authors combined the PHS with BC technology to link hospitals, patients, health bureaus, and healthcare communities for healthcare medical records review, data sharing, and care auditability. Finally, a prototype parallel gout diagnosis and treatment system was built to demonstrate and verify the efficiency of the PHS framework.

Sravan et al. [157] proposed a framework that provided a fraud-free solution to validate insurance claims. The usage of smart contracts helped in transparent transaction system interaction with BC. The authors designed a framework for processing health insurance-related transactions on ethereum using the technology of BC. They used the interoperability concept across different applications using IPFS. For future research, the authors suggested expanding and implementing the model on R3 Corda.

Koshechkin et al. [158] highlighted the importance of closed BC technology in the electronic form to improve the quality of public services quality. The example described of an electronic register of medicines did not require significant costing and was implemented soon. The authors suggested the importance of developing specific application solutions and their usage in the regulatory and production process. Authors seemed to get significant results in data processing by registration and licensing (in CTs), maintenance of specialized registers, quality control of treatment, accounting for medical care provided, drug turnover, arrangement of mutual

payments, remote monitoring of health status, support for decision making, distance consultations, etc.

Liang et al. [159] proposed a BC-based user-centric health data sharing solution using a channel formation scheme to protect the privacy of identity management by utilizing the membership service. The health data was collected from manual inputs and personal wearable devices. The data was synchronized to the cloud for sharing with health insurance companies and healthcare providers. For all this work, the authors deployed a mobile application and preserved health data integrity. Moreover, a tree-based data processing and batching method was adopted and uploaded by the mobile platform to handle large and complex data. For a society to make progress, it is important to have access to universal education and healthcare systems. Raju et al. [160] presented a data management approach called data bank that helped to track an individual's education and health in a personal specified data account. Right to data privacy and right to data portability was placed equally important by the bank design. Authors also believed in developing a proof-of-principle prototype to study the various challenges in real-world implementation to find a link between healthcare and education and the role of smart contracts.

## H. INTERNET OF THINGS

IOT always allows the transfer and exchange of data over the internet for communication. Hence it became extremely important to have a safe and secure IoT. Thus BC technology is used to protect the data over the internet, thus building trust among users. It helps in executing safe machine-to-machine transactions. It helps in creating a tamper-resistant record for the shared ledger. BC helps direct communication among users, thus removing the involvement of any third party and hence helps build trust among them. Table 11 shows the relative comparison of state-of-the-art approaches for IoT systems that helped to create a trusted and secure method. It contains the reputed journals and conferences from the last five years (2017-till date). The summary below for each paper shows the researcher's contribution toward building trust in IoT systems using BC. Transactions over the internet, tamper-resistant records, and shared ledger used to store data help people to trust BC in IoT. The authors created new prototypes containing new layers for data protection, discussed e-commerce, and reviewed articles to get an in-depth knowledge of BC affecting IoT to date. Thus, this made sense of trust for the system to be used for future purposes.

Pal et al. [163] reviewed the critical needs and recent trends for IoT access control solutions based on BC. The work identified many important aspects of BC: secure storage, decentralized control, and sharing information for IoT access control in a trustless manner, along with limitations, benefits, and some future research scopes. Ali et al. [164] presented the importance of BC-based IoT systems. Firstly authors highlighted the privacy issues of the systems and then presented the techniques for privacy prevention. Secondly, federated learning (FL) application was introduced in IoT

**TABLE 11.** Relative comparison of state-of-the-art approaches for IoT system.

Authors	Year	Tools Used	Objective	Limitation	Future Scope
Pal <i>et al.</i> [163]	2022	-	Reviewed the critical needs and recent trends for BC based solutions for IoT access control	Less efficient	More in-depth analysis required
Ali <i>et al.</i> [164]	2021	-	Overview of Integration of BC and Federated Learning for Internet of Things	Privacy concerns	Improve data management and privacy
Weerasinghe <i>et al.</i> [165]	2021	Ethereum MATLAB	Introduced a set of BC based modularized functions which are used to deploy different services for Local 5G Operators (L5GOs)	Low efficiency	Improve efficiency
Mohammed <i>et al.</i> [166]	2021	-	BC in e-commerce	Reviewed only few articles	In depth analysis required
Wang <i>et al.</i> [167]	2021	Hyperledger Fabric1.3	Paper proposed a novel Authentication mechanism based on Transfer Learning empowered BC, coined ATLB.	Low efficiency	Improve efficiency
Alfa <i>et al.</i> [168]	2020	-	Overview of security and privacy concerns of IoT	Less privacy and security	Target practical implementation of BC technology in IoT systems
Hassan <i>et al.</i> [169]	2019	-	Analysed integration of BC technology in IoT	Less secure	Improve privacy
Dorri <i>et al.</i> [170]	2019	Ethereum	Proposed a Lightweight Scalable BC (LSB) that is optimized for IoT requirements	Not explored suitability of LSB in other domains	Develop a prototype implementation of LSB
Dedeoglu <i>et al.</i> [171]	2019	Custom private BC	Proposed a layered architecture for BC-based IoT applications.	Less efficient	Can be implemented on Ethereum and Hyperledger Fabric
Hammi <i>et al.</i> [172]	2018	Ethereum	Proposed a decentralized system called bubbles of trust for robust identification and authentication of devices.	Less efficient	Allow controlled communication between bubbles
Qian <i>et al.</i> [173]	2018	-	Introduced three layers of IoT and corresponding security problems	Identity verification	Improve security and privacy
Minoli <i>et al.</i> [174]	2018	-	Highlighted IoT environments and BC mechanisms for IoT security	Less efficient	Identify IoT applications at the practical level
Buccafurri <i>et al.</i> [175]	2017	Ethereum	Proposed a way to implement a public ledger for IoT applications	Less efficient	Improve efficiency
Shafagh <i>et al.</i> [176]	2017	-	Presented BC-based design of IoT for distributed access control and data management	Less scalable	Improve efficiency and security
Lin <i>et al.</i> [177]	2017	-	Proposed a BC for Long Range Wide-Area Network (LoRaWAN)	Less scalable	Use smart contract script technology to define automated trading model

systems, devised taxonomy, and then highlighted the privacy threats in FL. Finally, IoT-based use cases were presented and introduced the traceability functions based on BC to improve privacy. Also, various open research gaps were addressed for future related work.

Weerasinghe et al. [165] showed different modular functions based on BC, which were utilized for deploying Local

L5GOs. These included bidding techniques, service rating systems, and selection functions used to deploy different features of L5GOs. The exploitation of BC technology ensured secure transfer payments, trust among users, availability, non-dependency on trusted third parties, and many such advantages. Using codes and simulations and then the analysis helped in their proper implementation. 5G is the most viable

and secure technology, but L5GOs were the most powerful among 5G technology. Authors in the research elaborated that BC was the most secure technology that helped consider future media transmission requests. As L5GO was a secure and trusted technology, BC was used using its key features to fulfill the requirements and needs. Authors expanded the L5GOs requirements and various opportunities of BC for the L5GO environment. Challenges along with their solutions were also outlined and suggested. The research proposed BC as a Service (BaaS) architecture simulated on MATLAB tool and Rinkeby Testnet. With the simulations, it was clear that the model was practical, with improved Quality of Service (QoS) contrasted to the real-world framework. Using the web3.js library, a DApp was created, which helped the system measure its functional performance. Upon seeing the results of various performance measures of cost-effectiveness and latency for the suggested system, the research showed that the model was cost-effective and yielded a lower latency.

Mohammed et al. [166] addressed the issues faced by BC-based eCommerce in terms of consumers' satisfaction, supply chain management, payments, retailers' satisfaction, data security, transparent marketplace, new BC business model, efficient management systems, and other related platforms. Authors elaborated 11 submissions accepted and presented guidelines and ideas to provide a valuable resource for eCommerce specialists and educators and stimulate further research. Wang et al. [167] proposed a novel ATLB that helped industrial applications in privacy preservation. For a specific region and to train the user authentication model, ATLB employed a deep deterministic policy gradient algorithm. It was transferred either locally for foreign user authentication or cross-regionally for other regions' user authentication to reduce model training time. Experimental results showed low latency, high throughput, and accurate authentications for Industrial Internet of Things (IIoT) applications.

Alfa et al. [168] did an SLR of 85 articles and showed the importance of security and privacy solutions for IoT. Authors investigated security concerns of IoT concerning pertinent challenges, current trends, applications, security methodologies and research gaps for future directions. Scalable and high-performance cryptographic schemes were suggested to deal with BC-based IoT systems with privacy and data security. Thus, the study provided the basis for evolving decentralized and secure applications in several domains. Hassan et al. [169] discussed various privacy issues and five strategies of privacy preservation in IoT systems based on BC. These preservation strategies include private contract, anonymization, encryption, and differential and mixing privacy. Finally, the authors discussed future directions and challenges faced in BC based privacy preservation of IoT systems and served as a base to develop privacy preservation strategies in the near future.

Dorri et al. [170] proposed a LSB that provided end-to-end security and was optimized for IoT requirements. The decentralized BC was achieved through an overlay network of

high-resource devices. The overlay had distinct clusters and a cluster head that managed the public BC to reduce overhead. The authors proposed a Distributed Time-based Consensus (DTC) algorithm that reduced processing delay and overhead. LSB incorporated Distributed Throughput Management (DTM) algorithm that ensured BC throughput does not deviate significantly in the network from the cumulative transaction load. The approach proposed was resilient from several security attacks, as demonstrated by qualitative arguments. Also, the simulations showed that delay and packet overhead were decreased and scalability was increased compared to relevant baselines.

Dedeoglu et al. [171] proposed a layered architecture for BC-based IoT applications to improve trust between endpoints. The architecture evaluated trustworthiness at the data layer for sensor observations and at the BC layer adapted block verification through the proposed gateway reputation and data trust modules. Finally, the performance evaluation of the data trust module was presented using the gateway reputation module and simulated indoor target localization by qualitative security analysis and end-to-end BC implementation for the architecture. In IoT, different entities exchange and process data without any human intervention. Therefore, to provide authenticity and avoid being the target of malicious users, the entities needed to be recognized. Hence, Hammi et al. [172] proposed bubbles of trust, which was an original decentralized system that ensured robust authentication and identification of devices. Furthermore, it protected data availability, integrity and thus helped in building trust. The proposed approach created secure virtual zones (bubbles), which made entities trust and identify each other. The authors also implemented the mechanism using Ethereum BC and C++ language. Qian et al. [173] introduced three layers of IoT for limiting security risks generated by the technology. These layers were the perception layer, network layer and application layer, and security problems corresponding to three layers were elaborated. Moreover, a BC-based high-level security management scheme for different IoT devices was presented in a full life cycle. The deployment of IoT required end-to-end security less severe. Various IoT applications included video surveillance, Smart Grid, Intelligent Transportation Systems, e-health, insurance, banking, logistics, and contract law. But all these applications needed the support of security in the IoT. Hence, several security approaches and techniques were proposed. The major role for security basis was deployed using BC mechanisms (BCMs) in IoT applications. Minoli et al. [174] highlighted about BCMs and their only part in IoT Security (IoTSec) solution and also presented some important IoT environments where they had their major role to play.

For industry and researchers, IoT appeared to have extraordinary benefits with BC features. However, the participation of IoT devices in shared public transactions enabled various limitations. The problems associated with IoT devices were related to storage capabilities and low computational power. Buccafurri et al. [175] proposed a way to

simulate a public ledger that enhanced the suitability of IoT applications. To ensure transaction security, the protocol leveraged twitter and worked by creating a meshed chain of tweets. Shafagh et al. [176] presented a design for IoT based on BC that brought data management and distributed access control. The design suggested empowering the users with the capability of data ownership and secure data sharing. Authors utilized BC as distributed access control and auditable layer that enabled a resilient and secure access control management to the storage layer. Using a decentralized storage locality-aware system, the authors facilitated the storage of IoT time-series data managed with BC technology at the network's edge. The system proposed was agnostic of the physical storage supports and nodes and cloud storage nodes.

Initially, LoRaWAN was mainly operated by private organizations or companies that brought trust issues between network operations and application customers. Lin et al. [177] proposed a solution and built a trusted, tamper-proof, open and decentralized BC-based LoRaWAN. The architecture proposed helped any server to join the system so as to expand and increase data processing capacity of the system as much as it can. The authors recommended that their work be the first to integrate BC technology and LoRaWAN IoT technology.

### I. INTELLECTUAL PROPERTY RIGHTS MANAGEMENT

Establishing trust in the IPR system is one of the users' major problems. The involvement of intermediaries and third party often results in the loss of original data. In such scenarios, BC provides rights to the owner of the content or property and stores in BC using hashing techniques. This helps to prevent tampering with data and hence build trust among users. Digital copyright data is also stored in blockchain. Table 12 shows the relative comparison of the state-of-the-art approaches for the IPR management system that helped to build a trusted and secure system. It contains the reputed journals and conferences from the last five years (2017-till date). The summary below for each paper shows the author's contribution toward building trust in the IPR management system. Various intellectual properties such as copyright trademarks and patents need protection for further usage and development of society. Thus BC helps to protect the original content of the writers, images, etc., which helps to build trust among participants. The authors created new prototypes for IPR management by using hashing algorithms to increase security against attacks. Thus, this made the system safe and tamperproof to be used for future purposes.

Denter et al. [178] conducted a SLR in certain steps. Authors selected 52 articles as relevant ones out of 714 articles and classified them accordingly to 7D Patent Management Maturity Model. The study contributed to management and scholarship and showed BT mitigated the behavioral and environmental uncertainty. Earlier, the most important achievement was to protect the original documents such as patents and copyrights from hackers and thieves worldwide. Zhu et al. [20] introduced a BC architecture that protected the originality effectively and enhanced the trust and information

trackability. The design used four important layers: data, logic, application, and contract. The proposed architecture used BC technology's core functions, including consensus mechanisms, encryption algorithms, distributed data storage, and P2P transmissions. BC's traceability mechanism helped secure records, trace originality transactions and validate the documents. The experiment used an incentive rewarding mechanism to create and protect the content's originality that helped build trust, traceability, and trackability. Moreover, the comparative analysis and performance analysis showed that the method proposed was more advantageous than other methods.

With the advancement of technology in multimedia and big data, the problems regarding the information, such as data tampering and information leakage, were becoming the major problems. The major problem regarding image security was one of the most typical multimedia problems around the world. Li et al. [179] proposed a BC-watermarking scheme that combined BC technology, compressed sensing, multimedia watermarking, and IPFS. It helped protect the integrity, privacy, and compressed sensed images availability. The scheme helped secure storage of IPFS, confidentiality protection of compressed sensing, and provided tamperproof image protection in big data for data protection and privacy. The compressive sensing was used to protect the images' actual content, and the watermarking process was done in the encrypted domain. The tampered or the changed areas on the compressive images were detected by the watermark, too.

Jing et al. [180] proposed a code copyright BC-based management system. Firstly, an originality verification model based on abstract syntax tree code was constructed. The similarity with the original codes of an uploaded code was used to determine the originality. Secondly, the original code copyright information was stored using the designed Peer-to-Peer BC network. Using the code originality verification model, the originality of the code was verified by the nodes in the BC network. The code copyright management structure was built through legitimacy validation, blocks' construction, and blocks' linking. The whole process guaranteed traceability and tamperproof copyright information. The experiments show the processing time and accuracy of the code originality verification model were shown by the experiments. The experiment showed code fingerprint's best storage type of code copyright information; a 256bits hash value converted from code eigenvalues. It performed better for both response storage and speed efficiency. Moreover, due to the irreversibility and uniqueness of the result from the Secure Hash Algorithm 256-bit (SHA256) algorithm, the code fingerprint storage yielded a better level of storage security.

Soni et al. [181] addressed the biomedical and healthcare industry with BC impact for privacy and security purposes. Based on BC, the authors elaborated on an exhaustive literature review in the biomedical sector. The results showed that the research on biomedical BC applications is an emerging field. The publications published so far

**TABLE 12.** Relative comparison of state-of-the-art approaches for IPR management system.

Authors	Year	Tools Used	Objective	Limitation	Future Scope
Denter <i>et al.</i> [178]	2022	-	SLR on BC supporting patent management	Less papers reviewed	Improve efficiency
Zhu <i>et al.</i> [20]	2021	PyCharm Postman	Developed BC architecture to enhance information traceability	Doesnot guarantee “ingenuity” Privacy protection	Conduct deep analyses for model development
Li <i>et al.</i> [179]	2021	IPFS	Proposed –BC based watermarking scheme	Only for images	Efficiency must increase
Jing <i>et al.</i> [180]	2021	ANother Tool for Language Recognition (ANTLR) JAVA platform	Proposed BC-based code copyright management system	Operational efficiency	Optimizing techniques
Soni <i>et al.</i> [181]	2021	Ethereum	Addressed BC impact on the healthcare and biomedical industry	Secrecy not maintained	Research on large scale applications Increase security
Garriga <i>et al.</i> [182]	2020	-	Presented ChainMaster, to aid solution for architects	Scope of our analysis is limited	Fine-tuning the framework by engaging more experts
Putz <i>et al.</i> [183]	2020	Parity Ethereum 2.7.2 and Swarm 0.5.7	Presented EtherTwin: BC-based Secure Digital Twin Information Management	Less efficient	Improve efficiency
Li <i>et al.</i> [184]	2020	-	Introduced the problems and challenges of privacy protection in BC	Less efficient	Test method under complex scenarios to validate robustness
Esmailian <i>et al.</i> [185]	2019	Questionnaire method	Discussed for design and manufacturing area for protecting intellectual property	Less efficient	Develop efficient mathematical models
Makkes <i>et al.</i> [186]	2019	Hyperledger Caliper Hyperledger Fabric	Presented a hierarchical distributed ledger called Apex	Smaller networks partitioning increase overhead	Improve efficiency
Halloush <i>et al.</i> [187]	2019	-	Preserved intellectual property law and proposed a hybrid model of consortium BC and private BC	Lacking implementation	Implementing the proposed model
Bhowmik <i>et al.</i> [188]	2018	Geth	Proposed a Joint Photographic Experts Group (JPEG)-BC framework for trusted media transaction	Less efficient	Improve privacy and security
Engelmann <i>et al.</i> [189]	2018	Ethereum BC	Explained the usage of digital rights management for the successful transition to Additive Manufacturing methods	Less efficient	Improve efficiency and security
Gürkaynak <i>et al.</i> [190]	2018	-	Focused on possible opportunities of BC with IP law	Less analysis	More review required
Savelyev <i>et al.</i> [191]	2018	-	Focused on legal-related aspects in the copyright sphere	Legal implications	Address multiple legal issues
Ishmaev <i>et al.</i> [192]	2017	-	Argued the practical implementation of BC technology is similar to legal institutions	Less in depth analysis	Improve efficiency
Tsai <i>et al.</i> [193]	2017	-	Proposed a BC based model for microfilms in China	Less efficient	Improve efficiency

confirmed that the research work for the mentioned fields started in 2016 and doubled in 2018 in the first eight months. Integrity, integration, and monitoring of associated patient

data and health records for the first three years were highly relevant. Hence, the authors believed that the study would serve as a framework for demonstration, future research, and

in the biomedical field evaluated using BC and will guide for systemic analysis on daily purpose for research associated progress. Garriga et al. [182] presented a framework to help software developers, architects and decision-makers to make the right decision about the adoption of BC. By gaining knowledge from existing academic-industrial products, literature, experts' feedback and technical forums/blogs, the framework highlighted the relation between architectural features and technological decisions. By dissecting the platforms used behind bitcoin and other top 10 cryptocurrencies, authors showed the framework applicability, a focus group aided by industry practitioners and researchers. Four real-world BC case studies were analyzed from academia and industry by leveraging the framework with the method of architectural tradeoff analysis. Results showed ultimate cutting costs, deeper understanding of the architectural tradeoffs, reduction in time-to-market, allowed more objectively assess of technologies and selection the best to fit developers' needs, and accelerated return on investment.

Digital Twins were the assets of complex digital representations used by different organizations in the Industry 4.0 value chain. With time Digital Twins became widespread and as a result, the need to develop secure data sharing models arose. Decentralized Applications ensured data integrity, availability, and confidentiality but avoided a single trust point. Hence, to minimize the issue of decentralized sharing of Digital Twin data, Putz et al. [183] proposed a decentralized and trustworthy owner-centric sharing model. They developed the prototype using encryption to provide data confidentiality to ensure users' trust. The prototypical implementation, EtherTwin, showed how to overcome implementation challenges of decentralized data sharing, enabling the management of Digital Twin components and their information. The prototype was studied for validation based on semi-structured expert interviews and industry use cases. Li et al. [184] analyzed BC privacy protection mechanism of the application layer, transaction layer and network layer that included encryption technology in transaction layer, mixed currency technology and access restriction technology and malicious node detection in network layer simultaneously. BC security system was built using multimedia data security and distributed communicable network technologies. The authors designed an efficient system for information protection and accurately analyzed the data. The results showed a better data security guarantee in the proposed method.

Esmaeilian et al. [185] discussed various opportunities in protecting Intellectual Property using BC technology in the manufacturing and design areas. The paper suggested a framework for an advanced digital platform and did a survey study to find out why to develop the platforms for product design and to protect intellectual property. The study discussed three main steps of designing purposes: (1) designing specialized utility tokens, (2) defining terms and the smart contracts included in the code, and (3) determining the incentives for every stakeholder using the platform. Moreover, using a questionnaire, the respondents gave their suggestions

about the more affected industry. They explained the role of BC-based intellectual property systems on the development and growth of innovation. Designing an effective, efficient and secure distributed ledger, like Visa, was very challenging. One needed both the security and the speed to work, but it became difficult to implement both properties simultaneously. So to increase the speed and number of transactions occurring in one second, users either break or partition the BC or adjust security. Makkes et al. [186] presented a hierarchical distributed system of ledger called Apex that increased the performance of the system by 1) grouping certain nodes into parallel distributed ledgers 2) limiting the transaction flow system and ensuring security 3) amalgamating blocks of every partition into a separate non-central ledger. System Apex was specially designed for use-cases related to intellectual property rights of the music industry that required transparent and public accounting. An experimental prototype evaluation showed that Apex's speedup scaled linearly in terms of several transactions per second using the tree constructs, thereby declining computing verification cost and latency per node.

Halloush et al. [187] proposed a hybrid model that combined private BC and consortium BC properties that helped to preserve intellectual property practice and law and had the required attribute-based access control mechanism. Using the BC concept, the proposed hybrid model helped solve problems detected, such as authenticity and provenance in Intellectual Property management. The authors also discussed the model in detail and analyzed its benefits and correctness. Bhowmik et al. [188] proposed a framework for JPEG-BC and presented the proof of concept and summarized the infrastructural development for trusted media transaction. The new tamperproof model aided emerging JPEG security and privacy standards. The BC framework helped record the media transactions with important information related to content signature, intellectual property rights, and access control rules. The content signatures were used to verify the image authenticity and integrity generated by low-resolution or compressed sensed samples and low bit-rate compression. The authors proposed that each BC record was connected to a unique hash enclosed in the metadata, contained in a JPEG box-type structure hence building trust among users. They used the case of the Galleries, Libraries, Archives, and Museums (GLAM) sector in their work. The authors maintained the forward and backward compatibility with JPEG and showed that the BC transaction hash is easily mixed within the family standardized by the JPEG committee.

3D printing technology was used as one of the most important innovations worldwide. It became necessary to differentiate between the original and the copied printed components. Based on the complexities and the security of the product, the license became the utmost important criteria in digital media and software. Engelmann et al. [189] used an important technology of digital rights management for the protection of intellectual property and the transition to Additive Manufacturing methods in its commercial usage



implementation. Moreover, risks were identified, and the solutions were presented while developing an 8-partner project named Secure Additive Manufacturing Platform (SAMPL). Gürkaynak et al. [190] suggested possible opportunities related to the future of IP law that BC offered and discussed the impact on the management, registration, and enforcement of intellectual property rights. Authors, too, proceeded with the solutions based on BC to detect counterfeit products to reinforce customs procedures, foster the operation of IP offices and enhance the efficiency of IP rights management. The authors also provided suggestions for BC technology advancement. They provided the way to make technology reach more people with its successful integration into various transaction/registration channels and services.

Savelyev et al. [191] focused on legal-related aspects of copyright in the application of BC technology. The challenges in the digital environment for the distribution of copyrighted works, their solution and associated issues that needed to be addressed were outlined. Ishmaev et al. [192] argued about the practical implementation of BC technology that could be considered a property similar to legal institutions. Invoking Hegel's system of property rights and Penner's theory of property and using the bitcoin example made it possible to depict that BC efficiently implemented all-sufficient and necessary criteria for a property without relying on legal means. BCs helped enforce exclusion rights and provided universal access to discoverability and knowledge about property rights and system functionality by eliminating third-party authority. The work highlighted that BC models can replace traditional property relations in society and can be used to be implemented in new domains. Microfilms were popular due to their low cost of production. However, the IP rights of microfilms were violated as they could easily be copied and transmitted through mobile devices. Tsai et al. [193] proposed for microfilms, a BC-based IP protection model. Information registered was tamperproof and provided IP protection thus build trust among participants. The work done was based on BC for microfilms in china.

## J. SUPPLYCHAIN

Trust in the SC management system became an important issue to be resolved. The involvement of intermediaries and third parties in the SC, from raw material production to final product development, often results in data breaches. In such scenarios, BC is used to prevent tampering with data and build trust among users and the system. They help provide a shared ledger with complete transparency and visibility, tamperproof data, and timestamped transactions to help companies query anything at any time. Table 13 shows the relative comparison of the state-of-the-art approaches for supply chain systems that helped to build a trusted and secure system. It contains the reputed journals and conferences from the last five years (2017-till date). The summary below for each paper shows the author's contribution towards building trust in supplychain management systems such as rice sc, medical equipment sc, etc. The authors had created a new architecture for sc to

trace and track the products at any location at any point in time. The shared ledger use of hashing algorithms increased security against attack, and the anonymity helped different participants to trust the system. Thus, this made the system safe and tamperproof to be used for future purposes.

Agrawal et al. [194] presented a BC based network that allowed manufacturers to monitor the drug effectively in SC with trust, improved transparency and security throughout the process. The study proposed forward and backward SC mathematical models to help minimize the time and cost to transfer the drug by the manufacturing company to the end-users. Specifically, a reliable transport model in the forward chain helped drug delivery from the manufacturer to the customer in less time developing trust among users. The backward SC model focussed on reducing the extra cost and time of the manufacturer to recall the defective drug. Moreover, a real-time implementation using Hyperledger Composer was done to depict the system's transparency.

In Kouhizadeh et al. [195] research, the innovative structures were used to judge BC appropriation hindrances. A far-reaching outline of barriers to adapting BC innovation to manage maintainable supply chains was given. The hindrances were investigated utilizing environmental, technology and organizational supply chain and external structure, followed by contributions from industry and academics experts, and analyzed using the DEMATEL tool. Outcomes showed that the technological barriers and supply chain were the basic obstructions for the two specialists. The authors further decided on the differences and similarities among scholastics and professionals in seeing the boundaries. The exploratory examination uncovered intriguing relative significance and interrelationships of important, practical and theoretical boundaries. The principal key result of this research was that the authors examined the hindrances using causality and accuracy. This helped them to manage both resources and time available to them. Besides, the examination fostered a few recommendations proposing significant links between technological and external concepts and ideas for BC selection. Thirdly, the work endeavored to systematically research and focus on the barriers to technology adoption in feasible supply chains.

Significant attention has been gained by BC technology in the food industry; however, the steps to implement food supply chains (FSCs) using were still missing. Vu et al. [12] did a systematic literature review of 69 articles and discussed current BC issues of scalability, incentivization, privacy and regulations as future opportunities for research. The authors developed a three-stage conceptual framework for FSCs based on BC. The proposed framework established the suitability of BC for the wider supply network to benefit food chain managers. Identified implementation stages, influential factors, and case examples were expected to develop a roadmap to adopt BC in the food industry to guide practitioners. Liu et al. [46] conducted an industrial investigation and a comprehensive literature review to clear the current status, challenges and problems of the BMSCS. The authors

**TABLE 13.** Relative comparison of state-of-the-art approaches for supplychain system.

Authors	Year	Tools Used	Objective	Limitation	Future Scope
Agrawal <i>et al.</i> [194]	2022	Hyperledger Composer	Presented a BC-enabled network that allowed manufacturers to monitor drug in SC effectively	Less efficient	Improve efficiency
Kouhizadeh <i>et al.</i> [195]	2021	Decision making trial and evaluation laboratory (DEMATEL)	Theoretically explored adoption barrier in BC	Looked only at a snapshot	Further studies are needed
Vu <i>et al.</i> [12]	2021	-	Review of 69 articles and implementation framework in food supply chains	Reviewed less of articles	More papers can be surveyed Strengthen sustainability
Liu <i>et al.</i> [46]	2021	-	Proposed BC-based maritime supply chain system (BMSCS)	Research is rare on maritime.	Systematic consideration for coastline
Collart <i>et al.</i> [196]	2021	-	Review on BC technology in the fresh produce supply chain	Economic feasibility analysis lacking	Evaluate economic feasibility of BC applications
Mathivathanan <i>et al.</i> [197]	2021	-	Paper identified the adoption barriers and interrelation	Lack of business awareness	Companies map BC with business
Ahmad <i>et al.</i> [21]	2021	Ethereum IPFS	Proposed BC solution for forward supply chain medical equipment processes of COVID-19	Privacy and security.	Develop incentive system for hospitals to dispose off medical waste.
Omar <i>et al.</i> [198]	2020	Remix Ethereum IPFS	Proposed generic framework for adopting a BC-based solution for Personal Protective Equipment (PPE) supply chains	Data related to PPE only. Smart contracts needs modification	Design decentralized applications to fully automate the PPE supply chain
Dutta <i>et al.</i> [31]	2020	-	Survey using 178 articles to examine the research done in BC integration in supplychain operations.	Low data integrity Low data privacy	Improve scalability Improve security
Durach <i>et al.</i> [199]	2020	-	Studied BC applications in Supply-chain transactions	Study limited to applications only.	Study the redistribution of power and trust
Wang <i>et al.</i> [200]	2019	-	Investigated BC's influence on future supply chain policies	Excluded certain BC articles	Research should add more empirical evidence
Schmidt <i>et al.</i> [201]	2019	-	Showed utilization of the transaction cost theory to check the future supply chain relations	Theoretical examination of BC in a context of supply chain relations	Topic should be extended
Leng <i>et al.</i> [202]	2018	MATLAB	Proposed BC of agricultural supply chain system	Couldnot consider real situations of carbon emissions etc	Improve efficiency and speed Develop method of selective incentive strategy
Kim <i>et al.</i> [203]	2018	Ethereum Truffle	Developed case for ontologies contributing to BC design.	Limited BC provenance capabilities	Convert Web Ontology Language (OWL) and Resource Description Framework (RDF) into BC-compliant representations.
Kshetri [204]	2017	-	Presented the use of BC in supply chain activities	Implementing BC solution is complex.	Improve security and trust
Kumar <i>et al.</i> [205]	2017	Smart contracts	Proposed rice supply chain system for safety of rice	Low efficiency	BC for every food supplychain
O'Leary <i>et al.</i> [206]	2017	-	Investigated different BC architectures for different applications	Less privacy	Usage and cost analysis Include sentiment analysis
Ruta <i>et al.</i> [207]	2017	Iroha	Introduced semantic-enhanced BC platform for flexible object discovery.	Less efficient	Advancement of product management

proposed an integrated BMSCS and constructed new operation mode management for a maritime supply chain that was expected to be suitable for global economic development. Moreover, the main aim was to accelerate the application of BC, achieve better coordination among members, and gradually realize the intelligent operations of the maritime supply chain was mainly based on a comparison of the current research results and suggestions put forward.

Collart et al. [196] reviewed applications of BC to help address major challenges faced by the US fresh produce industry across different directions. The challenges included food-related factors such as food loss and waste, food safety, food fraud, and the need for better traceability systems. The authors highlighted the challenges and limitations of various stakeholders and discussed the utility of BC technologies to enhance the resilience of the produce supply chain. Using Cross-Impact Matrix Multiplication Applied to Classification (MICMAC) and Total Interpretive Structural Modelling (TISM), Mathivathanan et al. [197] examined their interrelationships for the adoption of BC and identified the adoption barriers for the need to revolutionize supply chains. The TISM technique was used to identify the influential barriers and support the development of a structural model based on contextual relationships. Based on dependence and strength, MICMAC classified the barriers to BC adoption. The results indicated the most influential barriers, lack of knowledge for familiarity with BC and business awareness, impeded BC adoption for future supply chains.

Ahmad et al. [21] proposed a decentralized BC-based answer for computerized forward supply chain network measures for the COVID-19 clinical gear and empowered data trade among every one of the stakeholders engaged with their waste administration in a way that was completely secure, straightforward, detectable, and reliable. They created four smart contracts and proposed five algorithms to execute all functionalities and trigger events and notices. They coordinated the ethereum BC with IPFS to safely get, store, and offer the information identified with the forward supply chain network of COVID-19 clinical equipment and the waste administration. They created algorithms to characterize association rules regarding COVID-19 waste dealing with and punishments to be forced on the partners in the event of an infringement. They suggested a framework plan alongside its full execution details to assess the performance utilizing an analysis of cost. The analysis done for the security purpose was to confirm the dependability of the smart contract to present the solution from an application point of view. They additionally thought about the proposed approach in contrast to realized weaknesses utilizing the SmartCheck programming. The suggested approach was nonexclusive and pertinent to different use case situations with negligible changes.

Omar et al. [198] talked about the impact of the COVID-19 pandemic on medical services inventory network activities, especially in following and overseeing Personal Protective Equipment (PPE). To manage transactions and orders in a decentralized network, they introduced BC-based

PPE solutions using Ethereum smart contracts to build trust. The focus was on the PPE supply chains and suggested that the proposed framework could also be adjusted to address detectability needs in other business areas. Utilizing Ethereum intelligent functions could be used to accomplish obvious mechanization and decrease data unevenness and different failures in the supply chain measures. Author's coded in the Remix environment and made it freely accessible on Github. The assessment, cost, and security examination of the proposed framework have featured its practicality in a real-time environment, tending to detectability challenges efficiently. It also clarified the partners, consequently expanding their correspondence and trust. Receiving a BC-based answer for PPE supply chains was monetarily practical and gave a secure, trusted, and straightforward method of post among different partners.

Dutta et al. [31] studied 178 articles and examined the research done in supply chain (SC) operations with BC technology. Major current state-of-the-art technologies, corresponding opportunities, and possible societal impacts were highlighted, along with major challenges and trends. Several industrial sectors such as manufacturing, healthcare, shipping, automotive, finance, aviation, e-commerce, technology, agriculture and food, energy, and education were examined to revamp BC technologies through business process management and visibility successfully. A future research agenda was also established for further studies that laid the foundation for the emerging research area. Durach et al. [199] discussed BC application areas (BAAs) in SC transactions with their relevance in businesses. The study combined a Delphi study, an extant literature review, and a survey of 151 equipment sector business managers and German machinery. The results extended the study of SC transactions with BCs' business opportunities and extended Iansiti and Lakhani's (Harvard Business Review 2017; 95: 118) BC framework. The most important BC usages in SC transactions were product quality certification and verified customer reviews. Interestingly, authors anticipated less adoption of BCs for document-signing processes. Delivery and logistics systems and token-curated registries were ranked among the topmost relevant. The study of BAAs advanced theory and affected business strategies of when, where, and why the businesses should participate in networks of BC.

Wang et al. [200] showed the BC innovation impact on future supply chains and arrangements. The work distinguished the fundamental drivers of BC organizations inside supply chains. It exhibited a portion of the innovation's most recent applications and a scope of organizational, technological, and operational challenges that probably influenced its further dissemination. The supply chain procedure was especially keen on the BC feature that helped control the method without using any centralized authority. This component was of extraordinary interest since it worked to resolve issues related to the inter-organizational trust. The research was quick to inspect the present status of BC usage inside supply chains. The authors tried to combine the generally

incoherent studies distributed on BCs to clarify their relevance to the supplychains discipline. The research not just pinpoints regions where BC innovation may disturb existing supply chain arrangements but also features certain difficulties and obstructions to the technical deployment. Authors offered the experts and researchers significant bits of knowledge into distinguishing a utilization case that tended to a supply chain issue, operationalizing the ideal BC supply chain model. They focused on lawful and administration issues for long-term manageability. The discoveries alarmed administrators, especially the organizational members, of the need to support network connections among individuals and foster a common worth among all individuals.

Schmidt et al. [201] utilized transaction cost theory to find BC influence on relations of supply chain. With the set of eight propositions, two primary findings were yielded. First, BC reduced governance and transaction costs for supply chain transactions. Specifically, it was found that BC reduced information and search costs. Second, a BC-based economy significantly pushed many transactions into governance and market-oriented structures. More ad-hoc partnerships and short-term dynamic relationships challenged already established findings of supply chain processes and structures. Also, the authors explored future research areas for how BC built a supply chain management system. Leng et al. [202] proposed a public BC based on the architecture of a double chain for agricultural supply chain system to solve the challenges faced in the Chinese public service platform. The study mainly focused on the storage mode and dual chain structure, consensus algorithm, matching, and resource rent-seeking mechanism. The results showed that the chain proposed helped in security and openness for transaction information privacy and adaptively completed matching of resources and rent-seeking, and enhanced the overall efficiency and credibility of the public service platforms for the system.

Kim et al. [203] elaborated the need of ontologies to BC design. The work analyzed the traceable ontology and translated its few representations into smart contracts that helped enforce traceability constraints and executed provenance trace on the Ethereum BC platform. As a proof of concept, the source code on Ethereum BC was written and assessed. The data models and the excerpted assumptions of the TOVE Traceability Ontology were analyzed and were used on BC to develop the distributed ledger. Also, the authors translated TOVE Traceability Ontology axioms into smart contracts used in first-order logic that helped enforce traceability constraints and executed provenance trace on the Ethereum BC platform. Kshetri [204] examined the impact of BC on the various objectives of supply chain management, such as cost, flexibility, speed, quality, risk reduction, dependability, and sustainability. The authors presented evidence linking BC with supply chain activities to increase accountability and transparency. For diverse purposes and at various phases of development, the case studies of BC projects were discussed. The study evaluated the mechanisms adopted by which supply chain objectives were achieved

using BC. To validate assets' and individuals' identities, the authors also emphasized incorporating IoT with BC and its deployment.

Kumar et al. [205] presented a theoretical study on the BC technology and evaluated the benefits in the business practices. An example demonstrated the utility of BC technology on product safety in supply chain management. The example dealt with the rice supply chain. It showed the increase in the efficiency of the rice supply chain with a traceability system that helped record the events that happened and monitored the security and quality of rice. Hence the BC system helped to fight fraud, ensured integral traceability, and minimized the system errors. O'Leary et al. [206] investigated different BC architectures with alternative configurations to process and gather transactions for accounting, supply chain, auditing, etc. Apart from public versions and peer-to-peer BC, authors primarily focused on private configuration and cloud-based versions of BCs. The work investigated the advantages, use configurations, and limitations as firms bring market mechanisms based on BC into the organizations. In addition, some emerging issues were investigated based on the usage of BC in consortium settings. Finally, the research related a few proposed uses of BC in transaction processing with other different technologies of databases and data warehouses.

Supply chains were treated as cyber-physical networks grounded on object tracking and identification. A valuable and novel trust approach was introduced by BC, while semantic technologies permitted the things described. Ruta et al. [207] introduced flexible object discovery using semantic-enhanced BC platform. It adopted semantic match-making and was based on validation by consensus of smart contracts between object annotations and queries expressed concerning ontology models. Also, the early experiments assessed the good behavior for the proposed framework efficiently.

## V. TOOLS/Frameworks USED TO BUILD UP DECENTRALIZED SYSTEMS

Different researchers have used different tools and frameworks to build the BC systems. For example, Guo et al. [48] used Ethereum and IPFS system to build a private and secure academics and education system. The IPFS system was used to store large files to reduce the burden of handling big files on local databases. Jmeter and BigchainDB were used to design and develop the platform for agriculture SC management system [83]. The JMeter tool helped test the system's load and performance to ensure the QoS and bigchainDB provided a scalable blockchain database for work. Hyperledger fabric and composer were used by Ho et al. [90] to record spare parts traceability data using the managerial platform. The tools helped to design a business network framework and ensured transaction validation. Garg et al. [49] used SPSS for factor analysis and AMOS version 26 to measure the benefits of BC in the banking sector. Other tools such as MATLAB, Amazon EC2, and Ethereum were used by the authors in [27], [51], [134] to implement an electronic voting

system. Ethereum provided a private and secure BC system, Matlab provided a numeric computing environment and performance evaluation, and amazon ec2 provided scalable deployment of applications. The healthcare system network used Wireshark, which was used to measure performance and round trip time of the BC network, and spyder IDE, which helped to evaluate statistical data [148]. Thus, this section discusses various tools used in detail in different applications.

#### 1) HYPERLEDGER FABRIC

Hyperledger Fabric helps in developing applications using a modular architecture [208]. It allows components, such as membership services and consensus, to be plug-and-play. It is an open-source project from the Linux Foundation. It has a permissioned architecture with an open smart contract model written in chaincode. It supports different languages such as Go, Java, and JavaScript. It ensures confidential transactions with channel technology and makes it easy to get started. It is used in banking, IoT, healthcare, finance, manufacturing, etc. Besides many advantages, it also has disadvantages. It has a complex architecture and has got minimum SDKs and APIs. It is not a Network fault-tolerant and lacks skilled programmers [209].

#### 2) HYPERLEDGER SAWTOOTH

Hyperledger Sawtooth is a platform that helps in building scalable distributed ledgers. It is used to deploy and run the ledgers [210]. It is a BC-as-a-service and an open-source platform that helps deploy customized smart contracts without any underlying design knowledge of the core system. It is sponsored by various organizations and firms like IBM, Linux Project, Intel, and SAP. It supports Proof of Elapsed Time (PoET) and Practical Byzantine Fault Tolerance (PBFT) consensus mechanisms. It is used in aircraft systems in [23] that are used to scale up the size of the BC network by allowing any number of nodes to join and work in the network. It is energy-efficient and supports parallel scheduling and multi-languages and tolerance to byzantine faults.

#### 3) ETHEREUM

Ethereum [211] is an open-source, decentralized BC that uses smart contract functionality. Ether (ETH) is used as the native cryptocurrency of this platform. It is designed to work in public network [212]. It supports distributed ledger technology and is open source. The tool implements programs with the help of smart contracts that act as small codes. It helps to manage and track currency. It uses the PoW mechanism and creates chains of blocks for BC. Due to the continuous changes in the tool, it is unstable. Also, it faces hard forks and dependability issues. Apart from certain limitations, it ensures scalability, better performance, privacy in transactions, data coordination, and rapid deployment.

#### 4) INTERPLANETARY FILE SYSTEM (IPFS)

The IPFS [213] is a protocol that helps in sharing and storing data in a distributed file system. It uses content-addressing in

a global namespace that is usually connected to every computing device to identify every file. Using gateways replaces protocols used for static webpage delivery, which are accessible with HTTP. It can be used for academics and education systems, healthcare, and e-voting systems. It helps the local network users communicate with each other even if a wide area network is blocked, helps the creators distribute their work, and provides higher bandwidth. But for some instances, IPFS is not user-friendly, consumes a lot of bandwidth, etc.

#### 5) GANACHE

It is a personal BC for rapid Corda and Ethereum distributed application development. It is used in the entire development cycle and enables testing, developing, and deploying dApps in a safe environment. It has two flavors as User Interface and Command Line Interface. It is used to test solidity contracts by setting up a personal Ethereum BC. It has more features as compared to Remix [214].

#### 6) BC TESTNET

A testnet is an instance of a BC which is used for experimentation and testing without risk to the main chain and real funds. Testnet coins are distinct and separate from the mainnet coins that don't have value for themselves and are from faucets for free. While in use they can be reset at any time. It provides the advantage for analyzing blockchain data on a smaller scale compared to the public network. Also before the official release, it provides the early access to blockchain. The testnet can be used in car sharing systems etc [215].

#### 7) IROHA

It is a business design of BC framework incorporated in infrastructure projects using DLT [216]. The distributed ledger feature allows data in BC to be shared publicly. Hyperledger Iroha is easily integrated and is mainly used in inter-bank settlement systems and payments. The three important roles of Iroha are Architecture, Functional/Logical Flow and Consensus Mechanism. It was launched in May 2019 and is permissioned and is hosted by the Linux Foundation. It is used to build national identities, allows access to financial services, and helps merchants buy goods. It also provides the facility of multiple signatures for transactions and plug in modular design for BC running. Due to its various advantages, it is used in supplychain management system that helped in flexible object discovery in semantic enhanced BC platform [207].

#### 8) YAHOO! CLOUD SERVING BENCHMARK (YCSB)

It is a program suite and an open-source specification that helps in evaluating maintenance capabilities and retrieval of computer programs [217]. It is an open source, easily install benchmark that manages big data. Also it helps to compare relative performance of NoSQL database management systems as required.

### 9) TRANSACTION PROCESSING PERFORMANCE COUNCIL BENCHMARK C (TPC-C)

It is an OnLine Transaction Processing (OLTP) benchmark. It came into existence in July of 1992 and is more complex than earlier developed OLTP benchmarks [218]. It has complex database, multiple transaction types and overall execution structure. It is measured in transactions per minute and is not limited to any particular business part [219].

### 10) GETH

Go Ethereum is one of the original implementations of the Ethereum protocol. It is an open source and is written in Go [220]. It is a standalone client that can be installed on any operating system or as a library that can be used by embedding in Go, iOS or android project. Geth serves as a node and mines Ether to help users create software for Ethereum Virtual Machine (EVM). It helps to join ethereum network and transfers ether. It is used in e-voting and IPR management systems in [188] that helped to build personal BC network for communication and privacy.

### 11) HYPERLEDGER COMPOSER

It is an open development toolset and framework that helps in easy making of BC applications. It is a set of open source tools that aims at improving operational efficiencies and helps in solving business problems. It is an example of BaaS. The Linux Foundation hosts it with corporate members in collaboration. It is now part of Hyperledger Fabric platform. It uses JavaScript language and uses built-in libraries to make the utilities more reusable and scalable. It is used in agriculture and supplychain management system. It supports scalability, sharing, reusability of components across organizations and helps to generate the required APIs and scripts required for business implementation [221].

### 12) BigchainDB

It allows enterprise and developers to deploy BC proof-of-concepts, platforms and applications with scalable BC database. It offers various characteristics of immutability, decentralization and native assets. It deploys in various use cases of IOT, IPR and SC management system. It is built on open-source, large pre-existing database codebase that has been used in enterprise for many years and is Byzantine Fault Tolerant (BFT) that offers low latency [222].

### 13) VIRTUAL TRUSTED TRADE BC NETWORK CLOUD PLATFORM

It is a virtually trusted trade BC network cloud platform that is used in agriculture system [87] that helps to establish a self-organized, trusted, ecological and open BC smart agriculture application system.

### 14) TRUFFLE

It is a testing framework, development environment and asset pipeline for BC that uses Ethereum Virtual Machine

(EVM) [223]. It is the most popular tool used for blockchain application with over 1.5 million downloads. It manages smart contract lifecycle, automated contract testing, network, interactive console, etc. SC management system [203] used truffle to generate interface to interact with deployed smart contracts in BC network.

### 15) HYPERLEDGER CALIPER

It is a BC framework that helps users measure the performance of a specific BC implementation using a set of predefined use cases to get the performance test results. In blockchain system application it used to deal with health-care and IPR system for their management [224].

### 16) PARITY ETHEREUM

An open-source software solution allows an individual to run a node on the public Ethereum network using ethereum protocol. It is an alternative to the Geth Ethereum client. The tool is flexible to execute and adds interesting features for enterprise solutions and consortium blockchains. It is written in Rust and is modular which helps it to connect with different types of blockchain networks based on Ethereum. It is used in IPR management system [225].

### 17) SWARM 0.5.7

It is a communication system and decentralized storage for a sovereign digital society [226]. It is used in IPR management system in [183] for improving security of BC system.

### 18) DEMATEL

It is a technique that helps in proper evaluation of problem thereby making it easy for researchers to do research. It helps to identify the cause-effect chain components in complex system [227]. It evaluates interdependent relationships in factors and finds the critical ones using visual structural model. It is used for SC management system in [195] to develop secure BC system.

Table 14 shows the percentage of the papers using different simulation tools for their evaluation in the systematic literature review. It shows that most researchers have used Ethereum, about 30%, for their work on BC. Hyperledger Fabric, IPFS, and MATLAB are used by 12%, 11%, and 4%, respectively. Figure also shows other tools that researchers use. These tools help researchers in the backend process and the evaluation of the results.

## VI. OPEN ISSUES AND CHALLENGES

The section highlights different open challenges in various application domains such as academics and education, agriculture, aircraft, banking, car/ride sharing, e-voting, health-care, IoT, IPR, and SC systems. FIGURE 8 gives a detailed taxonomy of open issues in ten different application domains.

### A. BLOCKCHAIN OPEN ISSUES AND CHALLENGES

The future of BC is decided by its safety, smart contract, robustness, security tokens, database technology, and

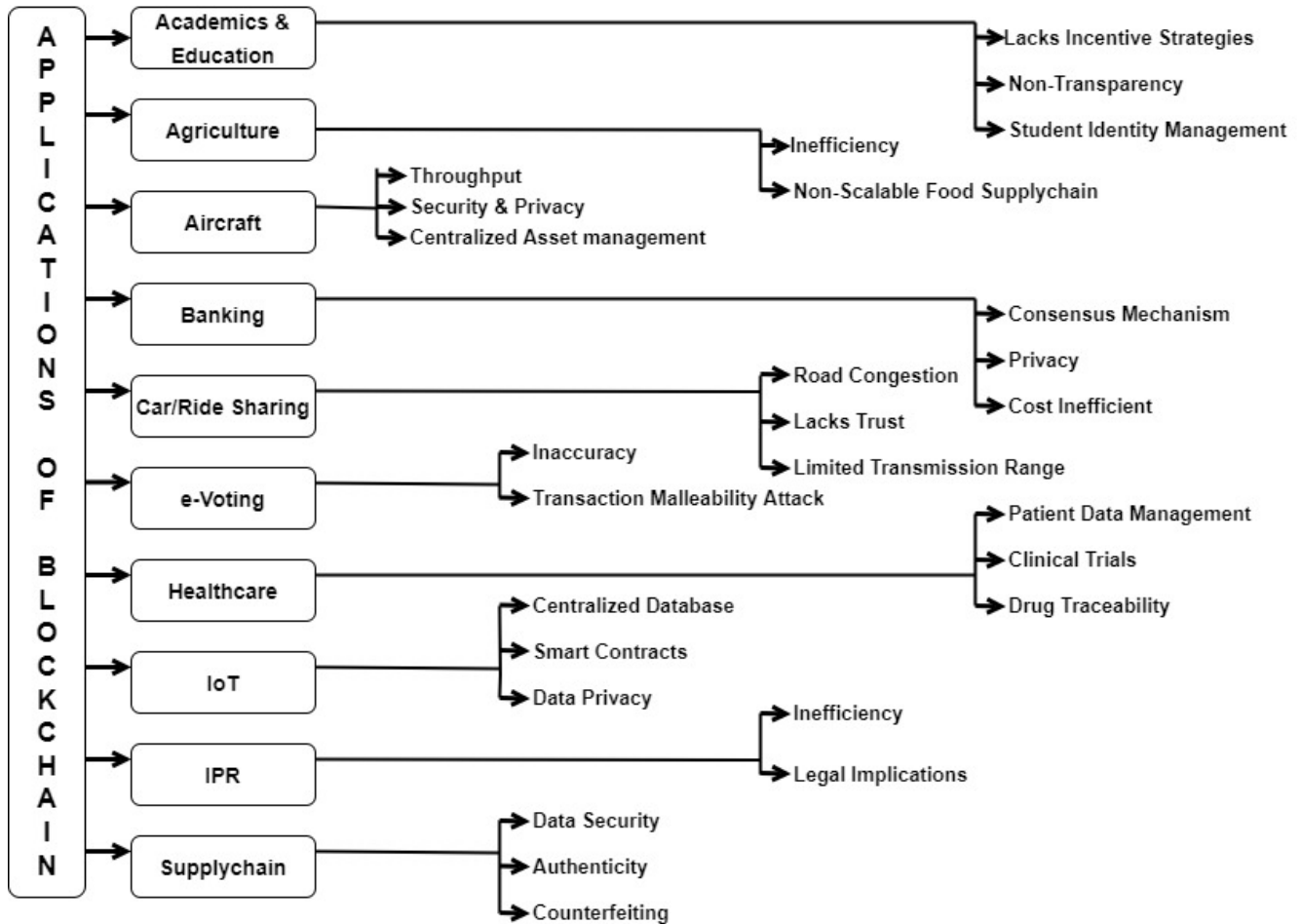


FIGURE 8. Taxonomy of open issues in Blockchain applications.

changing regulatory environment. However, to achieve the target, the implementation and design of the BC need to provide safety, reliability, and scalability that rely on the main technologies of consensus, shared ledger, immutability, provenance, and smart contract. This section outlines the implementation and challenges faced by the traditional systems and shows the possible solutions provided by BT.

1) SCALABILITY

The major concerns for scalability, especially in the traditional system, include the frequency of the blocks and their limited size with the total transactions that the network can handle. In today’s scenario, millions of transactions are executed and many transactions are executed in one second. BC technology helps scale up the network, thus removing the scalability issue from the network.

2) PRIVACY

The main reason behind the privacy concern of the traditional system is that it is vulnerable to information leakage. The systems were easily hacked and attacked by intruders. Thus BC technology uses algorithms such as SHA256 for privacy

and public and private keys to help secure the information system. The detail of the private key is not transparent to anyone present in the network and hence is secure against attack.

3) CENTRALIZATION

The major hurdle for the traditional system lies in its centralized mechanism. Such systems are complex and large for organizations. If the centralized system gets attacked or hacked, all the data gets lost. In addition, these systems require higher computing power and face network delay. The central authority usually has the privileges of the system. Thus, it can be replaced with the BC decentralized system, which helps store the data in all the system nodes, thus making the network secure against data loss and attacks.

4) TRUST

Establishing trust was the major problem the users faced in the traditional systems. Data breaches and attacks made it difficult for anyone to trust these systems. In such scenarios, the BC can be used to establish trust. It uses cryptographic techniques for building BC and helps in the immutable nature of the ledger.

**TABLE 14.** Table showing percentage of the papers using different simulation tools.

Simulation Tools	Percentage Usage
Ethereum	30%
Hyperledger Fabric	12%
IPFS	11%
MATLAB	4%
Hyperledger Caliper	4%
Hyperledger Composer	4%
Hyperledger Sawtooth	2%
Geth	2%
AMOS Version 26	2%
Parity Ethereum 2.7.2	1%
DEMATEL	1%
Swarm 0.5.7	1%
ANTLR	1%
Postman	1%
Pycharm	1%
Spyder IDE	1%
Wireshark	1%
OPNET Modeler	1%
Amazon EC2	1%
Eclipse	1%
AVISPA	1%
Testnet of Ethereum	1%
SPSS	1%
Trint	1%
VOS Viewer	1%
Truffle	1%
Django	1%
Truffle	1%
Bigchain DB	1%
Virtual trusted trade cloud platform	1%
Jmeter	1%
NS2	1%
Microsoft Visual Studio 2019	1%
Iroha	1%
TPC-C	1%
YCSB	1%

## 5) TRANSPARENCY

Different companies have different regulations, policies, and tracking systems. This leads to a less visible and poor connection between the businesses and customers. The decentralized and distributed nature of the BC transactions helps to make them verifiable and public to every user in the network with transparency.

### **B. OPEN ISSUES AND CHALLENGES IN ACADEMICS AND EDUCATION SYSTEM**

Some of the open issues and challenges of academics and the education system are discussed below.

#### 1) LACKS INCENTIVE STRATEGIES

Since 2020 with the rise of COVID, various online education platforms have received much attention and importance in academics and the education system. The online platforms fulfill the need to protect and save a life along with education. However, emerging online education faces many challenges. One of the major issues is that the students become lazy and lack interest in digital content. As a result, the seriousness toward education started lacking in students. Hence to

overcome the situation, BC provides an incentive strategy to reward the student for their achievements and helps support the academics and education system to help fulfill the desire of students, teachers and parents [48].

#### 2) NON-TRANSPARENCY

Schools and colleges have their own rules and management systems. The funds-related data is very important for the management to run their college. Also, the students' details and results need transparency for the parents to have a precise analysis of their child. Hence to achieve this vision, BC provides transparency in academics, and the education system [71] with full parental involvement to track their child records and also helps the management to get a clear idea about funds and expenditure.

#### 3) STUDENT IDENTITY MANAGEMENT

The school administration and offices usually store the data related to every school student. But sometimes, due to a large amount of data and mismanagement, school lose their data resulting in a bad impact. Hence to overcome this situation, BC offers a safe and secure storage solution that helps the school store a vast amount of data with full security. This helps students gain their data, if lost, whenever needed for usage and reduces the burden of manual management of the records.

### **C. OPEN ISSUES AND CHALLENGES IN AGRICULTURE SYSTEM**

Some of the open issues and challenges of the agriculture system are discussed below.

#### 1) INEFFICIENCY

The agriculture sector is falling behind in food safety, food traceability, changing consumer trends, and transaction costs. The increased usage of pesticides and fertilizers led to a major concern in food safety. Hence the demand for safe agricultural food and a need to track an efficient food supplychain came into consideration. BC helps in providing an efficient solution for food detail management from production to their supply and transaction management [81]. The details are easily saved on the BC and cannot be tampered and thus helping to improve the efficiency of the agriculture system. The sensor tracking system based on BC is a viable possible solution.

#### 2) NON-SCALABLE FOOD SUPPLYCHAIN

Earlier, the data related to agriculture and their supplychains were stored in centralized databases. But its limitation for data complexities and management led to the need for decentralized and simple systems. With the advancement in technology, BC came into existence, and the data related to the food supplychain started storing in decentralized databases. This helps in easy computation and provides scalability, transparency, trust, and less energy consumption for data management. With the BC usage, more number of transaction



processes in a short time, thus providing higher throughput for the agriculture food supplychains [79].

#### **D. OPEN ISSUES AND CHALLENGES IN AIRCRAFT SYSTEM**

Some of the open issues and challenges of the aircraft system are discussed below.

##### **1) THROUGHPUT**

Asset management and record-keeping were the main issues in aircraft systems to handle. With the advancement in technology, BC helped drastically in asset management and record-keeping. In real-time, the information about a plane's usage, makeup, and maintenance can easily be stored and updated using BT, which greatly impacts the aircraft system. Thus less time is required to handle backend data and thus results in high input of time and management in the aerial industry, resulting in higher throughput and an efficient system for the customers and the system.

##### **2) SECURITY AND PRIVACY**

Security and privacy are the major concerns in aircraft systems. The security challenges include unauthorized access, the impact of attacks, cloud configuration monitoring, mobile carriers' vulnerability, and modification of data by intruders. The BC helps record the transactions in blocks linked together and encrypted using cryptographic keys. The immutable ledger of the aircraft system thus makes it very difficult for intruders to delete or modify the transactions [93].

##### **3) CENTRALIZED ASSET MANAGEMENT**

A centralized database has limited storage capacity and computing power. It is always a time-consuming task to manage assets on a centralized database. The centralized databases usually lead to an increase in the computational and cost requirements. In the distributed BC system, multiple nodes have duplicate data stored so that if data once corrupted can be retrieved back from another node. This makes the aircraft system more safe and reliable to use for asset management [90].

#### **E. OPEN ISSUES AND CHALLENGES IN BANKING SYSTEM**

Some of the open issues and challenges of the banking system are discussed below.

##### **1) CONSENSUS MECHANISM**

The banking system provides financial services to all its customers around the world. The most important function of a bank is to provide transparency and maintain every detail of the transaction. BC provides all these facilities, which helps in proper storage and record management of the transaction details using a consensus mechanism. These mechanisms help add new transactions to the blocks and link the new block to the chain of blocks. They help in more secure with less time and energy consumption transaction banking system, allowing customers to rely on banks for their financial services.

##### **2) PRIVACY**

Data privacy in today's era is one of the key challenges in the banking domain. It encounters leaks of personal information, data breaches, unauthorized monitoring, breach of access control rights, data leaking, and stealing. With the distributed ledger system of BC, data is stored in an immutable system with a secure time-stamp, public consensus, and audit that helps makes the system robust and secure [105] to use.

##### **3) COST INEFFICIENT**

In the banking system, various intermediaries and different agencies mostly include commission charges, fraud, and duplication of products. The BC eliminates the need for a third party and thus results in fewer costs and fees. The self-executing smart contracts help in data execution and store on the blockchains. Due to the decentralized and tamperproof nature of the system, each party involved can trust its validity. Because of its immutable nature and high level of automation, the banking companies that adopted the BT experienced huge cost savings [49].

#### **F. OPEN ISSUES AND CHALLENGES IN CAR/RIDE SHARING SYSTEM**

Some of the open issues and challenges of the car/ride-sharing system are discussed below.

##### **1) ROAD CONGESTION**

Taxicabs play significant roles in the transportation system with the ongoing demand for on-demand taxi services. However, during peak hours, this leads to higher traffic and road congestion. Moreover, this often results in longer waiting times for passengers, and the fear of losing customers increases. To establish a possible solution for riders, BC helps analyze and minimize road congestion. Using BC road traffic management, algorithms are developed that help to give the real-time position of drivers and allocate the rides to the customers based on the backend logic and processes. The P2P protocol helps the riders book cab for themselves and reach their destination on time. Thus this helps in proper traffic and road congestion management for further usage and to make the lives of the people easier [117].

##### **2) LACKS TRUST**

Establishing trust in the car-sharing system is one of the major problems faced by the passengers. The involvement of third parties and intermediaries often results in data breaches and influences the customer's privacy. In such scenarios, BC is used to prevent tampering with data and build trust [19] among riders by using the P2P protocol. They help provide rental cabs, personal cabs, bike rides, carpooling, and luxury cab services to ease customer life. This protocol helps passengers book their cabs via an online platform and directly make payments. This removes the involvement of any third party, thus securing the customer's information and hence helps build trust among them.

### 3) LIMITED TRANSMISSION RANGE

The car-sharing systems usually face the problem of limited transmission range. With the increase in the demand for rides and cars for riding, the transmission range too was needed to extend. But the problem was that accuracy was not promised for a wide range. Thus to solve this issue, BC provided the solution by proposing frameworks and models that help get the details of drivers and get the location details using sensors. The sensors help in getting the current and the next point for location. All this helps expand the range of driving and helps customers ride for longer distances.

## G. OPEN ISSUES AND CHALLENGES IN E-VOTING SYSTEM

Some of the open issues and challenges of the e-Voting system are discussed below.

### 1) INACCURACY

An E-voting system is a system that helps in casting and counting votes by electronic means. It is cost-effective and applies effectively in real-time, and requires high safety. However, concerns about security and privacy for e-voting have grown. Accurate and secure e-voting results are very urgent for the country's benefit. Thus to help the system and avoid forgery of votes, BC uses DLT. Various models are also used to provide authentication of the votes. The models help in easy verification of the person's credentials and help in clean voting steps. Thus, the e-voting BC-based system can be used for a variety of network applications directly to provide accuracy [27].

### 2) TRANSACTION MALLEABILITY ATTACK

Prevention from attacks and double-spending problems is the major security concern in every organization. The security challenges include the impact of attacks such as changing bitcoin transaction identity numbers before confirmation, unauthorized access, and data breaches by intruders. The BT records the transactions and uses cryptographic keys to hash and secure data in blocks, thus making it difficult for attackers to attack or implement double-spending transactions.

## H. OPEN ISSUES AND CHALLENGES IN HEALTHCARE SYSTEM

Some of the open issues and challenges of the healthcare system are discussed below.

### 1) PATIENT DATA MANAGEMENT

Usually, hospitals control the patients' data privacy and security. But the patient transfers their medical information to a third party, such as pharmacists, for the correct prescription. This creates a sense of insecurity in the patient's mind and thus requires a system that can secure the patient's private information without being exposed. Hence, a hash for each patient's health-related information is created with BC. Using the BC API, the disease-related information of the affected patient is seen without revealing the patient's personal

information. Also, a patient has the privilege to decide who can access or view his data with a specific third party [29].

### 2) CLINICAL TRIALS

Researchers always want their confidential information to be stored securely and privately. They never want their data to be modified or breached, or stolen by any unauthorized person. Since BT uses the SHA256 algorithm, the data modification is almost impossible. The algorithm creates unique hash values of the data and links them in a chain of blocks. The healthcare industry needs privacy and security in maintaining and sharing clinical trial information securely with authorized parties of regulatory committees or research sponsors. The data is managed and traced with consent within multiple protocols, sites, and systems with BC. Patients with proper access privileges can also access information regarding their health issues [147].

### 3) DRUG TRACEABILITY

Currently, in pharmacology, the main hurdle is drug counterfeiting. A recent survey shows that about 10 to 30 percent of the drugs are false and duplicated in developing countries. This mostly affects the businesses and enhances improper usage of fake drugs, leading to severe patient health damage. The BC network thus helps to detect frauds from drug dealers. Furthermore, all the operations carried from manufacture to supply are stored in the BC network, which helps and enables to record and trace the whole route of drugs.

## I. OPEN ISSUES AND CHALLENGES IN IoT SYSTEM

Some of the open issues and challenges of IoT systems are discussed below.

### 1) CENTRALIZED DATABASE

A centralized database has a limited storage capacity and computing power. For work, many nodes connect to the server and make it a time-consuming task. Also, it is most challenging to detect faulty nodes in the structure. Since most IoT devices connect with the cloud network and centralized database, it usually increases the computational and cost requirements. Hence to increase the efficiency of the system, the distributed BT [170] is used where nodes have minimum connectivity and the system remains safe and reliable. With this technology, computing power increases for transactions irrespective of the device location. Thus, it makes the IoT system more cost-effective and reliable.

### 2) SMART CONTRACTS

The execution of traditional contracts required manual intervention and, thus third party for service. During disputes, the involvement of intermediaries became common and thus led to a high cost of the contract and higher time for resources consumption. With time BC created smart automation, which eliminated the involvement of third-party and unnecessary time delays.

### 3) DATA PRIVACY

Initially, the centralized databases stored the user's data which made security and major privacy concerns considered for the system. Nowadays, various companies store and sell users' data without users' consent to third parties to earn profit. Such actions make a serious concern towards user data privacy and security. With the advent of DLT of BC, the system stores data in an encrypted using hashing algorithms and thus limit the risk of data breach and stealing of user's privacy [165].

### J. OPEN ISSUES AND CHALLENGES IN IPR SYSTEM

Some of the open issues and challenges of the IPR system are discussed below.

#### 1) INEFFICIENCY

The protection of original work, such as copyrights and patents, is a significant issue in today's economy. Thieves worldwide steal the original work and sell it in their name to earn money. Hence the need to preserve and protect the originality of the work arose. With the development in technology, BC came into existence and helps in the protection effectiveness and information traceability of the data. Also, BC helps to store the original copyright date in the block. Furthermore, hashing algorithms such as SHA256 are also used to encrypt and store data for privacy and security concerns [180]. Thus, BC helps increase IPR management system efficiency and develops a sense of confidence to trust the technology for intellectual property protection.

#### 2) LEGAL IMPLICATIONS

The lack of transparency, piracy, and a central database for photos, music, and other copyrightable objects created legal problems for the owners or content creators to secure their original work. Hackers usually steal the original content and use it for their profit. However, during the period, BC helps secure the original work. It helps to increase the availability and visibility of information about copyright ownership using a timestamp. It helps to state immutably and publicly a certain event that happened at a specific time and thus helps define the work's authorship. It also individualizes each digital copy of a copyrighted work to gain control over digital copies and allows automatic payments and simplified licensing of the work.

### K. OPEN ISSUES AND CHALLENGES IN SUPPLYCHAIN SYSTEM

Some of the open issues and challenges of the SC system are discussed below.

#### 1) DATA SECURITY

Security of crucial and SC data is of major concern. The security challenges include monitoring the SC path flow, the impact of attacks, unauthorized access, and data modification by intruders. The BC helps in accurate and transparent

end-to-end tracking in the SC system. Organizations help create an immutable and decentralized record of all transactions, thus helping to track assets from production to delivery by the end-user [46].

#### 2) AUTHENTICITY

Today users trust document information to check the originality and validity of service. But such documents are easily attacked and tampered. The BT helps to avoid any breaching or modification of data. The technology traces the origin and movements of the products, thus helping clients and suppliers to get the required data movement information [21]. The use of RFID tags attached to the vehicles makes it possible to trace the products and record timestamps.

#### 3) COUNTERFEITING

Every organization or industry has issues with counterfeiting of drugs or products. This creates unverifiable products and poor customer satisfaction with quality or fake products. All of these influence the company's reputation and make the overall trust go down. The BT reduces the distance between companies and customers and makes the processes more transparent and traceable. In addition, the technology provides huge storage, which stores tamper-proof tracking history of the products, thus making it difficult to counterfeit the products.

## VII. KEY TAKEAWAYS

BC has achieved significant advancement in various applications. However, it still faces many shortcomings and takeaways for future research. Based on the thorough research done, the following research scope needs to be considered.

- Plugging BC technology with the incentive method for the users, for example, into legacy healthcare systems to motivate them to participate in DLT.
- Convergence of BC technology and artificial intelligence for providing security and privacy.
- Developing IoT-based healthcare systems that help in real-time access and remote access of the patients.
- Establishing BC policies that help in its global adoption.
- Decreasing Latency and improving the throughput of BC network. Latency can be decreased mostly in public BC by reducing the accessibility of each node to the full BC.
- Hybrid classification and clustering methods can also be added to improve the performance results of the experiment.
- Transaction processing and query rates should be increased using different consensus mechanisms and better storage techniques.
- Faster consensus algorithms and long short-term memory models, along with machine learning algorithms such as recurrent neural networks, can be used for time series Electronic Health Record data.

- Cross-platform communication ability to be developed to increase the system's productivity.

## VIII. CONCLUSION

This paper provides insights to the researchers and readers about the importance of BC for different applications. The report covers the basics of BC, its architecture, its characteristics, and its mechanism, along with an extensive survey on the role of BC in different applications. BC is widely used for other applications. Due to this fact, the paper has extensively surveyed and proposed taxonomy for the use of BC to build trust and make secure applications in academics and education, agriculture, aircraft, banking, car sharing, e-voting, healthcare, IoT, IPR, and SC systems. BC platforms like Ethereum, Hyperledger, and R3-Corda use different tools and frameworks. The paper categorizes thirty-six tools/frameworks used to build the decentralized system in other applications.

The comparisons and diagrammatic analyses of various work done in BC prove that society is moving towards building secure applications using BC. Among the works reviewed, Ethereum is found to be the most used tool in building applications. Finally, key takeaways are suggested for researchers to carry out further research in the field of BC to develop the technology.

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