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A Systematic Review of Blockchain Technology for Government Information Sharing

Lu Zhang[1], Jiarong Mao[1], Yuting An[1], Tianshuo Zhang[1], Jixin Ma[2], Chen Feng[3] and Xiaoyi Zhou[1,*]

[1]School of Cyberspace Security, Hainan University, Haikou, 570100, China
[2]College of Computer Science, University of Greenwich, London, SE10 9LS, United Kingdom
[3]School of Engineering, University of British Columbia, Vancouver, V5K—V6Z, Canada
*Corresponding Author: Xiaoyi Zhou. Email: xy.zhou.xy@gmail.com
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Abstract: Government information sharing (GIS) refers to that act of required or provided for duty government information, commercial information and public welfare information, and it is a basic issue of government services. However, the existing GIS has low transparency and is lack of flexibility between different departments. Aiming at such problems, this paper takes blockchain as a solusion, and systematically summarizes the development of digital GIS, the advantages and challenges of blockchain and its theoretical research and practical applications. Specifically, it reviews e-government interactive structure, big data and other solutions, analyses their imperfections, and puts forward blockchain-based solutions. The blockchain improves government service efficiency and data security, meanwhile it faces challenges in throughput and supervision. In order to meet these challenges, researchers propose solutions based on three data exchange scenarios: government-to-government, government-to-enterprise and government-to-individual. In addition to researches, blockchain-based GIS is put into use. The electronic licensing project of Nanjing (China) government is taken as an example to illustrate that blockchain has the ability to openly and securely verify, track, and exchange data, so as to improve management ability and public service level of government agencies.

Keywords: Blockchain; information sharing; government; cross-chain

1 Introduction

Since the concept of digital government first emerged in the 1990s, driven by policies, the decentralization of government departments, and the rising demand for government services, E-government systems have been undergoing rapid development. As of 2020, according to the United Nations (UN) E-Government Survey [1], e-government and digital government are no longer distinguished, and the two terms are also mixed in the existing literature [2]. All 193 UN member states have established government portals, which in China connects more than 90% of departments and regions with more than 400 million real-name users.

The UN quantifies e-government performance using the e-government development index (EGDI), which is a composite index based on the weighted average of the communication infrastructure index (TH), the human capital index (HCI), and the online services index (OSI). According to the EGDI, only eight countries are at a low level. Tab. 1 analyzes the digital-government indices of different countries using data from the 2020 UN E-Government Survey report.

Table 1: Analysis of digital-government indices of different countries [1]

Country	Human capital	Online services	Infrastructure	E-government development index
United States	High	High	High	Extremely high
United Kingdom	High	High	High	
Korea	High	High	High	
China	High	High	High	
Morocco	High	High	High	High
Philippines	High	High	High	
Brunei	High	High	High	
Mexico	High	High	High	
Palau	High	Low	Low	Medium
Rwanda	Low	High	Low	
Uganda	Low	High	Low	
Guinea	Low	Low	Low	Low
South Sudan	Low	Low	Low	
Central Africa	Low	Low	Low	

In underdeveloped areas, because of resource constraints and a lack of digital infrastructure and capacity, the service capacity of such countries must be improved. Under the impact of Coronavirus disease (COVID-19) [3], digital government is also under pressure even in countries with high EGDI. Problems such as duplication of construction, low transparency, and low efficiency of multi-party collaboration have gradually emerged. Therefore, more-flexible measures are needed in the operation and sharing of government systems.

According to the 2020 UN Electronic government (E-Government) Survey report, The ten countries with the best e-government performance: Denmark, South Korea, Finland and Japan, etc. seven of which have started to apply new technologies such as blockchain. Blockchain was introduced in 2008 by Satoshi Nakamoto in his article *Bitcoin: A Peer-to-Peer Electronic Cash System* [4]. With peer-to-peer (P2P) network technology, a financial architecture for e-cash is created by mixing cryptography and timestamping technology. The data structure of the blockchain, the setting of the timestamp, and the Merkle tree make it traceable, tamper-proof, public, and transparent. A smart contract can be regarded as a piece of code written on blockchains, which is automatically executed without manual operation once the preset conditions are met. Smart contracts are a biggest help for the blockchain to get rid of the restrictions in the financial field and integrate with other industries.

Governments regard blockchain as the key to keeping up with the trend [5]. Blockchain has also provided solutions for digital government, mainly in preventing corruption in (i) the voting system [6,7], (ii) the flow of funds issued by welfare departments [8,9], and (iii) the judicial system [10,11].

Blockchain technology can help build a more intelligent, efficient, low-cost, and trusted government model. Government digital-transformation planning schemes based on blockchain technology are very important for reshaping data sharing, transparency, and trust between governments and citizens, but in the transformation process, different speeds of economic and technological development mean that blockchains cannot communicate and interconnect, forming data islands. Currently, cross-chain technology can solve such problems, but the existing literature contains only a few instances of summarizing and establishing the use of blockchain to transform governments, while the interconnection among chains is yet to be considered. Government information sharing(GIS) has been a key issue in the development of the government system. It integrates the information of various departments, excavates the potential of existing government public data, and enhances the ability of innovation and development. In summary, our systematic literature review focuses on the following questions:

1. Before the emergence of the blockchain, what were the technologies for sharing government information and what problems existed?
2. What advantages and challenges does the emergence of blockchain bring to the transformation of the government shared information system?
3. What research does blockchain currently have on i) government ii) commercial organizations iii) individuals and employees in terms of government information sharing?
4. How blockchain breaks down information barriers?
5. What are the application scenarios of the existing blockchain government information sharing projects, and what are the effects?

This paper is organized as follows. Section 1 briefly introduces the current situation regarding blockchain and digital government, and Section 2 presents the current situation regarding GIS and the advantages of blockchain. Section 3 analyzes systematically the blockchain-based solutions, and Section 4 analyzes pilot projects that apply blockchain technology. Finally, Section 5 provides a summary and future work.

2 Analysis of Development Status

Digital government has achieved good effects, especially in improving service levels and efficiency. However, with the development of technology [12], it has not been able to break the restrictions and realize the sharing of information within the country.

In addition to subjective reasons such as outdated concepts and lack of vitality, there is a high risk of loss in data transmission and replication, as well as objective reasons such as technology and platforms. Blockchain technology can help build a brand-new trust system, promote information disclosure, and improve the quality of government services and governance.

2.1 State-of-the-art of Information Sharing for Digital Government

Information sharing for digital government can be divided into information presentation, communication, transaction, participation, opening, and integration. Various practical solutions have also been explored in countries around the world. As shown in Fig. 1, in 2000 the United States (US) launched the Federal Enterprise Architecture Framework [13] and the United Kingdom (UK) launched the E-Government Interaction Framework (E-GIF); the UK and the US aim to strengthen the degree of intergovernmental data sharing. In 2002, the US launched the Federal Enterprise Architecture [14] project, which aims to increase data sharing and information interaction among institutions, reduce unnecessary system duplication, and accelerate the progress of government affairs.

The Internet access plan issued by Germany in 2005 makes 80% of government affairs paperless through information sharing among government agencies, to improve the efficiency and transparency of government work.

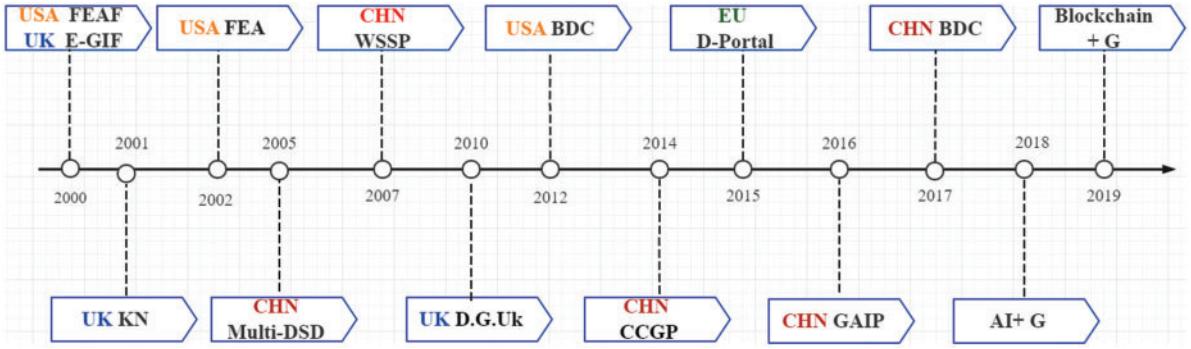

Figure 1: History of government information sharing (GIS) in various countries

For government departments, information disclosure is also important work, and to date many countries have entered that stage. In 2009, the US Obama administration issued the Open Government Directive, which requires all organizations to register their data on the government website. In 2010, the UK government announced that "data.gov.uk" [15] would be the only website for administrative public information from the government. In addition to releasing unclassified information to users, a few governments also encourage citizens to participate in the decision-making process through public information.

The European Union (EU) has also done a lot of work on sharing government data. Platforms such as the Open Data Portal 2011, the European Open Data Portal 2013, and the European Data Portal 2015 were established to collect datasets, and Eurostat provides more than 5913 data sets for statistical and scientific purposes. Countries such as Canada, Australia, New Zealand, and Germany have also gradually started the opening of government data. In 2017, the European Commission, European governments, automobile manufacturers, and service providers jointly established the EU Data Task Force, hoping to realize the safe sharing of automobile and infrastructure data under the current legal conditions of the EU.

Researchers in China have also been committed to exploring the sharing of government information across departments, such as building a shared database among departments and developing applications for exchanging and sharing information. In the process, an intelligent government collaboration platform has emerged, which has become a completely new path to drive development.

From the perspectives of technological level and development, the existing technologies include government resource databases and decision support systems based on data warehouse technology, platforms of government affairs technology, and information-sharing databases based on Web services. With the increasingly extensive application of big data, cloud computing, and other technologies, local governments are conducting data analysis through big-data technology and using cloud computing for centralized redistribution of resources. New microservice architecture have also emerged, such as service-oriented architecture (SOA) based on Spring Cloud, and the government integrated service platform of Enterprise Service Bus (ESB) enterprise service bus, etc. The new big-data technology frameworks—such as Spark machine-learning lib, Caffe, and Oryx2—are also promoting governments

at all levels to put forward more active and humanized services. However, a number of issues remain unresolved, especially regarding the following.

1) Without unified technical standards, services are heavily affected by technologies. Therefore, the portal websites of various departments update information slowly and have poor interactivity. The reusability of the original business system of a department is low and the transformation cost is high.
2) The online approval process is opaque. The business process is less open to the public, and the online process of exercising administrative rights cannot be monitored effectively.
3) Government data have high importance, while data from different departments have their authority levels to process data, resulting in security risks such as data leaks in the process of sharing.

In summary, there is still room for improvement in terms of information security, sharing, interoperability, and transparency.

2.2 Advantages and Challenges of Blockchain Applications for Digital Government Information Sharing

Shan et al. [16] used blockchain technology to introduce local governments, functional departments and end users into an evolutionary game model, and built a model that can simulate influencing factors by changing parameter assignments. Collaborative governance evolution model. This model verifies that the decentralized nature of the blockchain can achieve accurate services and improve the possibility of collaborative governance. Using mathematical models to prove that the application of blockchain to digital information sharing has great advantages. Briefly divided into 4 aspects.

1) *Reduce redundant construction*. The blockchain ledger must be maintained and managed by multiple parties; the participants are on equal footing and have no hierarchy. For government departments, this expands the scenario and scope of their data sharing. However, multi-party maintenance is not the absolute equality of all rights and responsibilities of all parties, but the effective and reasonable division of rights and responsibilities of each data subject according to the degree of data confidentiality and the authority of government departments through cryptography principles and other technologies. The scheme can also join the public and business owners into the data-sharing network, realize data security sharing, reduce redundant construction among government departments, and improve the utilization of data resources.
2) *Enhance government credibility*. Once the blockchain's open and transparent account book changes, it must be notified to the whole network, which is conducive to people's supervision of government behavior—especially in voting and welfare distribution—to effectively prevent black-box operation and corruption. At the same time, the data on the blockchain are tamper-proof: in the process of data sharing, this ensures that the transmitted data are neither tampered with nor forged, thereby ensuring the data's authenticity and integrity; it enhances the trust of both sides of data transmission and helps to improve the overall trust in government departments. The same approach can also apply to a government and enterprises, effectively preventing collusion between government personnel and enterprises so that only truly qualified companies are selected, and raising the credibility of the government among enterprises and citizens.
3) *Improving service efficiency*. Each node on the blockchain can establish point-to-point channels to realize direct information exchange among government departments, thus simplifying the approval steps, saving time, and improving efficiency. Most blockchain applications are

implemented through smart contracts: the difference between smart and traditional contracts is that a smart contract can be executed without reapproval once it reaches the pre-defined conditions.

4) *Increase data security*. The blockchain uses hash functions, Merkle trees, digital signatures and other algorithms to ensure the security of data. Hash functions computes a relatively unique output for almost any size of input. Fast computed can be achieved, but reverse calculation is very difficult, and the hash value will be different after modification, and it cannot be connected to the root node of the Merkle tree. Similarly, if the hacker successfully attacks the blockchain, it means that one third or 51% of the nodes are successfully attacked, at least. It is very difficult. For government departments, the data is safe.

However, as a new technology that is still developing, blockchain still faces a lot of challenges in the practical application of digital government information sharing. It can be boiled down to the following 3 points:

1) *Blockchain has limited transaction rate and throughput*. The blockchain was initially designed to have a capacity of 1Mb, the processing rate was limited to 7 blocks per second, and the transaction wait time for confirmation was 6 blocks. In the sharing of government information, the blockchain may cause a slowdown due to the influx of large amounts of data. Even if the consensus algorithm is optimized, the throughput of the system can be significantly improved, but compared with the existing mature and stable systems, the gap is still large.

2) *The storage space on the blockchain is small.* All government information cannot be stored on the chain, and you can choose to transfer certain operations to the off-chain. However, there are risks of privacy leakage and untrustworthiness in off-chain operations, and the transfer of on-chain and off-chain operations will cause problems such as increased latency. And it is also necessary to design a database that is compatible with the blockchain.

3) *The blockchain supervision system is not perfect.* The blockchain system standard has not yet been established, and the rules on the chain are not yet clear, which is very likely to lead to data or financial risks. The existence of the blockchain can ensure the integrity and unforgeability of the data on the chain, but it cannot guarantee that the data on the chain is authentic and credible. The behavior of data source nodes also needs to be regulated.

By introducing blockchain technology, the government can solidify and develop the authenticity and reliability of data, and open up the "last mile" of cyberspace and one-door government services. Government services have changed from the establishment of centers to decentralization. Government departments use smart contracts to view and use shared data, connect relevant businesses, and put the special item on the integrated platform for operation, i.e., multiple matters of different departments can be handled at the same time on this platform to improve service [17] efficiency and quality.

2.3 Development Status of Blockchain Government Sharing

To date, countries all over the world have praised blockchain technology to the height of national strategy. Before the birth of blockchain technology, Estonia launched a keyless signature infrastructure and then combined this technology with blockchain technology; to date, 90% of Estonian citizens have electronic identity cards.

On December 19, 2017, Sberbank—a state-owned bank of Russia—announced that it would cooperate with the anti-monopoly agency of the Russian Federation (FAS) to transfer and store documents through blockchain technology. In March 2018, VCIOM—the Russian state-run public

opinion research center—decided to use blockchain technology in the presidential election: the project provides a special blockchain polling station to receive voting data, maintain data transparency, and effectively reduce hacker attacks; the project is being undertaken by 2chain, a company specializing in providing consulting services for blockchain technology. The UK government has invested £10 million to support blockchain projects, involving solar energy, clean water, electoral systems, charitable donations, and other industries. The National Archives—the official record-keeping agency of the UK government—revealed that it was studying the use of blockchain technology to help record sharing. The World Food Programme also announced that the Belgian government donated 2 million euros to promote the blockchain project under the organization. The US state of Colorado will apply blockchain to government data protection and network security to protect confidential national records from criminal, unauthorized, or unintentional manipulation or theft. The US government, together with Coca-Cola, will use the verification and digital notarization capabilities of blockchain to create a safe registration form for workers and their contracts to solve the problem of forced labor.

China has also carried out blockchain technology practices. At present, the projects that have been put into practice in China are concentrated mainly in some departments in certain provinces and cities such as Beijing, Shenzhen, and Nanjing. According to a survey of Interlink Pulse Research Institute and the 2020 general survey on the bidding of government blockchain projects, ninety-six blockchain government applications were either completed or being prepared from 2017 to 2020. Many application scenarios are interconnected and highly comprehensive. The classification be shown in Fig. 2.

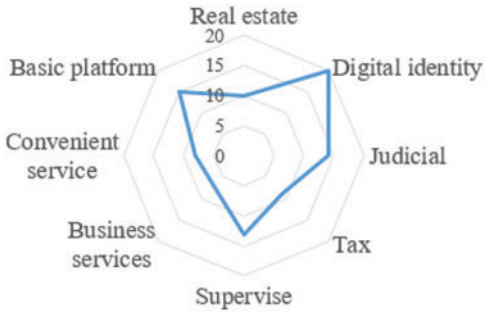

Figure 2: Classification of government application scenarios

3 Blockchain Solutions for Information Sharing

The application of blockchain has penetrated all walks of life, and research is increasingly being conducted on the sharing of government information [18].

3.1 Research Methodology

In the research reported in this paper, relevant literature was obtained through Web of Science, Engineering Village, Google Scholar, and other online database resources. Taking Web of Science database as an example, 5755 results were obtained in the database using "government," "information," and "sharing" as keywords. After adding "blockchain" as a keyword, the results were limited to 122, of which we intensively read 50 papers based on the numbers of citations. Our search process is shown schematically in Fig. 3.

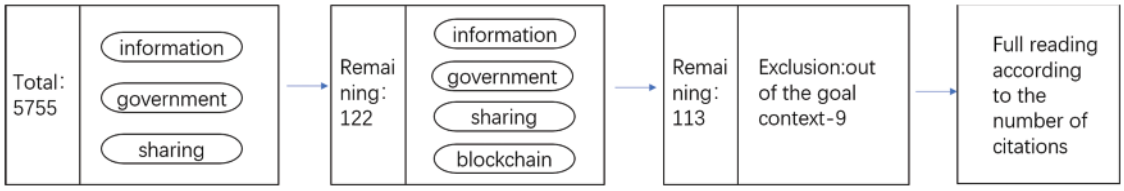

Figure 3: Literature search process

We also analyzed the number of papers on blockchain and GIS. Between 2016 and 2021, the data for such papers showed a growing trend, with a significant increase in the number of papers and an upward trend of highly cited papers during 2017. In 2019 and 2021, because of the rapid growth of the number of papers, a refinement trend appeared: the number of cited papers increased, while the number of highly cited papers decreased. However, in 2021, due to the more subdivision of the field, the number has increased again. This can be seen in Fig. 4.

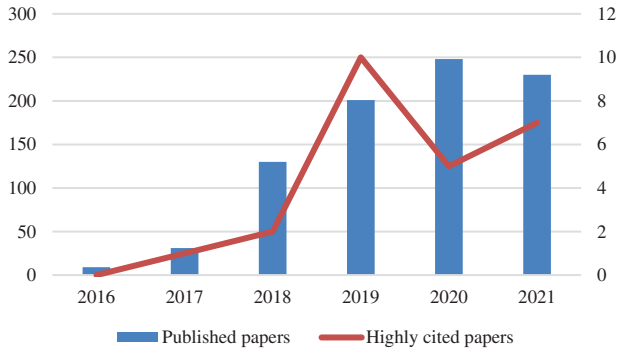

Figure 4: Analysis of papers on GIS

In terms of information-sharing methods, the solutions provided by blockchain can be divided into single chain and multi-chain according to the number of blockchains. To date, there has been far more single-chain research than multi-chain research in industrial application scenarios such as medical [19–21], finance [22–24], logistics [25,26], energy [27,28], and industrial Internet of Things (IIOT) [29–31]. As shown in Fig. 5, the amount of multi-chain research is 10% of single-chain research on average, and 5% of that for medical treatment. The reasons for this situation are as follows: (i) the financial field, as the initial application field of blockchain, has been studied for a long time; (ii) IIOT has many distributed devices, which is consistent with the concept of blockchain decentralization [32,33].

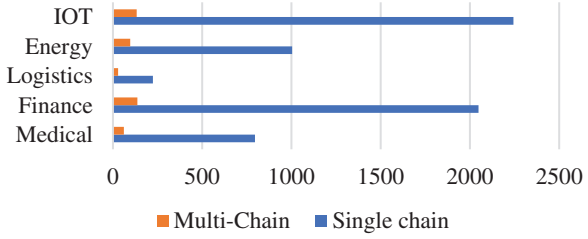

Figure 5: Single-chain *vs.* multi-chain solution scenarios

3.2 Single Chain

Because of the rise of blockchain technology in the field of data sharing, a number of scholars have begun to consider combining blockchain technology with government applications. Depending on the specific application scenario, it can be divided into three main categories, i.e., government to government (G2G), government to business (G2B), and government to citizen (G2C).

3.2.1 G2G

Li et al. [34] proposed a cross-sector-based information-sharing model that includes an on-chain model and an off-chain model, where the former uses a blockchain to share information segments in XML format and the latter uses addresses to access the intelligence information center; this ensures that information can be transferred efficiently within the limitations of storage capacity on the blockchain, but the security of the off-chain model must be improved, and their model is applicable only for cases in which the shared content is relatively fixed. Hao et al. [35] proposed a sharing blockchain framework for private data based on the risk that the privacy of citizens or enterprises may be revealed in government data sharing; however, the problem with their scheme is that it has no high performance for concurrent events and cannot handle high-scale concurrent events. On the other hand, Liu et al. [36] built a local differential privacy protection framework through a private chain; this method protects the privacy of the processed data when shared and used, and it enhances the security, credibility, and relevance of information sharing, but different data sources may cause information loss when processing.

Piao et al. [37] proposed a service-on-chain approach that is effective for identifying the data-retrieval needs of different departments, sharing government data, and has credibility and controllability in data content and ownership; however, their approach also requires the cooperation of both the on-chain and off-chain parties. Wang et al. [38] combined blockchain, a shared network, and consensus algorithms to build a government information resource (GIR) sharing model, in which each node has its own GIR and all nodes maintain the same area of the blockchain. It avoids the whole network collapse caused by the interruption of a single node, but it is unable to accurately identify similar GIR.

Karagiannis et al. [39] focused on the financial industry, arguing that a blockchain solution enhances security and trust in the process of information sharing; in addition, information shared among financial institutions is added as the basis for collaborative security services such as risk assessment. Lazuashvili et al. [40] considered land-related departments, focusing on a series of issues such as land circulation and registration ownership, information sharing among relevant departments, and integration of blockchain into land registration services; however, their scheme is only for specific business scenarios, and the security must be strengthened.

Under the impact of COVID-19, scholars are also researching information sharing in emergencies. Chen et al. [41] proposed a new framework of epidemic emergency intelligence organization management combined with a blockchain distributed trust mechanism. Tab. 2 compares the aforementioned single-chain G2G schemes, where the "+" and "−" signs indicate whether or not the stated condition is met, respectively, and the number of signs indicates the level to which the condition is met.

Table 2: Single-chain G2G applications

Scheme	Platfor m	Diversity	Anti-modification	Privacy	Sharing efficiency	Security
Li et al. [34]	Alliance chain	+	+	++	+++	+
Hao et al. [35]	Alliance chain	+	+	+++	++	++
Liu et al. [36]	Private chain	+	+	+++	+++	+++
Piao et al. [37]	Alliance chain	+	+	++	++	+++
Wang et al. [38]	Alliance chain	+	+	++	+++	++
Karagiannis et al. [39]	Alliance chain	−	+	+	++	++
Lazuashvili et al. [40]	Alliance chain	−	+	+	++	+

3.2.2 G2B

In enterprise-oriented application scenarios, sensitive information is generally hidden. Therefore, scholars are committed to the protection of private information and access control for different organizations.

Fu [42] focused on data sharing between governments and enterprises and proposed building a blockchain-based G2B system to form a virtual network that incorporates multiple G2B systems; based on blockchain, it forms multiple authentication centers through the enterprises' virtual links to provide services for enterprise management data and form a blockchain Internet, and the construction of this network makes up for the loophole that the data of the current enterprise government system may be tampered with. Guo [43] reasoned that blockchain technology can enhance the efficiency of credit transactions while ensuring authenticity and security.

Engelenburg et al. [44] established an enterprise-led G2B blockchain scheme to solve the problems that enterprises refusing to share competitively sensitive information. Both government and businesses use private keys to encrypt their Merkle roots to ensure data authenticity. Federated access control technology combines the authority control of agencies, which makes it possible to obtain secure access to specific information shared to provide for the needs of different departments in different agencies.

E-commerce is now an important part of life for Chinese citizens. Blockchain-based e-commerce tax platforms [45] combined with banks, taxation departments [46], and merchants enhance the transparency of information while improving efficiency and avoiding tax evasion. Similarly, in cross-border energy trading, blockchain can unite governments and energy suppliers and demanders to complete transactions automatically through smart contracts, weaken the centralization of national institutions, and build a transparent, secure, and stable transaction chain for all parties There have also been relevant studies of applying blockchain technology to establishing blockchain shared databases [47,48], archive data protection and sharing methods [49], and big-data open sharing systems in science and finance [50].

3.2.3 G2C

Patole et al. [51] suggested that governments solve the problem of identity forgery by placing personal identifiers on the blockchain, and they proposed corresponding solutions. Taking talent employment as an example, from the perspective of data circulation, Lu et al. [52] discussed secure

data transmission based on blockchain technology for protecting the security of personal information and the rights and interests of all parties. Both of these solutions are aimed at sensitive data stored in government databases, such as personal identity information and academic information; however, they both simply build a framework, and there are no details about stress testing and concurrent processing for practical applications.

Salah et al. [53] argued that disclosing review information is also very important, so they realized an online review system based on blockchain. Ethereum blockchain is used as the underlying platform, and smart contracts and the Inter Planetary File System are used to realize a transparent, secure, and reliable review platform. In this way, reviewers can upload and share their comments to effectively avoid false or malicious comments.

Li et al. [54] designed a digital rights transaction model based on an alliance chain to solve the problems of the high cost of digital rights registration and vulnerability to attack and tampering; it realizes a transaction model with no transaction cost and a short registration time, but regarding the implementation of digital copyright, there is still a need to communicate with the courts and other institutions. Niu et al. [55] wondered whether it was possible to protect users' privacy and punish malicious users in a public wireless local area network (WLAN). They proposed a solution based on a public chain and Intel Software Guard Extensions so that users in a public WLAN can access anonymously, be accountable, and be managed securely and safely; the solution is based on a public chain, has no threshold, and has a wide range of applications, but the code involved in the implementation may be attacked, and the security must be improved. Fig. 5 shows the distribution summary of single-chain GIS.

Singhal et al. [56] leveraged blockchain technology to build a personal document locker, using the Ethereum blockchain to securely store personal documents with high availability in a DAPP. Organizations or institutions with verification needs can make a request to the owner, and after approval, the shared document can be viewed in an encrypted URL. This solution provides a solution from another perspective, returning the data initiative to individuals. Compared with other schemes that require a trust endorsement from government agencies, this scheme is more acceptable.

3.3 Multi-chain

To date, most blockchain projects have been pilot ones. Because of various underlying architectures, data structures, and access standards, it is difficult to communicate and exchange data among multiple blockchains, but such problems can be solved by cross-chain technology. Because of the different levels of confidentiality of government information, the authority of each government department is also different. Four mainstream cross-chain technologies [57] are notary, side/relay chains, hash locking, and distributed private key (DPK), none of which are suitable for the context of GIS. The comparison of the four cross chain solutions is shown in Tab. 3.

The notary cross-chain scheme transmits and exchanges value through a third party notary [49]. Due to the possibility of corruption of notaries, there is a high probability of network collapse caused by single point, and any government data leakage will have a huge negative impact on citizens, so this scheme is not suitable for information exchange for government departments. A DPK cross-chain [58] stores a private key distributed based on a relay chain, thereby reducing the possibility of a single point of collapse; this is a comprehensive improvement on notarization and relay chains, but currently DPK control technology is still in the exploratory stage, the design and configuration of the smart contract are not perfect, and there are still large loopholes in practical application [59].

Table 3: Comparison of cross-chain solutions

	Notary	Side/relay chains	Hash locking	Distributed private key
Interoperabili ty	All	All	Cross-dependency only	All
Security	Low	Low	Medium	Medium
Cross-chain transactions	Support	Support	Support	Support
Trading speed	Slow	Slow	Medium	Medium
Difficulty in achieving	Moderate	Difficult	Medium	Medium
Scalability	Notary decision	Parallel extension	Parallel extension	Parallel extension
Representative project	ILP	Plasma,Wecorss	Lignting network	Wanchain, fusion

3.3.1 Sidechains Increase Information Scalability

As well as the main chain, there can be multiple sidechains, and data transfer between the sidechains and the main chain can be achieved through a two-way pegging mechanism. In this way, the pressure on the main chain is reduced and its performance is extended.

Guo et al. [60] proposed a secure two-way pegging multi-sidechain architecture with parallel processing of sidechains to increase throughput; different sidechains provide variable functions, and using licensed sidechains ensures user privacy and is effective for preventing transaction-order-dependence and denial-of-service attacks. This solution enables the isolation of functions and data among different blockchains and is suitable for cross-regional information-exchange scenarios among government departments, but it does not consider whether a security breach in a sidechain or the main chain will affect other chains and result in the collapse of the whole architecture. The parallel architecture of multiple sidechains proposed by Yun [61] realizes an index among main sidechains through two-way pegging technology and a smart-contract configuration; resources among main sidechains are independent and isolated from each other, and if there is a security problem, it can be separated in time to avoid contaminating other chains.

Rožman et al. [62] merged blockchain-based shared manufacturing (BSM) and the sidechain architecture to implement the main chain required by BSM through smart contracts. The scheme separates the functions of the side chain and the main chain, makes up for the shortcomings of the original main chain through the side chain, and improves the throughput and processing efficiency of the system. Zhang et al. [63] and Jin et al. [64] ensured the security and privacy of the structure by deploying a multi-sidechain structure and smart contracts in a smart grid scenario, making it feasible to realize in actual systems.

3.3.2 Hash Locking Increases Message Actionability

Hash locking is an off-chain transaction technology based on the Lightning network. It requires the middleman and receiver of a transaction to give the correct hash value within a given time, thus obtaining access to the assets of the previous person in the transaction chain.

Li [65] proposed an improved algorithm that encrypts the transmission of existing hashes based on hash locking and can verify whether the accepted hash has been tampered with. This scheme improves the security of the hash-lock approach to a certain extent, but the main scenario across chains is still between two point-to-point chains.

Zie et al. [66] proposed a new atomic cross-chain exchange protocol. The multi-signature mechanism is added to extend the support of atomic exchange to blockchains without hash-locking and time-locking functions without additional trust requirements. Users can conduct P2P transactions between blockchains with smart contracts and blockchains with only multi-signature transactions. This scheme extends the application scenario of hash locking to ensure security. Imoto et al. [67] proposed an atomic cross-chain protocol to improve the space complexity and local time complexity. Multiple threshold signatures are added to the hash-locked algorithm to set a time condition for triggering the contract according to the number of signatures sent to the contract. This solution addresses the situation in which multiple chains have inconsistent requirements with each other and is suitable for the interaction of multiple blockchains. Zhang et al. [68] extended the transaction model to multiple parties on the basis of cross-chain atomic exchange between two parties, and they proposed an optimal price algorithm for multi-party transactions through a mathematical notary cross-chain model; combining this algorithm with hash locking, the interaction between multiple parties and multiple chains is achieved while ensuring fairness.

4 Case Study of Blockchain Applied to Government Information Sharing

Blockchain information sharing and disclosure have ushered in an explosive period. According to the 2020 government blockchain white paper [60] issued by the China Academy of Information and Communications Technology, in the first half of 2019, local governments in China announced 13 application projects of "blockchain + e-government," and six blockchain government projects were under construction, far exceeding the 12 applications in 2018.

4.1 Systematic Analysis of Blockchain Projects

To meet the needs of the Chinese government for simplification, integrity, and information disclosure, the application scenarios focus mainly on building an authentication platform through digital identity to lay the foundation for developing public services and government management, such as digital identity, basic platforms, etc. The information resources of different institutions are connected and integrated so that the information related to public-interest supervision can be recorded and disclosed in the whole process [58], such as taxation, supervision, justice, real estate transactions, etc. The classification of application scenarios is shown in Fig. 6.

1. Real estate. Blockchain technology is reflected mainly in the data management of real-estate transactions and leasing. Connecting the transaction data to the Housing Administration Bureau, the Land and Resources Bureau, the Tax Bureau, and other departments allows the exchange of information, simplifies the transaction process, and improves efficiency. Such platforms include the Beijing Real Estate Platform, Xiongan City [69], and Hebei province blockchain housing rental application.

2. Digital identity. Digital identity can be subdivided into citizenship and electronic licenses. Citizens share trust with the government through blockchain and they can switch scenes according to different roles.

3. Justice. The application of blockchain justice is still focused on evidence collection and storage. One-stop service can be achieved by connecting superior and subordinate courts, public security, and procuratorial departments through the blockchain platform.

4. Taxation. The type of invoices used most widely by tax departments are electronic ones. The combination of blockchain and electronic invoices can ensure the authenticity of invoices and that they cannot be tampered with. In addition, there are also electronic tax archives and financial data declarations, mainly for enterprises and government departments, which are G2B applications.

5. Regulation. Blockchain-based regulation is an active research direction. Currently, it is used mainly in public bidding systems for government and other institutions and makes information public to society. Blockchain technology can ensure the fairness and transparency of the bidding process and prevent black-box operations.

6. Commercial services. The services for enterprises are relatively scattered, including business registration, copyright registration, traceability, supply-chain services, etc. In terms of copyright registration and traceability, the anti-tampering feature of blockchain technology and information disclosure can make the whole process transparent, thus effectively preventing infringement and reducing civil disputes.

7. Civic services. For basic public services, the government promotes the combination of blockchain with multiple fields—such as energy, healthcare, elderly care, community, public welfare, and poverty alleviation—to build a large-scale comprehensive service platform [70] for the people.

8. Basic platforms. Blockchain-based basic platforms constitute an indispensable part of governments [71]. The Fuzhou "urban brain" and the Beijing directory blockchain are such projects to promote blockchain and realize the unified scheduling, management, and control of government data.

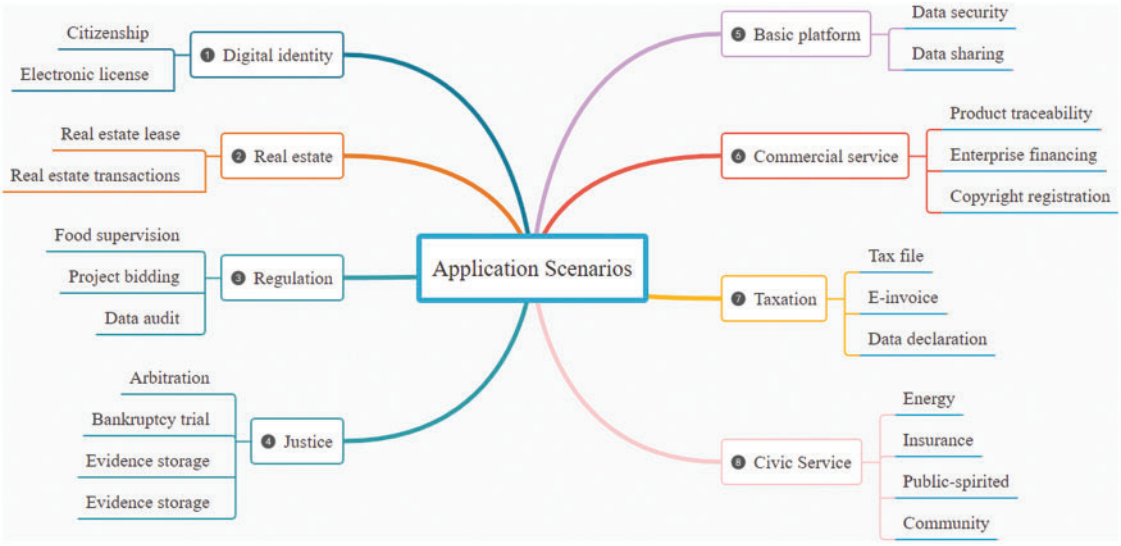

Figure 6: Breakdown of project application scenarios

4.2 Example Case Study

Officially put into use in 2017, the Nanjing Blockchain-based E-Certificate Platform [72] was the first blockchain sharing platform for government affairs in China. It integrates data from multiple

government departments—including public security, civil affairs, social security, and taxation—to provide a full range of government services to the public after real-name authentication. The basic architecture of the platform is shown in Fig. 7.

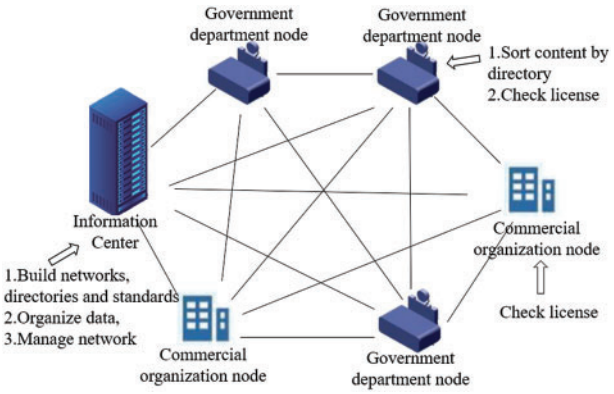

Figure 7: Architecture of nanjing blockchain-based E-certificate platform

There are three types of blockchain nodes: information center, government department, and commercial organization. The information center has four tasks: (i) to contact other government departments and jointly build a blockchain sharing network; (ii) to formulate rules for the shared ledger and smart contracts; (iii) to collate and analyze data; (iv) to manage and maintain the blockchain sharing platform, to establish on-chain standards, and to realize secure data sharing on the chain. The nodes of the police and other government departments are responsible for collecting data on the shared ledger according to the set rules and querying the data of other departments through the shared network.

Government-department nodes and information-center nodes form an intra-city e-certificate group network. Nodes with access rights can not only improve citizen information according to smart contracts but also obtain authorized license inspection services. E-certificate group network realize the routing function from national index chain to urban information chain, which is used for cross-regional transmission from index information to all detailed information. Account types include node account, corporate checking account, and company account.

The main data stored in the blockchain include mainly citizen information and the collection of transaction records, which form a public ledger that is used to establish a directory system of all legal entities and citizen information, record the process of information collection, share the whole information to all nodes within the city, and extract indexed information to share it to the national index chain. Smart contracts then operate automatically according to the set catalog rules and privacy rules. For example, in the traditional offline centralized process, the bureau of land and resources carries out real estate registration, while the real estate bureau carries out transactions. The result of data not being shared is that if the property is mortgaged or frozen, its normal transaction will not be affected, disputes occur from time to time after the sale of real estate. However, with the blockchain system, the land and resource bureau and the real-estate bureau jointly maintain property records, which are automatically synchronized and updated to the two departments; based on such information, both sides realize sharing, solve difficult problems of information mismatch, and avoid property-rights disputes. The process of uploading real estate information is shown in Fig. 8

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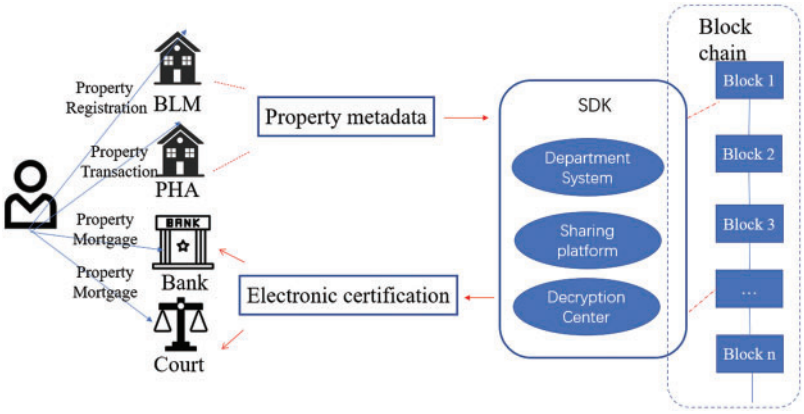

Figure 8: Property data upload process

As of 2019, the Nanjing Blockchain-based E-Certificate Platform [73] was connected to more than 30 departments (e.g., public security, civil affairs, land and resources, real estate, human resources), 130 matters (e.g., real-estate registration, sales, house purchases), and 36 e-certificates. This platform realizes business linkage and set up a comprehensive window. An applicant can complete on-site verification by taking the submitting materials.

The blockchain-based e-certificate technology enables the "Internet + government" service platform to achieve a closed circle, with the online business extended to more than 1600 projects. According the specifications of the public security system, when the registered residence information cannot be fully opened to the counterpart departments, the population information and the verification results are shared to meet the needs of more than 60 departments and relevant departments for the verification of registered residence information. According to public information, the Nanjing Blockchain-based E-Certificate Platform has operated stably for 20 months without accidents, failures, or data leakage.

5 Conclusions

Most countries have embraced digital government and are starting to consider how to apply new technologies to optimize digital government. Blockchain can be used to solve the problems of inconsistent technical standards of the digital government systems, inconsistent authority data of various departments, and insufficient transparency of the approval process. The advantages of using blockchain technology to transform the digital government system are obvious: the rights of data use, of ownership and of processing are clear, which will promote government data sharing and business collaboration. Based on the smart contracts, blockchain can: (i) establish an automatic processing mechanism for agreements, rights, and responsibilities through procedures, (ii) establish a government data integration and exchange mechanism with clear responsibilities, controllability, credibility, and traceability, (iii) replace manual confidentiality agreements with smart contracts, (iv) provide external results without leaving the original platform, (v) ensure data ownership, and solve the core trust problem in the process of data exchange. However, the application of blockchain to government information sharing also faces challenges in terms of trade-offs, efficiency, and supervision.

Scholars have studied how the blockchain is applied to government information sharing, and the results can be simply divided into three categories: government, commercial companies and individuals. In the blockchain pilot projects that have carried out so far, barriers to information interaction have been formed because of different chain platforms, different consensus mechanisms,

and different encryption methods. Although the emergence and research of cross-chain have brought hope to break those barriers, such technology has great limitations and is still in the initial stage of research, so more application scenarios must be explored.

China's practice of blockchain in government information sharing is also distributed in various application scenarios. Nanjing electronic license platform is a typical project of blockchain application. Compared with the past, it has higher efficiency and lower error rate, and is generally praised by users. But again, the geographical barriers between provinces and cities are not broken. Interoperability with other regions is not enough. Moreover, most pilot projects only introduce blockchain technology into the established data sharing platform, and do not establish a suitable model for the characteristics of government information sharing and blockchain.

Future research of blockchain and GIS can focus on the following aspects: (i) further promote cross-level and cross-discipline data sharing, strengthen the exploration and construction of data-sharing models for government blockchain, and improve the depth of blockchain data sharing. Break the boundary that government data only flows within government agencies, promote data collaboration, and add more nodes to continuously form a larger "chain network"; explore the depths of blockchain data sharing. (ii)Pay attention to privacy protection issues in the field of government information sharing. Ensure that government departments who possess enterprise data can realize multi-department data fusion calculation without revealing private data, complete the credit evaluation and control of enterprises, and realize the privacy protection of data between various departments. (iii) Strengthen supervision, pay attention to the tamper-proof problem in the process of government information sharing, ensure the trusted relationship in data sharing and transmission, and guarantee the transparency of information sharing processing. Avoid becoming a hiding place for illegal and criminal activities.

The application of blockchain in governments is expected to change the current trend of centralization in collection, control, usage, and distribution of rights and interests of government data, and promote mutual trust, sharing, balance and transparency of digital government, to completely improve the production relationship of government data and create a new model different from the industrial economy.

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References

[1] Y. M. Wang, "Frontiers and enlightenment of global e-government development——Interpretation of "2020 united nations e-government survey report"," *Administrative Reform*, vol. 1, no. 12, pp. 43–49, 2020.

[2] E. M. Styrin, N. E. Dmitrieva and L. H. Sinyatullina, "Government digital platform: From concept to implementation," *Public Administration Issues*, vol. 1, no. 4, pp. 31–60, 2019.

[3] X. R. Zhang, J. Zhou, W. Sun and S. K. Jha, "A lightweight CNN based on transfer learning for COVID-19 diagnosis," *CMC,Computers, Materials & Continua*, vol. 72, no. 1, pp. 1123–1137, 2022.

[4] S. Nakamoto, "Bitcoin: A peer-to-peer electronic cash system," 2008, [Online]. Available: https://bitcoin.org/bitcoin.pdf.

[5] G. Guowei, G. Zhangli and L. Yongxian, "Research on collaborative sharing mode of government basic information based on blockchain," *E-government*, vol. 1, no. 2, pp. 15–25, 2018.

[6] F. T. Hjalmarsson, G. K. Hreidarsson, M. Hamdaqa and G. Hjalmtysson, "Blockchain based e-voting system," in *11th IEEE Int. Conf. on Cloud Computing (CLOUD) Part of the IEEE World Congress on Services*, San Francisco, CA, pp. 983–986, 2018.
[7] E. Bellini, P. Ceravolo and E. Damiani, "Blockchain based e-vote as a service," in *12th IEEE Int. Conf. on Cloud Computing (IEEE CLOUD) Held as Part of IEEE World Congress on Services (IEEE SERVICES)*, MIlan, Italy, pp. 484–486, 2019.
[8] P. Joshi, S. Kumar, D. Kumar and A. K. Singh, "A blockchain based framework for fraud detection," in *2nd Int. Conf. on Next Generation Computing Applications (NextComp)*, Mauritius, 2019.
[9] Y. Jiao, P. Wang, D. Niyato and Z. Xiong, "Social welfare maximization auction in edge computing resource allocation for mobile blockchain," in *IEEE Int. Conf. on Communications (ICC)|Workshop on Integrating UAVs into 5G*, Kansas City, MO, 2018.
[10] P. F. Tsai, "The EU judicial legal assistance through electronic delivery document with certain research of blockchain," *Journal of Internet Technology*, vol. 21, no. 6, pp. 1829–1833, 2020.
[11] A. Verma, P. Bhattacharya, D. Saraswat and S. Tanwar, "Nyaya: Blockchain-based electronic law record management scheme for judicial investigations," *Journal of Information Security and Applications*, vol. 63, pp. 1–13, 2021.
[12] X. R. Zhang, X. Sun, W. Sun, T. Xu and P. P. Wang, "Deformation expression of soft tissue based on bp neural network," *Intelligent Automation & Soft Computing*, vol. 32, no. 2, pp. 1041–1053, 2022.
[13] C. S. Chung and S. B. Kim, "A comparative study of digital government policies, focusing on e-government acts in Korea and the United States," *Electronics*, vol. 8, no. 11, pp. 1362, 2019.
[14] W. Wang, "Application of blockchain technology in government data sharing," M.S. dissertation, Jilin University, China, 2020.
[15] I. Fauzi, R. W. Wardhani, S. Muhasyah and M. Delina, "The study of blockchain technology in election system," in *8th National Physics Seminar*, Univ Negeri, Jakarta, Indonesia, 2019.
[16] S. N. Shan, X. Duan, Y. Zhang, T. T. Zhang and H. Li, "Research on collaborative governance of smart government based on blockchain technology: An evolutionary approach," *Discrete Dynamics in Nature and Society*, vol. 2021, pp. 1–23, 2021.
[17] A. Kiayias and P. Lazos, "Sok: Blockchain governance," [Online]. Available: https://arxiv.org/abs/2201.07188, 2022.
[18] R. Qi, C. Feng, Z. Liu and N. Mrad, "Blockchain-powered internet of things, e-governance and e-democracy," *E-Democracy for Smart Cities*, vol. 1, pp. 509–520, 2017.
[19] V. Patel, "A framework for secure and decentralized sharing of medical imaging data via blockchain consensus," *Health Informatics Journal*, vol. 25, no. 4, pp. 1398–1411, 2019.
[20] S. Tanwar, K. Parekh and R. Evans, "Blockchain-based electronic healthcare record system for healthcare 4.0 applications," *Journal of Information Security and Applications*, vol. 50, no. 1, pp. 102407, 2020.
[21] X. Z. Peng, J. Q. Zhang, S. B. Zhang, W. N. Wan, H. Chen *et al.,* "A secure signcryption scheme for electronic health records sharing in blockchain," *Computer Systems Science and Engineering*, vol. 37, no. 2, pp. 265–281, 2021.
[22] M. Du, Q. Chen, J. Xiao, H. Yang and X. Ma, "Supply chain finance innovation using blockchain," *IEEE Transactions on Engineering Management*, vol. 67, no. 4, pp. 1045–1058, 2020.
[23] L. Liu, Y. Li and T. Jiang, "Optimal strategies for financing a three-level supply chain through blockchain platform finance," *International Journal of Production Research*, vol. 1, no. 1, pp. 1–18, 2021.
[24] S. Trivedi, K. Mehta and R. Sharma, "Systematic literature review on application of blockchain technology in e-finance and financial services," *Journal of Technology Management & Innovation*, vol. 16, no. 3, pp. 89–102, 2021.
[25] Y. Fu and J. Zhu, "Operation mechanisms for intelligent logistics system: A blockchain perspective," *IEEE Access*, vol. 7, no. 1, pp. 144202–144213, 2019.
[26] H. Yi, "A secure logistics model based on blockchain," *Enterprise Information Systems*, vol. 15, no. 7, pp. 1002–1018, 2021.

[27] N. S. Alghamdi and M. A. Khan, "Energy-efficient and blockchain-enabled model for internet of things (IoT) in smart cities," *Computers Materials & Continua*, vol. 66, no. 3, pp. 2509–2524, 2021.
[28] J. Wu and N. K. Tran, "Application of blockchain technology in sustainable energy systems: An overview," *Sustainability*, vol. 10, no. 9, pp. 3067, 2018.
[29] L. H. Yin, C. Li, F. Li, C. Huang, T. J. Luo *et al.,* "A traceable capability-based access control for IoT," *Computers Materials & Continua*, vol. 72, no. 3, pp. 4967–4982, 2022.
[30] A. G. Anagnostakis, N. Giannakeas, M. G. Tsipouras, E. Glavas and A. T. Tzallas, "IoT micro-blockchain fundamentals," *Sensors*, vol. 21, no. 8, pp. 1–24, 2021.
[31] D. Pavithran, K. Shaalan, J. N. Al Karaki and A. Gawanmeh, "Towards building a blockchain framework for IoT," *Cluster Computing-The Journal of Networks Software Tools and Applications*, vol. 23, no. 3, pp. 2089–2103, 2020.
[32] G. Jayabalasamy and S. Koppu, "High-performance edwards curve aggregate signature (hecas) for nonrepudiation in IoT-based applications built on the blockchain ecosystem," *Journal of King Saud University-Computer Information Science*, vol. 1, no. 1, pp. 1–2, 2021.
[33] H. R. Tang, C. L. Hu, T. M. Liu and J. Q. Ouyang, "A blockchain-based framework for secure storage and sharing of resumes," *Computers Materials & Continua*, vol. 72, no. 3, pp. 5395–5413, 2022.
[34] X. Li, Z. Li and B. Peng, "Research on the model of inter-agency intelligence information sharing," *Intelligence Exploration*, vol. 1, no. 3, pp. 55–60, 2021.
[35] Y. Hao, C. Piao, Y. Zhao and X. Jiang, "Privacy preserving government data sharing based on hyperledger blockchain," in *16th IEEE Int. Conf. on e-Business Engineering (ICEBE)*, Shanghai, China, pp. 373–388, 2019.
[36] L. Liu, C. Piao, X. Jiang and L. Zheng, "Research on governmental data sharing based on local differential privacy approach," in *IEEE 15th Int. Conf. on E-Business Engineering (ICEBE)*, Xian,China, pp. 39–45, 2018.
[37] C. Piao, Y. Hao, J. Yan and X. Jiang, "Privacy preserving in blockchain-based government data sharing: A service-on-chain (SOC) approach," *Information Processing & Management*, vol. 58, no. 5, pp. 1–12, 2021.
[38] L. Wang, W. Liu and X. W. Han, "Blockchain-based government information resource sharing," in *23rd IEEE Int. Conf. on Parallel and Distributed Systems (ICPADS)*, Shenzhen, China, pp. 804–809, 2017.
[39] I. Karagiannis, K. Mavrogiannis, J. Soldatos, D. Drakoulis, E. Troiano *et al.,* "Blockchain based sharing of security information for critical infrastructures of the finance sector," in *24th European Symp. on Research in Computer Security (ESORICS)*, Luxembourg, pp. 226–241, 2019.
[40] N. Lazuashvili, A. Norta and D. Draheim, "Integration of blockchain technology into a land registration system for immutable traceability: A casestudy of Georgia," in *Blockchain Forum/Central and Eastern Europe Forum (CEE Forum)/17th Int. Conf. on Business Process Management (BPM)*, Vienna, Austria, pp. 219–233, 2019.
[41] X. Chen, X. Xu, H. Shao, D. Hu, Y. Su *et al.,* "Research on the blockchain sharing system of public health safety emergency information in my country," *Chinese Engineering Science*, vol. 23, no. 5, pp. 41–50, 2021.
[42] Y. Fu and J. Zhu, "Operation mechanism for G2B system based on blockchain," *Tehnicki Vjesnik-Technical Gazette*, vol. 26, no. 6, pp. 1841–1852, 2019.
[43] S. H. Guo and Z. Q. Song, "Research on the design and application of blockchain model for credit investigation," *Chinese Journal of Network and Information Security*, vol. 4, no. 4, pp. 63–71, 2018.
[44] S. van Engelenburg, M. Janssen and B. Klievink, "Design of a software architecture supporting business-to-government information sharing to improve public safety and security: Combining business rules, events and blockchain technology," *Journal of Intelligent Information Systems*, vol. 52, no. 3, pp. 595–618, 2019.
[45] Y. M. Pan, "Exploration of constructing e-commerce tax collection and management credit system based on blockchain technology," *Modern Commerce and Trade Industry*, vol. 42, no. 35, pp. 103–104, 2021.
[46] C. Zhong and G. M. Zhang, "Application prospect and challenge analysis of blockchain technology in tax risk control," *Business Accounting*, vol. 1, no. 19, pp. 126–129, 2018.
[47] F. P. Chen, L. J. Chai and H. M. Fu, "On the co construction and sharing of characteristic databases in municipal public libraries," *Journal of the Library Science Society of Sichuan*, vol. 5, no. 5, pp. 71–75, 2021.

[48] S. T. Shen and F. Gao, "Anonymous sharing method of trusted optical network database based on blockchain technology," *Modern Electronic Technology*, vol. 44, no. 21, pp. 74–77, 2021.
[49] H. B. Tan, T. Zhou, H. Zhao, Z. Zhao, W. D. Wang *et al.,* "Archives data protection and sharing method based on blockchain," *Journal of Software*, vol. 30, no. 9, pp. 2620–2635, 2019.
[50] J. Wang, S. Wei and K. M. Dai, "Research on open sharing system of big data of science, technology and finance based on blockchain," *Modern Computer (Professional Edition)*, vol. 1, no. 22, pp. 52–58 + 78, 2018.
[51] D. Patole, Y. Borse, J. Jain and S. Maher, "Personal identity on blockchain," in *1st Int. Conf. on Advancements in Computing and Management (ICACM)*, Jagannath Univ, Jaipur, India, pp. 439–446, 2019.
[52] C. Lu, D. Batista, H. Hamouda and V. Lemieux, "Consumers' intentions to adopt blockchain-based personal health records and data sharing: Focus group study," *JMIR Formative Research*, vol. 4, no. 11, pp. e21995, 2020.
[53] K. Salah, A. Alfalasi and M. Alfalasi, "A blockchain-based system for online consumer reviews," in *IEEE Conf. on Computer Communications (IEEE INFOCOM)*, Paris, France, pp. 853–858, 2019.
[54] L. Li, S. Q. Zhou, Q. Liu and D. B. He, "Blockchain-based digital copyright transaction system," *Chinese Journal of Network and Information Security*, vol. 4, no. 7, pp. 22–29, 2018.
[55] Y. K. Niu, L. B. Wei, C. Zhang, X. Zhang and G. Vejarano, "Research on privacy protection of public wireless lAN access control based on bitcoin blockchain," *Chinese Journal of Network and Information Security*, vol. 6, no. 2, pp. 56–66, 2020.
[56] J. Singhal, A. S. Gautam, A. Bhatia, A. Agrawal, R. Kaushik *et al.,* "Dd-locker: Blockchain-based decentralized personal document locker," in *36th Int. Conf. on Information Networking (ICOIN)*, South Korea, pp. 68–73, 2022.
[57] A. T. Lu, K. Zhao, J. Y. Yang and F. Wang, "Research on blockchain cross chain technology," *Information Network Security*, vol. 1, no. 8, pp. 83–90, 2019.
[58] F. Li, Z. R. Li and H. Zhao, "Research on the progress of blockchain cross chain technology," *Journal of Software*, vol. 30, no. 6, pp. 1649–1660, 2019.
[59] Z. Y. Xu and X. Zhou, "Overview of cross chain technology development," *Computer Application Research*, vol. 38, no. 2, pp. 341–346, 2021.
[60] J. Guo, K. Gai, L. Zhu and Z. Zhang, "An approach of secure two-way-pegged multi-sidechain," in *19th Int. Conf. on Algorithms and Architectures for Parallel Processing (ICA3PP)*, Melbourne, Australia, pp. 551–564, 2019.
[61] C. Yun, "Research on scalability of blockchain based on side chain technology," M.S. dissertation, Tianjin University, China, 2018.
[62] N. Rozman, J. Diaci and M. Corn, "Scalable framework for blockchain-based shared manufacturing," *Robotics and Computer-Integrated Manufacturing*, vol. 71, no. 1, pp. 102139, 2021.
[63] L. H. Zhang, X. Y. Wang, F. Z. Hu, Y. Huang and J. Y. Bai, "Data sharing model of smart grid based on double consortium blockchains," *Computer Applications*, vol. 4, no. 1, pp. 963–969, 2020.
[64] Y. Jin, X. Danny, G. Wang and Z. Zeng, "Research on e-government big data security sharing based on block chain," *Inf. Secur. Res*, vol. 11, no. 1, pp. 1029–1033, 2018.
[65] Z. Li, "Research and application of blockchain cross-chain algorithm based on hash time locking protocol," M.S dissertation, Zhengzhou University, China, 2020.
[66] J. Y. Zie, J. C. Deneuville, J. Briffaut and B. Nguyen, "Extending atomic cross-chain swaps," in *24th European Symp. on Research in Computer Security (ESORICS)*, Luxembourg, pp. 219–229, 2019.
[67] S. Imoto, Y. Sudo, H. Kakugawa and T. Masuzawa, "Atomic cross-chain swaps with improved space and local time complexity," in *21st Int. Symp. on Stabilization, Safety, and Security of Distributed Systems (SSS)*, Pisa, Italy, pp. 194–208, 2019.
[68] S. T. Zhang, B. Qin and H. B. Zheng, "Research on multi-party cross chain protocol based on hash locking," *Cyberspace Security*, vol. 9, no. 11, pp. 57–62 + 67, 2018.
[69] Y. Li, "Xiong'an released China's first urban blockchain underlying operating system," *Hebei Pictorial*, vol. 12, no. 1, pp. 6, 2020.

[70] Z. Shahbazi and Y. C. Byun, "Blockchain and machine learning for intelligent multiple factor-based ride-hailing services," *Computers Materials & Continua*, vol. 70, no. 3, pp. 4429–4446, 2022.
[71] Z. Dlimi, A. Ezzati and S. Ben, "A lightweight blockchain for IoT in smart city (IoT-smartchain)," *Computers Materials & Continua*, vol. 69, no. 2, pp. 2687–2703, 2021.
[72] J. Huang, "Cross regional electronic license sharing platform based on blockchain technology," *Technology and Innovation*, vol. 1, no. 1, pp. 61–63, 2019.
[73] X. Min, K. Du and Y. C. Dai, "Design of electronic license sharing platform based on blockchain technology," *Command Information System and Technology*, vol. 8, no. 1, pp. 47–51, 2017.