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A Systematic Review of Blockchain Applications

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ABSTRACT For this study, the researchers conducted a systematic literature review to answer complex questions about the field of blockchain technology. We used an unbiased systematic review process to find works on blockchain-based applications and developed a Python code that searched various online databases. This paper provides an overview of the characteristics, mode of operation, and applications of blockchains in various domains such as transportation, commerce and industry, privacy and security, the financial sector, government, education, healthcare, and the Internet of Things (IoT). The aim was to identify the key research themes addressed in existing articles within each application domain and suggest future research directions for these domains. We analyzed a set of 750 articles published between 2015 and 2021 that dealt with blockchain applications. We found that financial management and security issues have been the main research focus since 2015. However, the use of blockchain in education has become a central research theme in 2021. Healthcare, IoT, and government applications have also grown in popularity. We furthermore analyzed some of the implementations of privacy mechanisms, as well as the challenges and future directions that need to be addressed for effective blockchain deployment. This study contributes to existing research by providing a comprehensive overview of blockchain application themes and their emerging areas for stakeholders in diverse sectors.

INDEX TERMS Blockchain, applications, business and industry, internet of things, privacy and security.

I. INTRODUCTION

A blockchain is a technology that chains several blocks of information together in ways that are decentralized, traceable, and unalterable. It was first introduced in 2008 to track transactions of the decentralized digital currency Bitcoin. Various transactions are verified in a distributed and decentralized database and can be updated on all nodes of the peer-to-peer (P2P) network. Each block formed is a collection of new information gathered whenever a transaction occurs, and it has a unique hash value based on complex computations. The blocks are chained together in a highly encrypted format [1], [2]. Nowadays, privacy is one of the major concerns in all types of transactions. The use of blockchain technology can bring about a revolutionary change in terms of privacy and authentication, and therefore it is gaining popularity in the fields of supply chain management, financial services, cloud services, smart contracts, research, government services, and consumer credit transactions. By integrating this technology, problems of risk management, security, and resource allocation may be solved. There is no need for a central database or the involvement of a third-party service because the data in a blockchain cannot be altered. This removes the overhead costs for managing intermediary services from different companies and organizations. In addition, the identification of individual users is done by various Internet of Things (IoT) applications. In order to maintain anonymity, the blockchain creates a changeable public key that can be

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given to any user and maintains the identity of users in each service [3]. In a traditional transaction system, a central authorization or third-party verification of a transaction is required. If this party is not trustworthy, the security of the transaction is compromised. In blockchain, the decentralization of the transaction and the use of public and private keys minimize opportunities for fraud.

The key features of blockchain technology were discussed in [1], including its applications in various fields; it was suggested that blockchain technology may have more benefits for business transactions that use currencies other than Bitcoin. It has various applications in fields such as transportation, business, government, digital rights management, supply chain management, energy management, and healthcare. In government sectors, blockchain can help us by preserving digitized land rights in developing countries in which land titles are problematic. In healthcare, doctors are often unable to track patient health profiles due to inconsistent and insecure data storage processes. However, patient data can be stored on the blockchain network in an encrypted format rather than on a central server, mitigating this problem. In efforts to build a smart city [4], a huge amount of data needs to be collected to create value. Blockchain can combine and manage the data to achieve the best quality of service. Combining blockchain with big data allows the beneficial results of important data innovations to be merged so that a smart city can be developed [5].

With these benefits in mind, a model for evaluating the improvement level of the TOPSIS (technique for ranking preferences by similarity to ideal solution) algorithm was developed for the city of Hefei, China. IoT is considered another emerging technology that integrates various devices so they can interact with each other without human-to-human or human-to-machine cooperation. In conjunction with blockchain, IoT-based applications can provide more secure, verifiable, and immutable services for society [6]. In terms of the economic development of a smart transportation system, blockchain can address situations in which communication technologies, IoT, and other technologies are important. To address the inherent difficulties such as security in transportation systems, the innovations of blockchain enhance decentralized governance and accelerate the communication between vehicles and the transportation framework.

In recent years, blockchain has gained popularity in the field of public administration and research innovation. It is a trusted process and a new application model for computing technology [7]. There are many challenges to be faced in implementing this technology for any organization in which it must be implemented with multiple technologies [8]–[10]. The organization should analyze this technology carefully. In terms of capacity and storage [11], all the blocks of data cannot be stored in one node indefinitely.

Zheng *et al.* [12] conducted a comprehensive survey of blockchain technology by introducing the blockchain taxonomy and discussing crucial technical challenges. Several papers have conducted systematic reviews of existing blockchain applications [13]. Casino *et al.* [13] identified 314 relevant articles published between January 2014 and April 2018. The presented categories of blockchain applications allowed the authors to define six requirements that enable blockchain applications: (1) privacy, (2) scalability, (3) auditability, (4) interoperability, (5) visibility, and (6) latency. Among them, auditability is mandatory for most categories of blockchain applications. The main limitation of this study is that the findings were based only on articles collected from the Scopus database; a large body of articles available on other databases, such as ACM, Web of Science, and IEEE Xplore, was ignored. This also prevented the authors from being able to analyze research topics in each application domain. Moreover, the omitting of databases oriented more toward technical literature led to the overlooking of some important research topics, especially within the IoT, transportation, and security application domains. Several other studies focused on specific blockchain application domains. Sanka *et al.* [14] provided a list of use cases with examples of blockchain technologies. Sekaran *et al.* [11] surveyed the main challenges of implementing blockchain in IoT. Wang *et al.* [15] and Taylor *et al.* [16] performed systematic surveys of blockchain cybersecurity applications, showing that IoT is particularly suitable for novel blockchain applications. Other application areas systematically surveyed in earlier studies included supply chain processes [17], [18], agriculture [19], the smart grid [20], education [21], healthcare [22], business management [23], and industry 4.0 [24]–[26]. Therefore, we argue that there is a lack of comprehensive review studies oriented toward diverse blockchain applications, and this is particularly important with regard to the relatively short history of blockchain and its rapid development, including the expansion of its application areas. To provide guidance for further research, it was necessary to conduct a comprehensive review of recent research articles, in particular those that addressed the emerging blockchain-based application domains.

In contrast with previous comprehensive application-oriented review studies [13], we focused on emerging areas of blockchain applications by covering those collected from 2015 to 2021 from multiple research databases. In addition, we introduced a more detailed categorization of blockchain applications by identifying key research themes in each application domain. We showed trends by outlining state-of-the-art blockchain solutions in the domains. Therefore, we believe that our approach fits well with current blockchain developments and illustrates existing challenges and future directions for both research and practice. Our findings show that education, healthcare, IoT, and government are the emerging blockchain-based application domains. From this paper, researchers and practitioners will obtain information on the diverse blockchain-based technology areas, challenges, and policies that should be considered. The main contributions of this study are as follows:

- 750 articles related to blockchain applications are identified in the period from 2015 to late 2021.

- Key stages in the development of blockchain technology in specific industries are identified.
- Diverse areas of blockchain technology are analyzed based on the systematic review.
- The benefits of the integration and implications of blockchain technology in various domains are summarized.
- Challenges faced in the adoption of this technology are examined.
- Future directions for the implementation of blockchain technology in different areas are identified.

The remainder of this paper is organized as follows. In II, an overview of blockchain technology is provided. Section III presents the research methodology of this paper. The various applications of blockchain technology are described in Section IV. The various challenges and future directions of this technology are presented in Section V. Finally, we conclude this paper by outlining some directions that future research on blockchain technology could take (Section VI).

II. BLOCKCHAIN OVERVIEW AND ARCHITECTURE

Each block has a header and a body. The header contains a hash value and a hash reference that points to the hash of the previous block, and as each hash reference of each block points to the block generated before it, this sets up the chain between blocks. All transaction types of blocks are recorded in a ledger that is shared by all the connected nodes in the network. A transaction is confirmed by the nodes only when a block is added. A consensus protocol needs to be verified and maintained for each block. Because many nodes or computers are connected as a chain and each node has a copy of the main chain, the information cannot be easily accessed by hackers. If hackers want to break a block, they must break the hash reference that is pointing to the previous hash. Because of the protective processes embedded in blockchain technology, breaking the chain is impossible at present. Participants manage the blockchain using matching mechanisms such as Proof-of-Work (PoF), Proof-of-Elapsed Time (PoET), or Proof-of-Stake (PoS). Figure 1 shows the blockchain architecture, and Figure 2 shows how transactions are managed in blockchain.

There are two types of blockchain technologies:

- **Public blockchain**: It is decentralized. Users can put data into it and view the data, and it is open to all. No permission is needed to access the blocks.
- **Private blockchain**: Only legal users can access the information in the blockchain, and they must maintain their authentication and control of the access.

There are three phases in creating a blockchain: blockchain 1.0, blockchain 2.0, and blockchain 3.0 [27]–[29].

- **Blockchain 1.0**: Digital currency, such as Bitcoin, is the first production application of blockchain.
- **Blockchain 2.0**: Refers to economic and financial applications such as Ethereum.

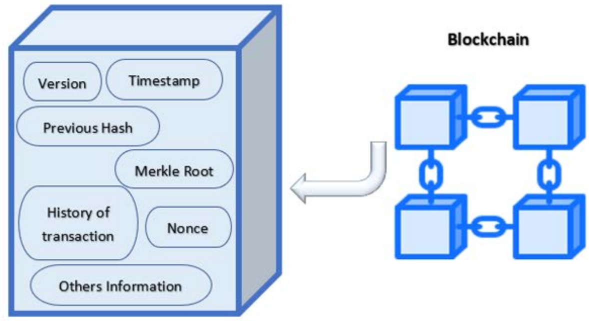

FIGURE 1. Architecture of a block in blockchain.

- **Blockchain 3.0**: Refers to applications related to the digital society, such as education, healthcare, and government, where money is not involved.

From the perspective of the value factor and maturity, there are four different phases of blockchain technologies, blockchain 1.0, blockchain 2.0, blockchain 3.0, and blockchain 4.0, as analyzed in [30]. The application area of blockchain 1.0 is related to digital payment systems and currency transfer and remittance, which are mainly transaction oriented. Bitcoin is an example of blockchain 1.0. A smart contract is an example of blockchain 2.0; it provides value in the area of privacy. An opensource software platform called a decentralized application (dApp) uses blockchain 3.0 and is a platform on which application developers can conduct their transactions. Blockchain 4.0 is considered an emerging technology that uses a decentralized artificial intelligence (AI) system driven by autonomous decision making.

III. RESEARCH METHODOLOGY

The current state of blockchain technology was discussed in detail in terms of its applicability to different technologic scenarios. This paper summarizes the latest research results of blockchain technology-based applications in seven industries. A systematic literature review on blockchain-based applications was performed to answer the following research question: What research themes are addressed in existing research articles on blockchain-based applications? An unbiased and methodical screening process was used to find scientific papers on blockchain-based applications for our literature review [31]. We developed a Python code that searched various online databases such as Google Scholar, IEEE Xplore, ACM, DBLP, SCOPUS, and the Web of Science and used a number of keywords related to blockchains to identify relevant articles. Some unpublished and/or archived articles related to blockchain-based applications were also included in the online search.

Specifically, we adopted the systematic literature search used by Yli-Huumo *et al.* [32]. For the initial identification of articles, the term "blockchain" was combined with terms for each of the corresponding application areas, resulting in the following search strings:

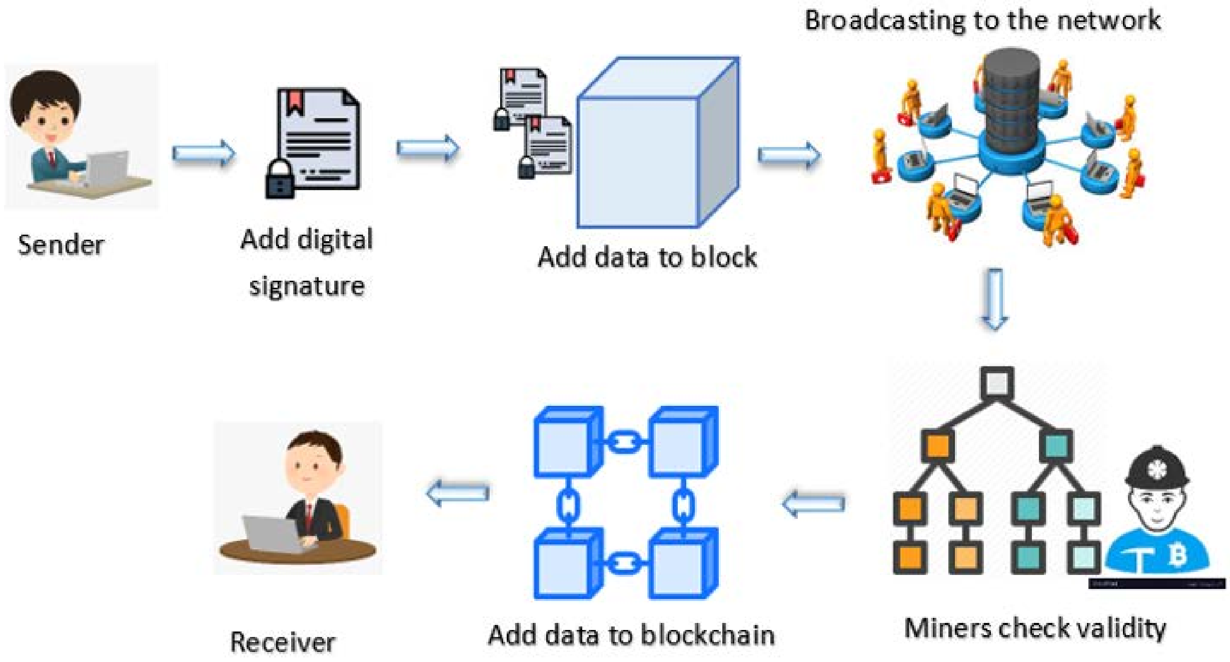

FIGURE 2. Blockchain-based transaction process.

- Education: ("blockchain" OR "block-chain") AND "education"
- Security & Privacy: ("blockchain" OR "block-chain") AND ("security" OR "privacy")
- Financial Management: ("blockchain" OR "block-chain") AND "financ*" AND "management"
- Society & Government: ("blockchain" OR "block-chain") AND ("societ*" OR "government")
- Healthcare: ("blockchain" OR "block-chain") AND "health*"
- Transportation: ("blockchain" OR "block-chain") AND "transport*"
- Healthcare: ("blockchain" OR "block-chain") AND ("IoT" OR "internet of things")

As all the identified articles were not necessarily related to the application domains, it was necessary to examine their relevance. Therefore, the screening of articles followed, and duplicates were removed. During the screening phase, articles from unrelated research categories were excluded. In the next step, the records were assessed for eligibility based on their titles and abstracts, and irrelevant articles were excluded. The list of the articles included in the systematic reviews is provided in the Appendix, categorising the articles by the application domains and year of publication. The results of the search and selection process are given in the PRISMA flow chart (Figure 3).

The numbers of articles for each theme and year are shown in Figure 4. The full texts of all potentially related articles were extracted.

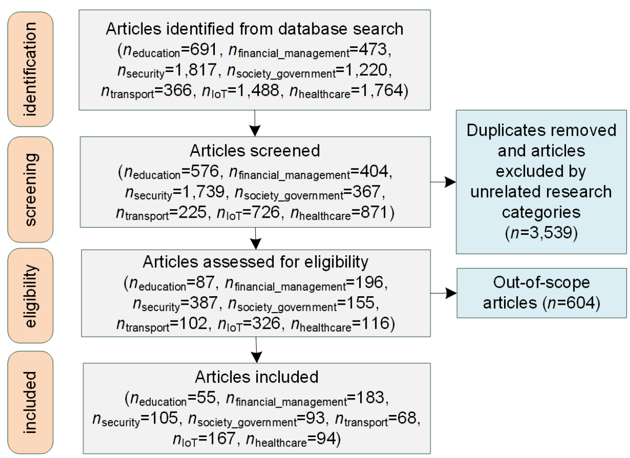

FIGURE 3. Search and selection process of the thematic articles.

The keywords from the mind map obtained from the assessment of articles are shown in Figure 5; the time frame was January 2015 to October 2021. The mind map shows the diversity of blockchain technologies by connecting the main application domains at the first level. It is worth noting that the identified first-level application domains are consistent with those observed in [13]. Deeper classifications of each domain based on blockchains have been assigned to the next levels.

From this massive group of articles, we extracted a remarkable number of articles by fine sorting. We then used a

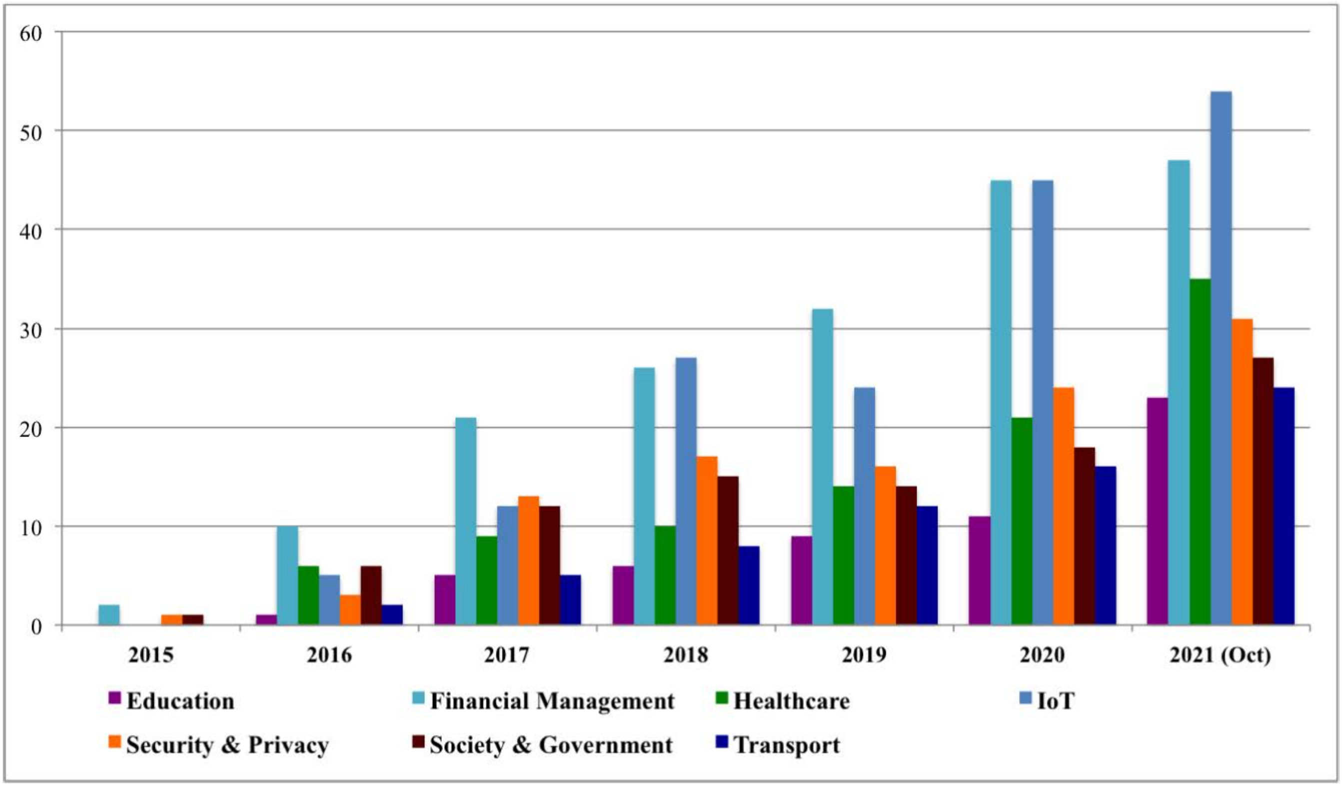

FIGURE 4. Number of thematic articles per year.

methodical approach to conduct the review; it had the following steps:

- Based on the impact (citation numbers) of the articles on other researchers, we determined whether the article needed to be reviewed or not.
- We identified articles relevant to our research objective.
- We assessed each article through data extraction and its contribution to the chosen blockchain-based applications.
- We wrote a report on our findings.

In our report, we considered more than 750 research articles published between January 2015 and October 2021 (unpublished articles were excluded from the illustrative investigation for compliance reasons). We also categorized the selected articles by year of publication and subject area and found that some articles overlapped in multiple areas. The result of this methodologic approach was threefold:

- It provided helpful insights into modern research trends in blockchain technology and its applications.
- It helped in visualizing the multidisciplinary research approaches that have evolved in the literature to date.
- It helped in constructing the taxonomy presented in Section IV.

It should be mentioned that Bitcoin was the underlying technology in [33], where a distributed ledger system was introduced. Also, it took several years for blockchain to be introduced to an interdisciplinary range of fields with respect to different perspectives and benefits. Figure 4 shows the exponentially increasing interest of researchers in working on blockchain technology in different fields and/or themes, and this confirms the evidence and acceptance of blockchain-based applications in these fields.

The collected papers, which are shown in Figure 4, formed a basis for a comprehensive analysis of our research based on themes or domains in each year. We found that the education, healthcare, and IoT domains were not embedded in blockchain research in 2015. In 2017, there was a significant change in this regard due to the ease of implementation of blockchain technologies and Ethereum [34], along with other platforms [35]. Our mind map showed that before 2017 there were only 37 articles but in 2017 there were 77 articles, and later on the numbers were in the triple digits. The increase highlights the evolving nature of blockchain technology and the growing academic attention to it.

We also found that financial management and security issues have been at the forefront of the field since the initial phase, and these issues have become of increasing interest each year, comprising 106 and 53 publications, respectively, between 2015 and 2019. The areas of education, healthcare, IoT, and transportation emerged later on, but they now have a massive presence in the research community. Other domains or categories that are not exclusively mentioned in this article also have significant potential for real-world use but on a small scale.

FIGURE 5. Mind map of blockchain-based applications.

We have analyzed the growth of research in each domain, and the findings are shown in Figure 4. The graph shows the trends of interest of researchers in different areas. We found that blockchain-based research in education grew exponentially in 2021, with one of the main reasons being the search for solutions for COVID-19. Researchers are focusing more on healthcare, IoT, societal issues, and government; the financial management and transportation sectors have seen relatively less interest. Thus, it can be assumed that blockchain-based applications have already been well received by the research community and that it is now only a matter of time before we implement them in our daily lives.

IV. APPLICATIONS OF BLOCKCHAIN

This section explains in detail the applications in which blockchain has been used in recent years and the areas in which blockchain can be used in the future, with some pictorial representations.

A. BLOCKCHAIN IN TRANSPORTATION

The intelligent transportation system (ITS) is a result of the growth and development of technologic innovations. The use of a smart framework in transportation can save human, financial, and material resources, and it can also immensely improve the processes of automation and traffic management.

Humayun *et al.* [36] proposed a blockchain framework called the smart transportation and logistic framework (BCTLF), which provides the logistics for transportation in combination with blockchain and IoT. Traditional vehicular communication systems are vulnerable to breaches of privacy, which can compromise security messages containing personal information, such as the identity of the driver of a vehicle, type of vehicle and area in which it is located. A well-known method for managing this problem was the use of a pseudonym that would conceal this information. Numerous articles have shown that the cost of maintaining these pseudonyms may increase and that the distribution of certificates will also be difficult. Blockchain's attributes of distribution and decentralization can help to minimize these limitations [37].

1) TRAFFIC REDUCTION

In a blockchain-based ITS proposed in [38], users were to share the traffic conditions for a specific location and then suggest a better route for other users. This sharing could become flawed if security issues arose. Li *et al.* [39] proposed an ITS with blockchain technology that would validate the trust (security) infrastructure.

2) PAYMENTS

For some specific applications, mobile payment systems already exist in many countries. All transport-related payments, such as ticket purchases for buses or light rail transit, vehicle registrations, and parking fees, can be managed using blockchain technology [40]. This reassures drivers and passengers so they do not have to worry much about trading their credits. This can open new opportunities for enhancing transportation scenarios based on a smart contract scheme.

3) ENERGY EXCHANGE

In supporting unmanned aerial vehicles and connected electric vehicles, an important issue is how to exchange energy. A blockchain-based energy exchange method has been proposed to support a secure and energy-efficient transportation system [41]. Blockchain is used to approve the energy requests of electronic vehicles in a delegated manner, in which the mining node verifies the validity of each request. In addition, a software-defined backbone controller is used.

4) DATA DISTRIBUTION

For smart transportation, many tools and techniques have been considered for obtaining real-time responses, such as route distribution, time management, environmental challenges, and safety management [42], [43]. Blockchain technology facilitates the management of these tasks. In vehicular communication systems (VCSs), the number of nodes in the network can be high. Thus, the security key management process is time consuming and requires a central administrator. By using blockchain with ITS, this key management procedure can be performed dynamically without a central authority. A secure key management procedure using blockchain technology is proposed for an ITS with different performance results [44], [45].

B. BLOCKCHAIN IN IoT

In recent years, IoT-based applications have gained popularity in various fields such as smart cities, healthcare, education, government, and social applications [46]. In IoT-based networks, many datasets are available publicly for all users. Blockchain is used to guarantee the privacy and integrity of these shared data sets. The graph in Figure 6 shows an overview of how blockchain is combined with IoT. Sensors are connected with many devices or nodes in the IoT network [47]. A huge volume of data is captured on the IoT platform by a cloud service. Many nodes are connected with a gateway in small networks. In a large network, many nodes are also connected with gateways based on the cluster. Each node contains a pair of public and private keys. Every node in the network uses its public key at the time of registration and creates a digital profile record on the blockchain. When a node receives a transaction, the private key is used for creating a digital signature, which is verified by the gateway. Different IoT devices are connected with the blockchain to synchronize and maintain a protocol for interacting with the blockchain network. Danzi *et al.* [48] proposed two protocols for the synchronization and control of traffic between IoT and blockchain networks. They analyzed the bandwidth requirement and time needed to synchronize them.

Using blockchain, a reference integrity metric (RIM) is maintained to ensure the integrity of the dataset; the process is shown in Figure 7 [49]. Casado-Vara *et al.* [50] proposed a model for determining the optimal number of blocks. For sending blocks in IoT-based applications, they developed an algorithm using hashmaps, which makes monitoring IoT networks faster and more reliable. For the proper implementation and use of blockchain technology, many questions need to be answered by managers, entrepreneurs, and business owners. Chen *et al.* [6] analyzed some questions that need to be answered before implementing IoT with blockchain technology.

1) SMART CITY

A smart city is a diverse IoT-based network system that offers several applications and security solutions to citizens. Smart cities rely on the assembly, analysis, and digitalization of information. To solve single-point failures of IoT devices in smart city applications, Vivekanandan *et al.* proposed a blockchain-based authentication protocol [51]. In their protocol, a private blockchain is used to register the IoT devices instead of a registration center authority (RAC). Singh *et al.* presented a detailed analysis of necessities for a sustainable smart city [52]. Their requirements for a blockchain-and-artificial-intelligence-based sustainable smart city are shown in Figure 8. Another blockchain-and-IoT-based research proposal for a smart city application is shown in [53]. The authors proposed a consensus algorithm for secure data transmission for a smart factory.

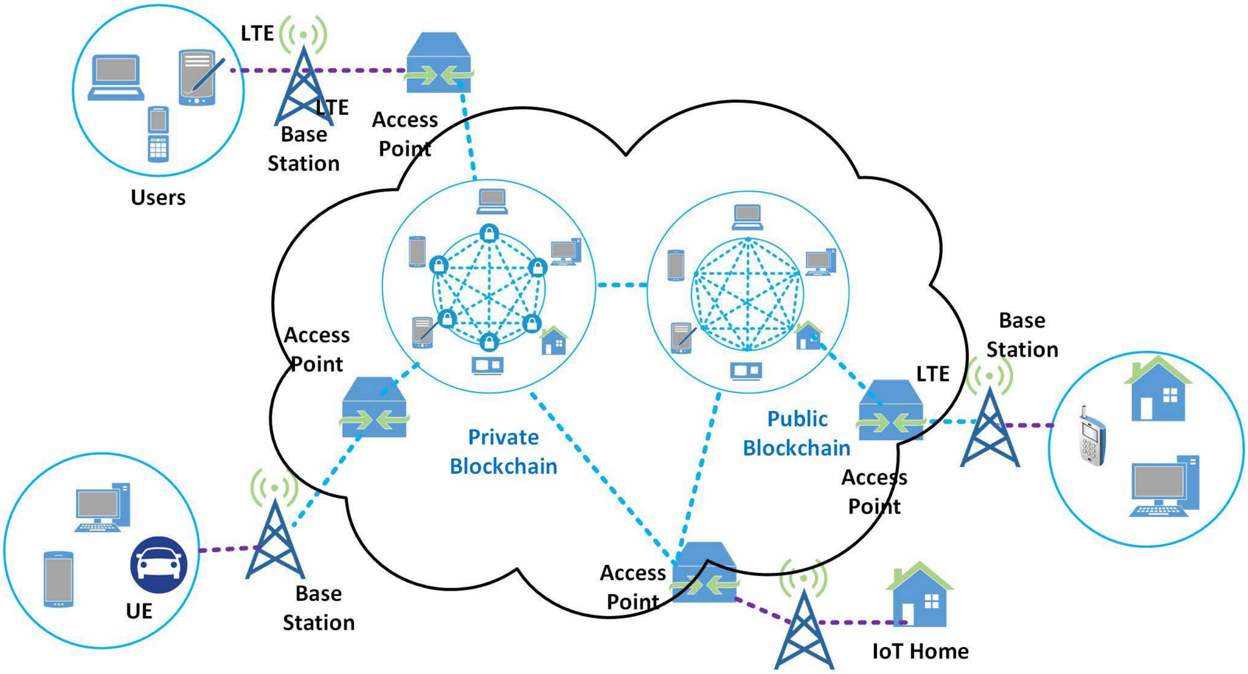

FIGURE 6. Blockchain architecture with IoT.

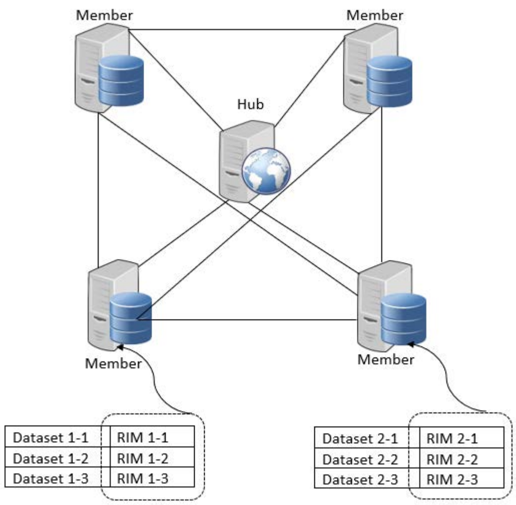

FIGURE 7. Blockchain-based reference integrity metric (RIM) and membership management [49].

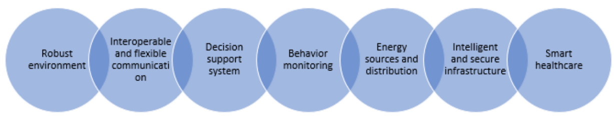

FIGURE 8. Requirements of smart cities.

2) INDUSTRIAL SECTOR

Blockchain and IoT have opened numerous new opportunities and provided hope for improved productivity, efficiency, and transparency in the industrial sector [54]. IoT provides real-time data by using sensors. Because the prices of sensors are falling day by day, sensors are becoming affordable for many industries. Blockchain is combined with IoT for sharing real-time data among users in a decentralized and distributed manner.

3) SUPPLY CHAIN

The supply chain is an area in which many business problems occur, such as late deliveries, absent suppliers, and untrustworthy intermediaries. There is a lot of paperwork involved in the shipping procedures for supplies. In addition, there are many losses of supplies and delays in deliveries of them. These problems can be resolved by using blockchain, which removes the dependency on an intermediary. IoT devices can be connected to components or products, and the blockchain captures the data from these devices [55]. Using blockchain, the location of the shipping container and the time stamp of the transaction can be captured. This eliminates the need for paperwork, and delays can be minimized. Digitization creates more opportunities for many companies and drives the supply chain. The use of technology creates not only opportunities but also manages complex procedures for following various rules. Rozman *et al.* [56] proposed a logistics platform based on the blockchain and IoT for manufacturing companies so they can maintain the supply chain. Their proposed plan has the following steps:

- The supply chain is an automated process that is complex and challenging. An interface node called a genesis node can provide platform information remotely.
- The genesis node sends a link to the platform information to all other nodes. For transport services, a mapping node is required, which is provided by the address resolver node (ARN).

- When a company is aware of which providers are available, it sends a request using the company API. The transport providers receive the information and send a response to the company. The latter selects the best provider, enters into an agreement with that provider with the help of an agreement node, and thereby forms a smart contract with the provider.
- The company can enhance its product shipping platform by using packages.

4) AUTONOMOUS VEHICLE

The autonomous vehicle is an attractive technology that may offer benefits for years to come. Sensors are attached to vehicles and all of their information is captured on the IoT platform, which is connected to a blockchain. The data can show when a car needs to be refueled or repaired due to an engine breakdown or other problems. Because the blockchain keeps a permanent record of each transaction, the trust between the manufacturer and the consumer increases. The whole process can be explained as follows:

- The vehicle sends data about the requested service, such as refueling, parking, or repair of engine failure, to the IoT platform.
- An open API is used for these services. Once the service is completed, a blockchain-based transaction is recorded.

5) PLANT ASSET MANUFACTURING MANAGEMENT

Blockchain and IoT can be used to predict and prevent failures of manufacturing products. IoT sensors can identify failures due to heat or extreme vibration. Proactive management with blockchain used with IoT can prevent these failures. This allows a factory to produce more reliable products. Recording and maintaining huge volumes of data can be handled by digitization with blockchain without the involvement of a third party.

6) TRUST MANAGEMENT

To ensure data integrity and interconnectivity, a trust mechanism must be established for end users in IoT applications. A blockchain-based trust architecture with three layers (blockchain layer, data layer, and application layer) has been proposed in [57]. The data layer consists of collected instances from IoT platforms and other sources. These data are hashed by a cryptographic function and stored in many blocks that are concatenated in the blockchain layer [58]. This layer maintains the chain and records every transaction that interacts with the application layer. The responsibility of the application layer is to process the data and provide services to the end users. In a gateway, many sensors are connected and a sensor node can communicate with neighboring sensors for trustworthiness. When a node records a transaction, the gateway accepts it and creates a new block after authentication. Trustworthiness can be achieved by recalculating the value by verifying the data in the block. Some researchers [59], [60] proposed a method called TrustChain to increase integrity and reduce traceability in the supply chain. They used a three-layer architecture with a collective blockchain to track the interactions among the supply chain participants. Based on the interactions, trust and reputation gateway points were assigned.

7) BeeKeeper

Zhou *et al.* [61] proposed a blockchain-based IoT service method called BeeKeeper. They based it on the methods a beekeeper uses to collect honey from a hive. A beekeeper does not need to know how the honey is produced or who collects it. Three participants were considered in the proposed system: the leader is like the beekeeper, the devices are like the bees, and the servers are like the hives. The user records are stored in the blockchain instead of on cloud servers. The leader can choose any node from the blockchain to be used as a server and can generate and encrypt the shared data using TSMPC (threshold secure multiparty computing protocol); the servers do not need to know the details of the data. The leader recovers the result that is processed by the servers and verifies the correct answer using the threshold. In addition, data sharing, responses, and malicious nodes can be verified. The system can also use external resources for a better performance. The authors evaluated the system's performance with the Ethereum private blockchain and found a server response time of 107 ms.

8) SMART AGRICULTURE

In [62], an energy-efficient smart agriculture scheme was proposed to improve the network's lifetime. Food traceability can help to ensure food safety; to do this, information is collected about the entire life cycle of food, such as production, cultivation, and storage. In the smart agriculture ecosystem, a food traceability system based on blockchain and IoT has been proposed [63], [64]. The use of smart technologies reduces the human involvement in recording and verifying food production. Nowadays, there are many problems related to human health because of unhealthy food. Some of the problems are as follows:

- Many farmers and wholesalers use highly toxic chemicals, fertilizers, and mineral oils in the cultivation of fruits and vegetables because they increase the brightness of food colors and other attributes. However, they are very dangerous for the human body.
- Some foods are packaged in plastics, which may contain traces of heavy metals. Polythene bags have harmful effects on human health.
- Some aspects of food production are harmful to human health, such as the use of polluted water or waste oil and the selling of meat from diseased chickens.

To solve this problem, blockchain and IoT applications can be used to track food production. A long-range radio (LoRa)-based IoT technology in a smart agriculture ecosystem with blockchain has been proposed in [65]. Blockchain can help to verify the quality of food and improve its trustworthiness mechanism. The New Zealand government has introduced blockchain-based smart agriculture [66]. Consumers can use this system to track their foods' origins, place of production, quality, and safety.

9) SMART CONTRACT

A particular IoT device manufacturer can obtain the latest firmware version from a distributed file system using a smart contract. A dynamic record of authorized devices is maintained by smart contracts for IoT networks [67]. The workload of devices can be balanced using smart contracts. A smart grid shows where energy resources are stored and whether they are distributed properly. Blockchain is combined with IoT to reduce the limitations of individual devices. How does this interaction take place? This question is answered by the authors in [68]. According to them, four layers, including communication, consensus, data, and application, are considered. An example of the application layer in this proposed model is smart contract technology.

C. BLOCKCHAIN IN FINANCIAL MANAGEMENT

Each financial system can provide its services to thousands of users by regularly carrying out many transactions. Increasingly, however, these services have to face economic crime. In addition, their providers face increased regulation costs and their consumers incur additional costs. They have to maintain all types of transactions using centralized databases and face many types of attacks. Blockchain is considered a solution to this whole problem [69]. This technology has some attractive features such as decentralized and distributed databases, P2P communication and transparency, and the keeping of a permanent record of each transaction. Morkunas *et al.* [70] explained the working procedures of blockchain technologies and discussed two types of these technologies, public and private. They illustrated how blockchain affects the nine elements of an established framework of a business model. They collected information on this procedure from countries in North America and Europe and from South Africa, where blockchain technologies are implemented. They cited several obstacles, such as high costs due to the requirement for dedicated developers and complex integration. In a period of greater risks and uncertainties, blockchain architecture and potential remedies were proposed to overcome the challenges in the business sector and increase supply chain resilience [71]. In this proposed architecture, five modules, data source, transaction, block creation, consensus, and connection and interface, were discussed. The difference between risk management using blockchain and conventional risk management was evaluated.

A blockchain-based trading platform scenario was proposed in [72] for financial product lifecycle management. In this architecture, two financial institutions were responsible for product management and each institution had three departments where all nodes were connected to a P2P network. The proposed business network included product creation, modification, and processing and basic operations. After receiving a certificate from each institution, the institutions were allowed to create and modify the product. The verification and execution of transactions were handled by the other departments. The different types of blockchain application domains and IoT networks in the financial sectors are described below:

1) BANKING

The banking sector can create several blockchain-based applications that can reduce transaction and intermediary costs by $20 billion [73]. Several cloud-based startup companies have been created to provide users with all the services of the banking system, such as access to regular and savings accounts and to applications for loans and other financial products. After two years of research and development, another banking system based on the distributed ledger of blockchain called Corda has been created. This can provide banking services to users without intermediaries such as bank offices. Some global banks are using the blockchain system to provide secure, efficient operations and safe banking services to users.

2) COST REDUCTION

The consulting firm Capgemini estimates that up to $16 billion in banking and insurance fees could be saved by using blockchain-based applications. Blockchain does not need an intermediary to maintain the system. This can reduce the cost of intermediaries. Six blockchain-based services are being considered for financial management systems around the world [74]. The available blockchain technology services in the world that reduce transaction costs are listed in Table 1.

3) PRODUCT TRACEABILITY

A decentralized supply chain management system as a blockchain-based token recipe is proposed for product source traceability and its revolutionary process, and a prototype implementation is evaluated in terms of smart contracts [66]. Each token contains one flexible size of goods that can be evaluated in terms of weight, item, size, and volume. A new token can be created from multiple tokens. Contract owners can create, merge, split, transfer, and consume batches of tokens. During token production, the number of units and components for a given batch can be determined using a designed algorithm. Some found goods with similar qualities that should be used for production are identified by the certificate contract. The traceability process is described using the example of the wood industry. A set of solid contracts is used to achieve traceability in the supply chain, and the Ethereum request for comments (ERC) 721 interface is implemented to achieve compatibility. Tokens are created for all produced batches of wood, which are approved by resource suppliers or testifiers.

4) LOAN MANAGEMENT SYSTEM

In the current loan management system, data protection for transparent transactions is not as strong. To minimize this problem, a financial loan management system called loan on

TABLE 1. Established blockchain-based transaction services around the world.

Name	Country	Service
Align Commerce	USA	Enabling payments to businesses in local currencies
Rebit	Philippines	Money transfer system for immigrants
Abra	USA	Mobile application-based money transfer system; can be downloaded from the Google Play Store.
Bitspark	Hong Kong	Remittance platform
BitPesa	Africa	Money transfer system
Slock	Italy	Universal Sharing Network (USN)
CoinRip	Singapore	Money transfer system

blockchain (LoC) based on a smart contract has been proposed [75]. The architecture and process of the LoC system are shown in Figure 9. To secure the transaction using LoC, the designers generated a digital account to automate the execution using the generated chain code. A digital signature is provided for the validity of the loan.

The LoC system has different components, including the roles of the participants (e.g., finance department, bank, customer). They are linked to the fabric SDK node in the system, which is connected to the participants by channels. Membership management provides enrollment services for each node. The channels are also responsible for broadcasting services for the messages and the ordering platform that incrementally creates transaction blocks. There are several channels, each of which is associated with a single peer called a chaincode in the smart contract implementation. The ordering platform sends the order update status in the form of blocks (containing the hash value of the previous blocks and other information about the block) to the chaincode through the channels.

5) CORPORATE TRADING

Blockchain provides various benefits such as transparency of ownership, faster transactions, elimination of middlemen, and cheaper settlements when it comes to trading with businesses [76]. The activities of shareholders, managers, and investors can be easily tracked. However, all participants may not agree to use this system because they may not want to disclose their trades to other managers and shareholders of small organizations. This problem can be solved by using smart contracts, in which visibility can be limited for some users. In this blockchain system, individual shareholders and shareowners can be identified [77].

6) TOURISM

Blockchain can help the travel industry to maintain all its processes seamlessly using various tools and technologies. In the traditional system, customer reviews have promoted tourism, but unfortunately, some of these reviews have been fraudulent. This problem can be curbed with the help of blockchain-based applications by verifying user profiles. Many researchers are trying to develop and analyze blockchain applications in the tourism industry. There are many challenges to be faced in considering blockchain technology, and researchers are trying to mitigate these challenges. For example, Airbnb and Uber are popular applications that do not rely on a traditional business model but rather are based on the consumer-to-consumer (C2C) model [78]. Some basic information about blockchain-based travel platforms that has emerged in recent years is given in Table 2.

7) CLIMATE PROTECTION

Global warming has been a pressing issue in recent years, and its impact is evident in various countries. Manmade greenhouse gas emissions are the main cause of global warming, which will increase by 2.8° by 2050 if no action is taken in this decade [79]. The author in [79] argues that blockchain can solve this problem by limiting human activity. Factory and livestock farming results in deforestation and the reduced absorption of CO_2, and this can lead to the accumulation of CO_2 in the atmosphere. Blockchain can reduce paperwork and human activities in digital applications. If blockchain technology is implemented by 2030, global warming can be reduced by at least 4° by 2050. The Reducing Emissions from Deforestation and Forest Degradation (REDD+) project offers developing countries monetary incentives to reduce emissions from forests [80], [81]. The authors analyzed several flaws of REDD+ and found solutions in blockchain technology, such as cryptocarbon management, green finance, and sustainable investments.

D. BLOCKCHAIN IN SECURITY AND PRIVACY

In this section, we address the security and privacy issues in the use of blockchain technology. A distributed cloud architecture based on this technology has been designed to improve privacy and security issues, which are the most challenging aspects in recent times. This model takes minimal effort, is secure, and offers on-demand access to the most concentrated computing framework. It has some metrics that enable cost-effective high-performance computing in IoT networks [82]. Some researchers [83] analyzed blockchain as a security factor after analyzing the challenges, feasibility, and effectiveness of IoT-related deployments. For a smart city, Sharma *et al.* [84] proposed a hybrid system of architecture with an Argon2-based PoW scheme to achieve superior privacy and efficiency. The network was divided into two parts, the core network and the edge network. The nodes with extensive storage and computational resources belonged to the core network, which was responsible for creating blocks and edge nodes. This network contained limited storage and computational power where the nodes acted as a centralized server. However, an effective deployment strategy and caching technique was not implemented in that work.

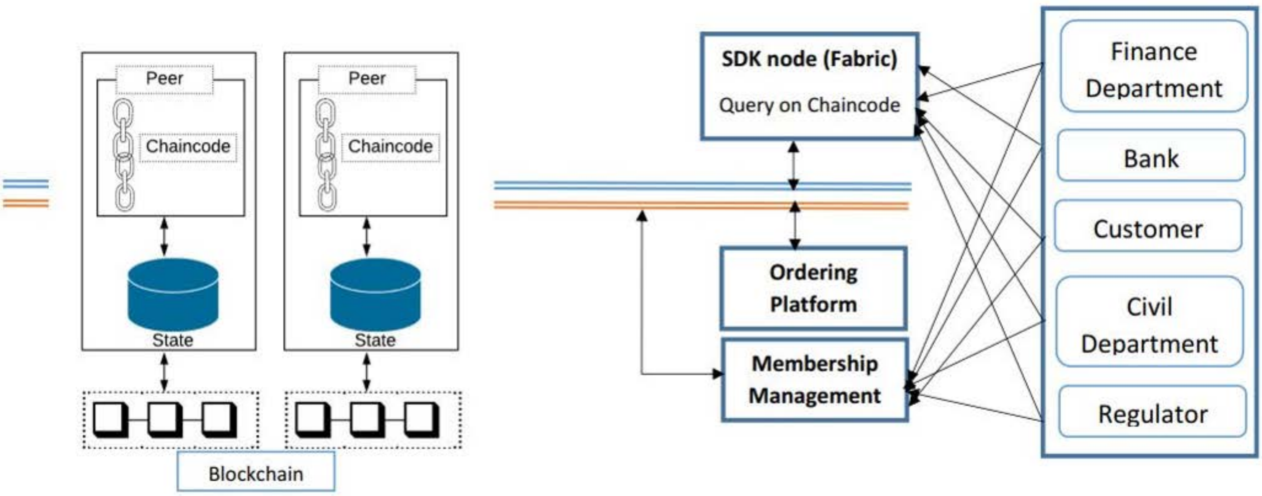

FIGURE 9. LoC architecture [75].

TABLE 2. Blockchain in distributed travel platforms.

Platform name	Blockchain approach
Nocturus	Hotel management app in China. Implemented on Hyperledger platform. Uses two cryptocurrencies: an internal currency called Noctcash and another called Noctcoin Easy-to-manage system with less cost, less dependence on intermediary, fast transactions
SmarTrip	Application based on smart contract TripCash is used for payment Fraudsters are identified Fast transactions
Further	Tour management platform for all types of participants Small and large businesses can participate Easy provision of all services through one platform
GOeureka	Hotel booking system Ethereum blockchain with smart contract Reduction of transaction costs

The application areas of blockchain with respect to security and privacy are analyzed in detail.

1) HEALTHCARE

Blockchain can be used effectively in healthcare to store patient medical records, images, videos, and documents. All of these types of data are sensitive and need to be made very private and secure but must also be available for those who need them. Blockchain technology can be used to maintain the security and privacy of data [3], [85]. In a Bitcoin-based healthcare model, the health data from each user can be stored [86]. However, the storage management system is not bandwidth intensive, and there is a massive dispersion of network resources via throughput optimization [87]. Instead of using Bitcoin, a better solution is to use an access control manager and store the instances in a database management system. An authorized administrator can access these records using a unique identifier that locates them where they are encrypted and time-stamped in the storage device. All the data of the blockchain database are called data lakes, which are very essential for data analysis [88]. Figure 10 shows the architecture of a healthcare system using blockchain.

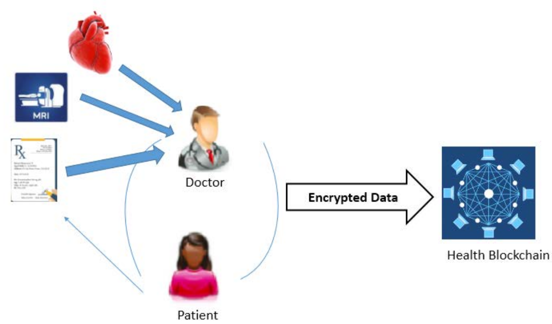

FIGURE 10. Healthcare transactions using blockchain.

2) FINANCIAL SECTOR

Blockchain is used as the backbone for Bitcoin, which has been a popular digital currency technology in recent years.

Various technologies are used for verification and validation in many methods [70]. Figure 11 shows a transaction for blockchain in finance using smart contracts. In this industry, data are encrypted from each block in the blockchain, and this provides security and confidentiality. In addition, private and public keys are used by financial organizations with high security needs. The consistency and integrity of data are confirmed in blockchain, which depends on the nature of traceability and immutability. There are diverse solutions for this kind of problem. In this system, user information is encrypted to ensure the security of records. Then hash values are included in each transaction. In addition to this, traceability is tracked over time and nonrepudiation records are used to ensure data security [89].

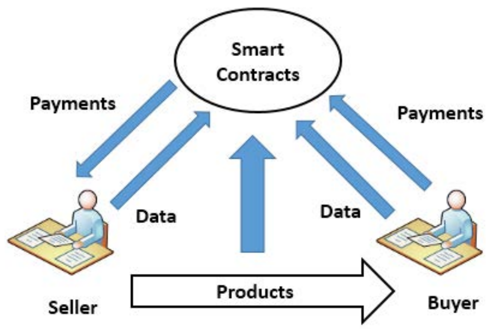

FIGURE 11. Finance transactions using blockchain.

3) INTERNET OF THINGS

The IoT is a system that connects a vast number of components, such as digital devices and computing machines that communicate with each other without any human interactions. Blockchain is used in IoT for data storage and security [90]–[92]. Users can access and store data remotely from any device and location. Moreover, the blockchain effectively ensures the security and privacy of the stored data [93]. In this case, an account is set up, missions are generated, and the account can be controlled securely. In addition, authenticated users can extract hash value managers and block numbers or generate a unique identifier. The data are stored and extracted from the repository system using this identifier. The number of digital devices used in the IoT is increasing, so blockchain is gradually truncating the business process. Using a public blockchain, users can store, extract, and share data between different devices and protect it with a private key. Figure 12 shows how blockchain technology is used in IoT.

4) DEFENSE SECTOR

Most weapons and related equipment in the defense sector are vulnerable to cyberattacks by hackers at any time [94]. Blockchain can reduce these kinds of threats by encrypting confidential data. Moreover, the data are transmitted using secure hashing and consensus mechanisms that enhance the authenticity of data in the communication mode. Blockchain also successfully controls the data maintenance process.

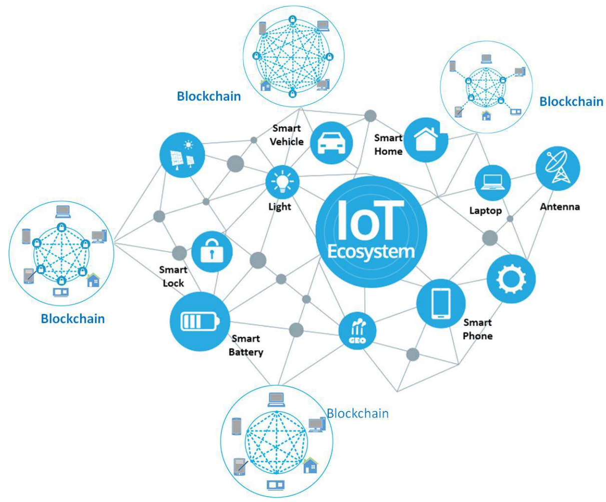

FIGURE 12. Blockchain in Internet of Things.

Records cannot be altered or changed, because they are protected by highly secure blocks and hash values. Various secret documents and information (e.g., videos, images, and plans for advanced weapons) can be kept in the storage system using this technology. It maintains a highly secure and protected mode using hash values and block numbers. Thus, this technology confirms the privacy and security of data.

5) MOBILE APPLICATIONS

Blockchain can be used in various mobile applications through device-to-device communication, data transfer, and a payment system [95], [96]. For example, edge computing is performed based on the concept of blockchain. Figure 13 shows a conceptual representation of the use of this technology in mobile applications. The blockchain concept is used where transactions take place on online devices. It is a secure protocol for transferring sensitive data or messages. Blockchain provides well-maintained security and privacy during money transfers with mobile applications.

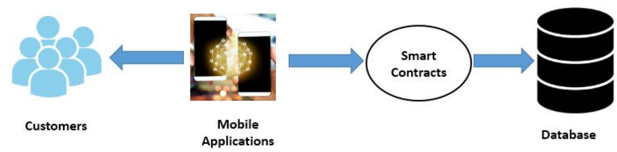

FIGURE 13. Mobile applications using blockchain.

6) AUTOMOBILE INDUSTRY

The number of vehicles is increasing day by day, and it is difficult for drivers to communicate safely with each other. Blockchain technology is mainly used in the automotive industry [97], [98]. A secure and safe architecture can protect a smart vehicle from external and internal threats. Moreover, blockchain has a decentralized architecture that can be more useful than a centralized architecture. It does not have a single point of failure at which continuous communications between smart vehicles is lost. In blockchain technology, data communication is done by an encryption process with high integrity. Using hash values and block numbers can make transactions from different blocks between smart vehicles more secure. In addition, the drivers use different applications and upload records to the cloud in a secure manner. Figure 14 shows how blockchain technology is used in the automotive industry.

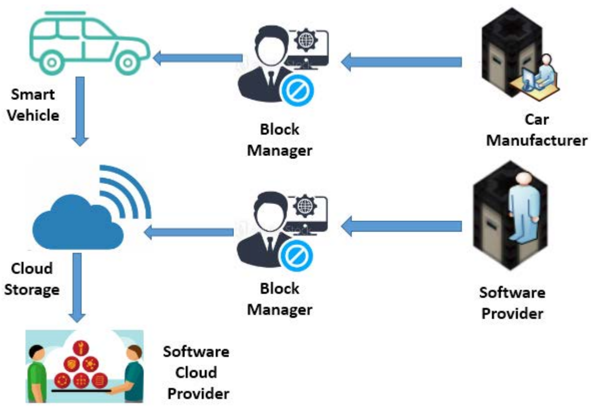

FIGURE 14. **Automotive applications using blockchain.**

E. BLOCKCHAIN IN HEALTHCARE

The medical and healthcare sector needs to handle vast amounts of patient and other health-related information in a safe and secure manner. When such information is properly recorded, the quality of treatment is improved [99], [100]. Singh *et al.* proposed a model for electronic health records (EHRs) using JavaScript-based smart contracts [101]. Another group of researchers proposed a framework based on smart contracts to collect more accurate healthcare information [102]. Figure 15 shows how health and patient information is better secured using blockchain technology.

In the medical and healthcare sector, a huge number of patients and other health-related information should be processed in a secure and protected way. If the patient's health data is recorded properly, then the quality of treatment is increased [99], [100]. Singh *et al.* proposed a model for electronic healthcare records (EHR) using JavaScript-based smart contracts [101]. Another group of researchers proposed a smart contract-based framework for collecting more precise healthcare information [102]. Figure 15 shows how health and patient information are more secured using Blockchain technology.

1) COVID-19

The coronavirus has caused a worldwide pandemic and has affected human lives greatly. It is important to reduce the extent of the damage caused by this crisis. Blockchain is an effective technology for combatting the COVID-19 pandemic [103]. It is mandatory to quickly identify and track cases in different places. Thompson *et al.* [104] proposed a self-testing system with a combination of blockchain and AI. Marbouh *et al.* [105] proposed a blockchain-based COVID-19 crisis tracking system using smart contracts and Ethereum oracles. Blockchain ensures the authenticity of information and provides a suitable solution for reducing the panic of this pandemic. The proposed system is connected to various web channels through oracles to collect real-time data.

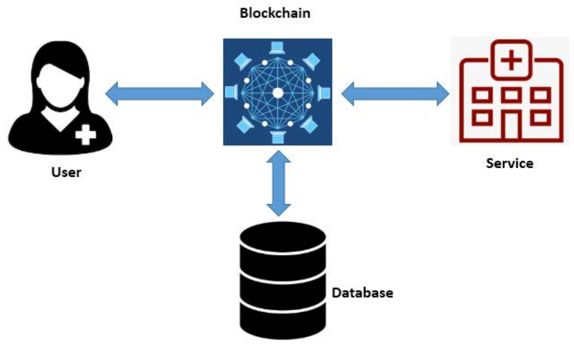

FIGURE 15. **Blockchain in healthcare.**

2) ELECTRONIC HEALTH RECORDS

Blockchain can be used to store and analyze EHRs to provide flexible and secure services [106], [107]. In this system, all medical devices are preserved and potential quacks can be identified [108], [109]. The Estonian government adopted a blockchain-based startup called Keyless Signature Infrastructure (KSI) that allows access to almost one million public health records without the need for a third party [110]. These records help patients to access and update data efficiently.

3) TELEMEDICINE

Telemedicine is becoming a more popular service for patients every day. With the help of this technology, a patient who is located far away from a medical provider can get extensive care. Additionally, patients get immediate treatment and do not have to wait for the doctor in the hospital. Telemedicine is considered an advanced technology in modern times, and data communication between patients is cited as a primary concern [106]. Blockchain technology can connect patients and telemedicine. Using this technology, patients' medical records are collected and stored using hash values and block numbers. Furthermore, blockchain technology provides a high level of security for health data. According to Angraal *et al.* [111], a platform called MedRec, which shares health and administrative data between a medical center in Israel and MIT's Media Lab, has been implemented.

4) EXPENSES AND SERVICES

In the traditional hospital management system, there are many errors in the calculation of patient treatment costs.

Poor management has affected the popularity of hospital services. Blockchain technology is used to mitigate these kinds of mismanagement issues related to additional costs and services [112], [113].

5) DRUG SUPPLY CHAIN

Many drug supply companies have faced many problems and losses owing to inadequate monitoring [114]. These companies are not only facing losses but may be liable for the effects of counterfeit drugs in patient treatment. Blockchain technology can help by tracking products and accurately measuring drugs as part of supply chain management [115].

6) HYGIENE RESEARCH

If researchers want to work for patients, they need to collect data on many diseases. This process may be lengthy and inflexible. Blockchain can store patient health records and link them to the healthcare network [116].

F. BLOCKCHAIN IN SOCIETY INFRASTRUCTURE AND GOVERNMENT

Blockchain technology plays a vital role in the development of social and governmental activities for e-governance [117]. In the current system, data such as employee IDs are stored in a centralized database with multiple duplicate servers. However, this centralized system suffers from many cyberattack issues, such as denial of service (DoS) and distributed denial of service (DDoS) [118]. Blockchain technology can initialize many flexible services, such as voting records, property registrations, patent exchanges, criminal records, and licenses for driving and other activities. Many researchers are focusing their attention on the implementation of various blockchain-related technologies. In a distributed system, shared and approved transactions are stored and each block contains a hash value to ensure its integrity in the ledger [119]. All of the nodes contain blockchain information, and there is no change in the entire chain that could corrupt the blocks. This technology allows access to and submission of records for e-governance at any time [120]. Ojo *et al.* [110] analyzed the implications of blockchain in the Digital 5 (D5) countries, which are South Korea, Estonia, the United Kingdom, Israel, and New Zealand. In order to create a robust digital economy, the D5 countries agreed to use a digital governance system and have encouraged their citizens to develop technologic skills for use at home and in the business world. Some of the objectives of these network groups are as follows:

- Providing services to citizens according to their needs
- Sharing standard policies and resources among users
- Allowing competition between companies or business organizations on an open market platform
- Providing opportunities to children to learn how to code and achieve next-generation goals
- Making a commitment to learn, share, and help each other

To achieve the goals and objectives, D5 countries have taken various initiatives in different areas. They have developed and digitized their services in the following sectors:

- South Korea: governance, finance
- Estonia: health, economy
- United Kingdom: finance, welfare and social security, education, public service
- Israel: finance, economy
- New Zealand: agriculture, energy

The following are different application areas where blockchain can be involved in government and societal activities:

1) INDIVIDUAL IDENTITY

In the traditional system, personal records are stored separately in different systems, such as an employment file, educational file, and business file [121]. The information about an individual that is stored in a government database may be different from the information stored in other databases. This problem can be solved by using blockchain technology, where information about a person is permanently recorded at a single point in time and can be made available for anyone, or any institution, that wants it. Nowadays, verifying the identity of refugees and immigrants is a serious problem in the world because their records may be lost or difficult to access. With the help of a blockchain-based digital identity, records can be accessed by anyone in any location.

2) E-RESIDENTS

Estonia offers an electronic residency system that can be used by people inside and outside the country [110]. The Estonian government introduced this system in 2014 with the aim of creating a borderless country. The main idea is a location-independent online business with a digital identity that is accessible to anyone, anywhere in the world [122]. The project is called Bitnation, and it is based on blockchain technology in a virtual nation. People communicate using a public key infrastructure (PKI).

3) LAND AND PROPERTY REGISTRY

Ownership of property, such as a house or land, can be transferred using a blockchain-based smart contract [123]. The rules of the transaction are maintained by the smart contract. The buyer keeps the total cost of the property in the blockchain and distributed system. Then, the seller can receive the transferred money, and this transaction is confirmed before the property is handed over. After that, the registration of the property is updated in the blockchain. For example, the valid owner of a lost car can be found by viewing the car's transaction history in the ledger. Only the valid owner can sell the car, and ownership must be confirmed. Blockchain technology rapidly confirms the identity of the owner and buyer and the buyer's financial status. It keeps track of the transaction history so that unauthorized or fraudulent persons cannot steal the car [124]. This can reduce human involvement in registrations for cars or land and also reduce the possibility of errors.

4) BIRTH AND MARRIAGE CERTIFICATES
Some vital records such as birth, marriage, and death certificates can be permanently stored using blockchain technology [118]. This ensures that the total number of citizens listed in the automated system cannot be changed.

5) VEHICLE REGISTRATIONS
If someone wants to buy a used car, its mileage records can be analyzed by its vehicle identification number (VIN) using blockchain technology [125]. Because the mileage and history records of the car are permanently stored, the seller cannot cheat the buyer.

6) VOTING RECORDS
Blockchain technology is useful for voting systems, especially in national elections. A voter can cast a vote only once and check whether it has been correctly recorded or not. This process ensures data integrity. The use of a consensus protocol in the distribution and authentication process makes fraud easy to detect and prevents any type of alterations [126], [127]. Estonia was the first country to implement a voting system using the Internet. Norway used a remote voting system in 2011 for its local elections [128].

G. BLOCKCHAIN IN EDUCATION
Every educational institution must keep track of the demographic information about students and teachers, the test results of students, and the certificates and diplomas awarded to students. In order to keep track of all these components, many stakeholders are involved. Blockchain is considered the best technology for keeping records in a flexible and reliable manner [125], [129]. Optimizing the learning and teaching processes offers many challenges in many countries. Blockchain can help to manage these challenges by keeping records efficiently and accurately. Moreover, learning is not limited by time or space. The Knowledge Media Institute of the Open University has established a blockchain-based project called OpenBlockchain in collaboration with British Telecommunications in the United Kingdom [130]. Several benefits can be achieved with blockchain in educational institutions:

- Secure and protected data on students and/or departments
- Access restriction can be effectively defined
- Transparency between data is preserved
- Trust is created among all users
- Costs are reduced
- Students' and resource owners' identities can be authenticated
- Student performance can be evaluated efficiently and quickly

1) CERTIFICATE MANAGEMENT
Many blockchain applications for educational systems have been designed for managing academic certificates. Grather *et al.* proposed a complete certificate management platform implemented as a blockchain-based platform [131]. All records can be managed without any third party assistance [132], [133].

2) DATA SCIENCE
Blockchain technology can be revolutionary for maintaining and processing huge amounts of data. To increase the knowledge and skills in data science, the European Data Science Academy offers training on interactive tools, and the blockchain smart badge system [134] has been designed as part of the course.

3) STUDENT LOAN MANAGEMENT
Using a smart contract, blockchain can be connected to a student loan management system. The repayment process is linked to the student's performance, salary, and other issues. In a traditional loan management system, more time is needed for processing and approval. To reduce the time needed, a blockchain-based student loan management system called Social Finance (SoFi) has been launched [135]. It reduces the processing time, documentation overhead, and intermediary costs. The SALT (Secured Automated Lending Technology) Lending Company, a personal loan management company, used Bitcoin and Ethereum [136].

V. CHALLENGES AND FUTURE DIRECTIONS
Blockchain can provide many benefits in networked areas. It always works with a large amount of data because the chain of nodes provides the resources needed to maintain a huge collection of data. When the chain becomes too long, the performance of the entire network can be reduced. The probability of a double-spend attack has become more likely. The total number of transactions per second is lower in blockchain than in the Visa International Service Association (VISA). According to Panarello *et al.* [137], there are two solutions to this problem:

- Reducing the block size by allowing communication only with digital signatures
- Increasing the block size to increase the number of transactions

As for smart contracts, keys can expire if users do not send coins intermittently. Another issue for blockchain is the large amount of traffic within its system; transactions are maintained for multiple nodes, multiple users, a huge number of blocks, and multiple devices. When a user completes a successful transaction with a merchant, a second transaction may not be accepted. However, if users are sent multiple conflicting transactions, the possibility of a certain kind of double-spend attack, the race attack, may occur. In a blockchain, block miners keep records of transactions and verify them. Pool mining is the process of passing the control of a pool from one miner to another at the wrong times. In this process, several attacks may be introduced on the mining pool:

- **Coin Hopping Attack:** When the pool manager misuses its computational power, it does not tell its miners to choose another blockchain that provides a higher transaction verification reward [138].
- **Selfish Mining Attack:** When honest miners' computations are wasted, the miners cannot use their mining power properly. Then the pool exceeds the threshold of this mining power, and a selfish mining attack may occur.
- **Pool Hoping Attack:** This attack was first introduced in Bitcoin. It tries to split the block reward of a pool hopper. When a miner wants to earn more profit than expected, the miner does not hand over control of the pool to other miners. Thus, honest miners may lose their profit [139].
- **Block Withholding (BWH) Attack:** When a miner does not share a full PoW with the pool manager, it can be assumed that the miner is a BWH attacker.

Privacy and security are ensured by the digital identity of the private key. If this private key is stolen, all assets associated with the private key may be lost. Thus, a public key can be chosen when it is visible during the transaction [140]. Given that the existence of IoT devices is physical, a research question may be how blockchain can ensure the security of IoT datasets.

When it comes to e-government, the upfront investment of money and time will be high because there is no common platform or standard for implementing blockchain technology with different areas. Before implementation can take place, it is necessary to determine the requirements for the system and how the system will be maintained. Each organization must understand its responsibility because many organizations, institutions, companies, and technologies are connected together. For this technology, a high-speed Internet and bandwidth may be required. On the other hand, this technology cannot provide a guarantee that it will never make a mistake. Many researchers have proposed many solutions for these situations, but more research is needed to find an overall solution. In public blockchain networks, the computational power of each block needed is too high to maintain different companies. The total cost of creating this robust system can be so high that most companies or businesses cannot bear it. Another problem is that publicly accessible devices can provide information to malicious users about the interests or ideas of valid users. In the future, blockchain may be combined with AI so that decision making can be automated without human interaction. In AI, related records are collected and trained and a pattern is extracted from the data. Blockchain can provide a huge volume of data, and AI can provide more reliability and security of data.

After reviewing trends in the literature, we found the following directions:

- To reduce the confirmation time, transactions can be configured and processed in parallel.
- A payment is verified when the payment details are attached to a block in the blockchain.
- Because the size of the blockchain can be increased and contains the entire transaction history, the blockchain should be editable. For example, data from the distant past that has no future value should be removable from the blockchain.

A. POLICY AND GOVERNANCE

The lack of policy implications is one of the challenges in the adoption of blockchain technology. Policymakers need to examine the current state of blockchain technology and the related policy issues. We have explained and listed some directions of policy implications for blockchain-based applications. Examples of the use of blockchain in policies of different countries are shown in Table 3.

1) TRANSPORTATION

- Fagnant and Kockelman recommended some policies for autonomous vehicles, such as research funding, certification guidelines, and appropriate standards for safety and privacy [141]. Policymakers can apply these recommendations to blockchain-based transportation systems.
- Privacy is one of the constraints in ITS deployment [38]. The General Data Protection Regulation (GDPR) is a law introduced in Europe. By implementing this law, users can protect their data in a blockchain-based ITS.
- Maintaining policy is one of the critical success factors for implementing a blockchain-based ITS [142]. Policies will help in making decisions and taking actions to preserve the ownership of digital records.

2) IoT

- Smart contracts help blockchain-enabled IoT networks secure records. This application requires proper agreement and the regulatory stipulations of contract law.
- Smart contracts need time-, service-, and location-based policies for 5G mobile networks [143].

3) FINANCE

- Blockchain transaction policies form an important framework for blockchain adoption. They influence the retail market for the implementation of this emerging technology [144].
- To find the optimal outcome and limit market failure, a certain policy approach is needed to implement the new technology. Some countries have enacted policies for blockchain adoption referred to as cryptofriendly.

4) SECURITY AND PRIVACY

- In a private blockchain, users can store data automatically by applying their policies. This will increase security by limiting manual interactions. The authors proposed a framework known as PleBeuS that stores data in a specific blockchain based on policy (input) from users [145].

TABLE 3. Blockchain applications in policies of different countries.

Country	Policy
Switzerland	Crypto Valley is an ecosystem that uses cryptocurrencies to pay for public services. Financial Market Supervisory Authority (FINMA) is a key policy actor that has developed guidelines for the use of cryptotokens.
Australia	To ensure clarity for blockchain participants, the Australian Taxation Office (ATO) has introduced taxes.
Estonia	To ensure an efficient, faster, and user-oriented government, the authority has developed a policy framework recognized as e-Estonia.

- Data owners may take responsibility for providing access policies and data encryption. Users can decrypt the data based on a hidden policy.
- A structured security policy specification is a non-functional security requirement for blockchain 5G networks [143].

5) HEALTHCARE

- Blockchain can be an adaptive technology in healthcare systems by introducing a regulatory sandbox system [146].

6) SOCIETY AND GOVERNMENT

- Each government should create a public policy for blockchain-based applications [147]. This will increase the use of blockchain through security and trust.

7) EDUCATION

Zhou *et al.* analyzed some challenges and policy implications for the maritime industry in Singapore [148]; they found that policies for blockchain-based applications should be prepared to encourage the use of this technology; some policies can be developed to revive the implementation of blockchain in educational applications:

- A lack of trained people is one of the constraints in the adoption of blockchain technology. Educational institutions need to train their staff in blockchain.
- Institutions need to put in place rules to record educational resources using the new technology.
- Policymakers can support educational programs and organize conferences to promote the use of blockchain technology. Experts and researchers in the field of blockchain can be invited to participate in promotional activities.

VI. CONCLUSION

Blockchain is a decentralized technology that can be merged with many technologies, such as the IoT, smart contracts, cryptography, and cloud computing. It was first introduced with Bitcoin but is now available with other applications where trust and high-speed transactions are the main concerns. We have explored the importance and benefits of implementing blockchain technology in various domains, such as the IoT, supply chain, financial sector, education, and healthcare. We tried to analyze the potential implications of blockchain in different industries. After reviewing the latest research papers, we found that blockchain technology is a boon for organizations but has some drawbacks, as well. Many researchers have identified problems, such as a high transaction confirmation time and high costs of implementation. It is problematic to just assume that the disadvantages of blockchain have been mitigated and that all client encounters will be perfect. All things being equal, blockchains are useful when full decentralization is essential. Before introducing a new technology, stakeholders should determine their requirements and the impacts and drawbacks of the technology on their transactions.

We found that the focus in the traditional financial application domain has shifted toward the banking and tourism industries. Similarly, mobile applications and the automotive industry have become key research themes in the security and privacy application domain. Blockchain in education has become a hot research theme in 2021 owing to the COVID-19 pandemic. In contrast to an earlier application-based review study by Casino *et al.* [13], we recognized that transportation-based applications were a crucial blockchained-based research theme. Other potentially important research themes were telemedicine and the drug supply chain within the healthcare domain. We identified emerging government agendas and IoT industrial applications for these domains. Big data in smart cities would provide fertile ground for the certification of blockchain usage. Further studies need to explore the conceivable specialized difficulties of blockchain in smart transportation and smart city development. To build on these recommendations, there should be solid, well-established instructional resources and activities. Likewise, building an action plan when implementing blockchain, including the unmistakable idea of how a blockchain-based action plan creates value, raises new difficulties.

Although this study is based on applications of blockchain in various industries, this work has some limitations in terms of methodologic narrowing. This research did not analyze the sources of each publication. In future work, this analysis may include a broader view of the implications of blockchain. Scalability analysis was also not considered for blockchain-based solutions. Despite some limitations, this research can help researchers explore blockchain for future implications.

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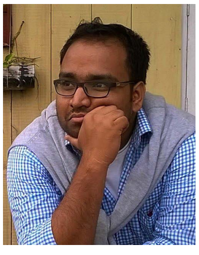

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