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Information Sharing in Land Registration Using Hyperledger Fabric Blockchain

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Abstract: Blockchain technology is increasingly being recognized for its pivotal role in enhancing security, immutability, and transparency across government sectors, notably in land registration (LR) processes. This research emphasizes the need for contextually adapted blockchain technology solutions, particularly in resource-constrained and culturally diverse settings. Utilizing the elaborated action design research method, this study presents a Hyperledger-based blockchain technology system tailored for Sudan's LR, addressing technical challenges, evaluation frameworks, privacy measures, and deployment strategies. This system not only facilitates secure and transparent land transactions from planning to certificate issuance, but also integrates the management of land sales, significantly reducing the need for intermediaries. By providing a detailed exploration of the system's goals, technical hurdles, and practical deployment insights, this research contributes valuable knowledge to the implementation of blockchain technology in LR, with findings that are applicable to similar contexts globally. This study underscores the importance of customizing blockchain solutions to meet the unique requirements of different environments, thereby advancing digital government in resource-constrained settings.

Keywords: land registration; blockchain technology; Hyperledger Fabric; digital government; digital assets

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1. Introduction

Digital government is the utilization of information and communication technology (ICT) in order to offer efficient public services in ways that guarantee integration and a smooth flow of administrative processes internally and externally [1,2]. Blockchain technology in particular is emerging in the public sector as a secure and transparent technology platform in digital government [3]. For example, the land registration departments of several countries have initiatives on the use of blockchain technology [3]. The power of blockchain technology lies in several features such as smart contracts [4], immutability [5], transparency and trust [6], and safe asset transfer [7], among many others. The decentralization capability also offers several attractive features such as anonymity and peer-to-peer authentication, and auditability [8], in addition to openness and extensibility [9,10].

This study uses land registration as its case study. Land registration functions across a range of stakeholders with the primary objective being to safeguard land ownership rights, thereby preventing unlawful disposals and streamlining the resolution of land disputes. In a government-to-government (G2G) context, the land registration department collaborates closely with the urban planning bodies responsible for land allocation and planning. For citizens (G2C), it offers services like issuing land ownership certificates and overseeing the legal transfer of land, whether through sales or inheritance. The department also maintains a strong relationship with its workforce (G2E), providing a suite of benefits including training programs, incentives, and employment opportunities. In the private sector (G2B), it engages with financial institutions, particularly in matters related to mortgages and regular payments. Of particular note is the distinct governance structure for Islamic Sharia-based land registration. Governed primarily by the Quran, this system has unique features, especially in the areas of inheritance and mortgage [11].

This study aimed to develop a blockchain-based land registration system for resource-constrained countries with diverse cultural contexts. Specifically, the study sought to answer the following primary research question: how could blockchain technology be designed in the context of land registration in resource-constrained countries with diverse cultural contexts?

This primary question is linked to the following two secondary questions:

- What are the gaps in existing practices in the context of land registration in resource-constrained countries with diverse cultural contexts?
- How could land registration systems be improved using blockchain technology?

Blockchains could guide us to a new approach of network computing wherein private value transfers of money, assets, and contractual preparations can be conducted in an automated and dependable mode through computational systems [12].

This study makes a contribution to three areas. Firstly, it contributes to the literature on digital government in resource-constrained countries, especially for those countries that are strongly influenced by a religious culture, by introducing blockchain technology at both the national and social levels. Secondly, this study contributes to the literature on information sharing by presenting how blockchain technology could improve information sharing and exchange between different sectors in the context of digital government. It tracks the land registration life cycle in terms of land being formally assigned by governments to citizens, land title registration, the selling of land, and land ownership transfer by making use of blockchain technology to achieve ownership trust. The proposed system simplifies land management by shrinking its processes, as it removes several steps that are usually repeated. Instead, the proposed system keeps traceable and unalterable logs of the processes, which are shared with all stakeholders to be accessed via a secure channel. Thirdly, this study contributes to practices by creating a secure and trustable blockchain technology artefact that improves digital government ecosystems in resource-constrained countries.

The remainder of the study includes a literature review in the second section and the methodology in the third section. The fourth section presents a description of the current system. The fifth section presents an analysis of the current system. The sixth section describes the proposed system. The seventh section demonstrates the proposed system's functionality. The eighth section describes the limitations. The ninth section presents the conclusions. The last section details the further research.

2. Literature Review

2.1. Digital Government and Information Sharing

In public sector management, the primary responsibilities include ensuring a country's economic growth and establishing policies and strategies aimed at citizen well-being. However, much of the existing public sector management is perceived as being inefficient, unresponsive to citizen needs, and overly bureaucratic [13].

Digital government has been defined as the proper utilization of ICT in order to offer efficient services in a way that guarantees integration and smooth business flow internally and externally [1,2]. Digital government incorporates other important values such as openness, accountability, and citizen participation [14]. According to [15–17], digital government involves several forms of interactions, as illustrated below: G2C collaboration focuses on the techniques involved in how governments deliver services and respond to citizens' needs; G2B collaboration focuses on the processes and structures that realize the relationship between governments and the private sector; the G2G partnership focuses on the processes and constructions that fulfill the needs between a central government and the governmental sectors and authorities; and the G2E interaction focuses on how internal employees meet their cases in order to achieve proper productivity. However, digital government faces multiple challenges in its execution. Common issues in existing architectures include a lack of system integration, unified information standards, flexibility, adaptability, compatibility, scalability, reusability, performance, and stakeholder trust [18].

Given these complexities, it is essential to understand the impact on information sharing. Information sharing is crucial for collaborative activities, especially in digital government initiatives [19,20] where no single institution has all of the resources needed to operate independently [21]. Recognizing this, managers and IT personnel emphasize the importance of sharing information to enhance efficiency [22], facilitated by integrated, accessible, and usable data [22,23]. Extant research in the literature also suggests the multiple benefits of effective information sharing, including increased productivity, improved public accountability, better decision making, cost reduction, revenue growth, and enhanced services [24,25]. Information sharing in the public sector is characterized by four key elements: social actor networks with mutual trust, sharing both implicit and explicit information, data integration, and communicative hardware/systems [21].

However, there are also obstacles to overcome within information sharing. Privacy concerns pose significant risks [26], as sharing sensitive data may violate citizens' rights under country-specific regulations [26]. Therefore, building trust among participants is essential for maintaining data confidentiality [20]. On an operational level, frameworks suggest various supportive strategies, such as encouraging the use of shared information, adopting sharing practices at the managerial level, and fostering trusted relationships based on mutual needs and joint responsibilities [19]. Technical issues also exist, such as the need for secure, immutable systems [27] that control access and prevent data manipulation [22]. In addition, the heterogeneity of systems across different institutions complicates integration [21,22]. Additional challenges include the lack of unified standards, ensuring high data quality, and providing transparent tracking of data origin and distribution [28,29].

The landscape of digital government and information sharing poses unique challenges, but emerging technologies like blockchain offer promising avenues for fostering secure, efficient, and transparent collaboration.

2.2. Blockchain's Capability for Information Sharing

Blockchain technology presents a promising avenue for enhancing effectiveness in the public sector by fostering trusted, tamper-proof collaboration among governmental institutions [30,31]. This technology can serve as a secure, reliable infrastructure for information sharing, aiding primarily in decision-making processes [32] to meet the needs of the workforce and beneficiaries [31,33]. For example, blockchain can facilitate the transparent and secure exchange [29] of various types of information among governmental institutions, such as judicial records, academic certifications, supply chain data, and land information.

Enhanced stakeholder interaction and a more robust regional information-sharing infrastructure can be achieved through blockchain, given its key features [33]. Smart contracts, for instance, can act as catalysts for digital transformation, disrupting traditional workflows and business architectures. The traceability and transparency of ledger transactions improve the trust and accountability between citizens and governments. Sharing a ledger among trusted parties enables the creation of innovative "smart" services that extend beyond traditional organizational boundaries [24]. Moreover, blockchain's inherent features like traceability and tamper-proofing offer primary advantages, while secondary benefits such as transparency, accountability, effectiveness, speed, and information sharing arise from its structural and environmental attributes [29].

The challenges in both digital government and traditional land registration systems make it clear that innovative solutions like blockchain could offer a unified approach to enhance security, efficiency, and public trust in these crucial public sector domains.

2.3. Land Registration

Land registry systems serve as a critical component of both governmental and social frameworks, given the unique position of land in most communities as a source of livelihood, wealth, and, in some cases, conflict [34]. The steps involved in land registration can vary significantly based on local regulations and may involve multiple governmental bodies, each responsible for specific procedures [35].

However, traditional land registration systems, often centralized, suffer from several shortcomings. These include a lack of traceability for ownership transfers, inadequate verification mechanisms [36–38], and security vulnerabilities such as data theft and record manipulation [37,39,40]. Practices like land double-spending [37,41] and bribery [38] further exacerbate governance issues, often resulting in fraudulent land transfers and disputes. Centralized systems also contribute to operational inefficiencies, including costly verification [37,38,41] processes and delays in record updates [39].

In resource-constrained countries, additional challenges exist. Weak land administration systems [42] lead to owner frustration and hinder economic development [43]. Informal land tenure systems often escape formal registration, resulting in disputes and conflicts [44,45]. Land grabbing by powerful individuals occurs frequently, often without legal repercussions [6]. A lack of public involvement further impairs transparency and accountability in land governance [43,46].

Addressing these issues requires a comprehensive overhaul of land registration systems in resource-constrained countries, along with capacity building and resource improvement [47]. Community involvement in land governance and the protection of local and smallholder rights are also essential for sustainable solutions [46,48].

Blockchain technology offers a robust solution to the challenges seen in traditional land registration systems [12]. Its decentralized nature [49] and use of smart contracts [50] enhance transparency, reduce fraud [37,51], and streamline transaction processes [8,52]. The immutable ledger ensures data integrity [52], making unauthorized alterations virtually impossible [8]. This not only strengthens the citizen–government relationship [5], but also holds particular promise for countries undergoing transitional phases [51].

2.4. Blockchain Technology's Challenges in Land Registration

The evolution of blockchain technology from theoretical concepts to practical applications presents substantial challenges, particularly within governmental operations. Achieving the optimal utilization and implementation of blockchain technology requires a profound comprehension of its intricacies and a clear understanding of the prerequisites essential to attaining the specified objectives [53]. The main challenges confronted by the current Hyperledger forum and business organizations concern interoperability, scalability, storage, technical skills, organizational standards, and legal compliance [28,29], as follows.

Interoperability: Hyperledger Fabric uses consensus mechanisms, communication protocols, and data formats, which may differ from other blockchain platforms.

Scalability: Using Hyperledger Fabric channels that each have different participants, rules, and policies for privacy and confidentiality purposes could lead to network management complexity. Therefore, the management of multiple channels, each with its own set of participants and policies, can be resource-consuming.

Storage: Hyperledger Fabric maintains a ledger of all transactions on each node. Storing large amounts of data across multiple nodes could cause tension regarding storage capacities, particularly for organizations with limited infrastructure resources.

Technical skills: There is a lack of skilled professionals and experts in the field of Hyperledger Fabric to design, develop, and maintain Hyperledger Fabric-based solutions and to train other personnel.

Organizational standards: There is a need to establish governance models, protocols, and industry standards for Hyperledger Fabric networks, particularly in multiple-stakeholder ecosystems.

Legal compliance: Governmental legislations must formulate laws to deal with compliance issues related to data privacy, security, and sector-related regulations.

3. Methodology

Design research and case study methods offer complementary approaches to understanding the challenges in Information Systems (IS) research [54]. Design research focuses on bridging the gap between objectives and limitations, often leading to innovative solutions. It aims to simplify applications to address challenges faced by IS practitioners, thereby gaining new insights [55]. In contrast, case study research provides a qualitative lens, particularly useful for understanding the interplay between technological innovations and institutional contexts [56].

In this study, Sudan serves as the case study, employing a design research method to analyze the current land registration system (LRS). The existing practices in Sudan are complex and involve multiple stakeholders, including governmental institutions like land registration offices and urban planning departments, as well as external individuals like notaries and lawyers [57]. This study identifies five main stages in the registration process for newly allocated land, detailing the specific procedures at each stage, as illustrated by Figure 1. The entire process can take weeks or months to complete, underscoring the need for improved systems that potential leverage blockchain technology for enhancements.

Figure 1. Current land registration processes in Sudan.

In addition to blockchain features, the Hyperledger Fabric mechanism allows the building of a permissioned blockchain network that involves authenticated participants based on a modular architecture, enabling organizations to customize the network to implement governance, regulations, and legalities [31,33]. In addition, it offers confidentiality features through private channels, which ensures that sensitive information is only shared among authorized parties [24]. Based on this principle, Hyperledger Fabric emerges as a feasible blockchain for the purpose of combating corrupt practices, thereby significantly contributing to the development of resource-constrained countries, considering its feature of providing detailed transaction information for auditing, monitoring, and tracing purposes [57]. This study adopted these recommendations for designing a blockchain-based land registration system due to its capability for executing smart contracts and its additional features [58]; Hyperledger Fabric offers modularity and flexibility, with a pluggable architecture that enables easy customization and scalability to meet organizational needs [59]. Its design also allows for scalability by facilitating the addition of new nodes to accommodate increasing transaction volumes [60]. Importantly, the platform addresses security and confidentiality through its channel architecture, where only authorized nodes can access data transactions. It employs a Membership Server Provider (MSP) for identity verification [61] and a Public Key Infrastructure (PKI) mechanism for managing the digital identities of all participants [62]. This platform's features align well with the needs identified in the land registration context, offering a robust, secure, and scalable solution.

3.1. Data Collection

The first stage of the design research process employed a qualitative and interpretive approach to gain in-depth insights into the land registration context in Sudan, focusing on understanding the socio-technical dynamics through Actor Network Theory (ANT). This involved engaging various stakeholders in land registration, including government officials, ICT personnel, professional employees, and citizens, using a combination of random and non-probability sampling. Data were collected through structured interviews, ethnographic observations, and the analysis of official documents related to the land registration process. This approach aimed to capture the lived experiences and interactions among human and non-human actors within the context of introducing blockchain technology for land registration in traditional and resource-constrained environments. Using a thematic analysis with open-coding, related codes were grouped into themes from the data, and a brief narrative around each theme was created. Table 1 provides the themes and their associated codes.

Table 1. Themes and their related codes.

Theme	Codes	Narrative
Stakeholder Involvement	Government officials, ICT personnel, local communities	The findings highlight the critical role of engaging a broad range of stakeholders in the design and implementation of a blockchain solution for land registration. This underscores the importance of including government bodies, IT experts, and local communities to ensure the system's relevance and usability.
System Security	Data integrity, privacy, access control	Security emerges as a paramount concern. This finding reveals the necessity for robust data integrity measures, privacy safeguarding, and stringent access control mechanisms within the blockchain solution to protect sensitive information and prevent unauthorized access.
User Accessibility	Interface design, language support, user training	Accessibility is identified as key for user adoption. This finding suggests that the system interface should be intuitive and should support local languages, and that comprehensive user-training programs are essential for facilitating smooth transitions and usage among stakeholders.
Legal and Regulatory Compliance	Land laws, regulatory frameworks, stakeholder alignment	The need for the blockchain solution to align with existing legal and regulatory frameworks is emphasized. This finding points to the need for a thorough understanding and integration of local land laws and regulations to ensure the system's legitimacy and acceptance.
Technical Infrastructure	Connectivity, system scalability, maintenance	The findings identify challenges related to technical infrastructure, including the need for reliable internet connectivity, scalability of the system to handle growing transaction volumes, and ongoing maintenance to ensure operational efficiency.
Cultural Sensitivity	Societal norms, land ownership traditions	The importance of cultural sensitivity in the system's design is highlighted, recognizing the influence of societal norms and traditional practices on land ownership and transactions in Sudan.

The above findings contribute to the growing field of digital government research and organizational policies. The findings also equip policymakers with trustworthy digital transformation tools and methodologies, offering informed decision-making avenues that could enhance operational efficiency. This is particularly relevant in a pluralistic legal context that encompasses both Sharia law and customary laws.

The primary findings describe how the implementation of blockchain technology could enhance land registration in Sudan. The utilization of an untamperable ledger, coupled with consensus mechanisms, proves instrumental in addressing transaction-related challenges. Additionally, the study identified an opportunity to formulate a blockchain technology framework using the stages of Actor Network Theory. This innovative framework has the capacity to augment and refine services provided by land registration offices, introducing valuable features for safeguarding citizens' property. For instance, the blockchain technology framework facilitates citizens' access to land registration services for monitoring and validating the ownership of their land and assets. Furthermore, it streamlines workflow through integration and collaboration with stakeholders, emphasizing transparent transactions and an immutable ledger.

The integration of blockchain technology is a means to enhance human development by fortifying and guaranteeing property rights, ultimately mitigating conflicts over land. This technological intervention also addresses the vulnerabilities associated with single-copy paper-based titles, enhancing the reliability, authenticity, and transparency of the land registration system.

The findings also revealed the importance of comprehending the formation, advancement, or dismantling of industries with the involvement of different actors. The study predominantly utilized Actor Network Theory as a guide to make sense of the existing social, legal, and cultural processes of land registration before proposing a technological artifact.

The findings therefore contribute to organizational policy by empowering policymakers to make decisions that positively impact the land registration process through the incorporation of blockchain technology. Moreover, they add to the digital government literature by illustrating how the public sector can embrace new technologies while considering the alignment of interests. Consequently, this study offers a secure roadmap for the digital transformation of the public sector, particularly in regions with mixed Sharia and customary laws.

3.2. Current System Processes

In this section, the study considers the existing procedural mechanisms governing land allocation and ownership transfer, spanning from the initial assignment of land to a citizen by governmental authorities to the subsequent issuance of land ownership certificates. The section further explores the intricacies involved when the initial landowner opts to transfer ownership to a subsequent buyer. Each process is described in detail, elaborating on the procedures for successful completion [63]:

1. Land Allocation: In the context of Sudan, land allocation is managed by a designated governmental entity known as the Urban Planning Authority (UPA). This authority coordinates closely with several other governmental institutions, including the Civil Registry, the Ministry of Social Affairs, and the Ministry of Labor, among others. Citizens desiring to formalize their land ownership are required to navigate a series of procedural steps, culminating in the acquisition of a land ownership certificate issued by the Land Registration Authority (LRA). The initial phase of this process entails the citizen engaging with the UPA to secure a preliminary contract, which serves as the foundational document for subsequent land registration under the individual's name. This constitutes the official mechanism through which the government allocates land to its citizens.
2. Land Registration: Land registration is the process of documenting a citizen's land ownership with the official authorities to ensure the right when needed. Registration is conducted in cases of purchased land, land granted by the government, inherited land or gifted land, or land granted through a mortgage in the case of banks, large companies, or legal entities. Citizens are required to take their copies of the contract to the LRA to register their ownership of their land. This process will culminate in the land ledger being updated.
3. Ownership Certificate for the Purpose of Selling: Once the owner has delivered the ownership certificate, he/she must access the land registration system to request a land-selling certificate in order to be able to sell his/her land to a buyer through the selling process.
4. Selling Land: Only after securing a valid land-selling certificate can a landowner/seller contact a lawyer to initiate a sale of the land. It is important to point out that, like in Western countries, Sudanese lawyers are private and the sale transaction costs are

therefore handled by the landowner/seller. The lawyer is the main actor who controls the process of selling the land; he/she is responsible for documenting and contracting the sale to ensure that the agreement flows properly and legally. The selling process is considered complete when the purchase funds are delivered to the owner.

5. Ownership Transfer: Upon completion of the selling process, the buyer assumes control of the process of transferring the ownership of the land from the seller to the buyer until the delivery of the ownership certificate. This process is undertaken with the assistance of the lawyer. The new owner has the option of appointing the lawyer who was involved in the original sale of the land, or the option of appointing a new lawyer. Whichever option is adopted, the transaction costs relating to the transfer of the land from the seller to the new owner remain the responsibility of the new owner. By the end of the selling process, the owner takes his/her money and leaves, and the buyer continues the process of transferring the ownership until the delivery of his/her ownership certificate.

3.3. Analysis of Gaps in the System

The existing centralized system shows several weak points, which directly affect the workflow and the quality of the services, as illustrated in Table 2.

Table 2. Gaps in the existing land registration system.

Type	Gap	Description
Technical Improvements	Data integrity	Centralized systems are vulnerable to system failures and security attacks, leading to data loss or manipulation. Blockchain technology offers immutable ledgers, enhancing data security and availability.
Social Considerations	Transparency and fairness	Societal issues like bribery and favoritism can corrupt the land registration process. Blockchain technology eliminates this by automating procedures through smart contracts, removing the need for human intervention.
	Privacy and security	Current systems risk leaking or modifying property information, affecting court judgments. Blockchain technology secures data through enhanced anonymity and security mechanisms.
Operational Efficiency	Process streamlining	The existing system has redundant operations that consume time and resources. Blockchain technology automates these through smart contracts, improving efficiency.
	Document verification	Traditional methods like manual forms and stamps are easily falsifiable. Blockchain technology offers robust verification mechanisms, ensuring a consensus among parties.
	Accessibility	The centralized nature of current systems makes data retrieval cumbersome and region-specific. Blockchain technology ensures that the data are accessible anywhere, anytime, removing the need to visit specific offices.
Cost Efficiency	Intermediary costs	Existing systems often involve intermediaries, inflating costs for both buyers and sellers. Blockchain technology eliminates the need for such intermediaries, reducing the costs.
	Human resources	Current processes require multiple parties like lawyers and witnesses, adding complexity and cost. Blockchain technology streamlines this by making transactions direct and trusted.
Inter-Organizational Collaboration	Information sharing	Poor information sharing exists between governmental bodies, leading to redundancy and complexity. Blockchain technology facilitates seamless data integration among parties.

Considering these aspects and the other features detailed earlier, this study posits that blockchain technology can fundamentally reform the business logistics in land registration, thereby enhancing service quality.

4. Hyperledger Fabric Platform

4.1. Hyperledger Fabric

Hyperledger Fabric is a private open-source blockchain platform used at the institutional level that makes use of blockchain technology to reform its workflow and improve its services [58]. It offers mainly scalability and security through its flexible architecture, with which the whole performance can be enhanced [35,62].

The Hyperledger Fabric network involves various nodes, each of them uses an identity that is presented by the Membership Service Provider to enroll users [35,62,64]. The ledger can be divided into the world state, which is a database that contains the last up-to-date values of the object properties, and the blockchain, which is a log of transactions that holds all of the historical values in the form of connected blocks [65]. Each node possesses a ledger copy that is updated by the nodes via a consensus mechanism, which guarantees that all nodes have the same ledger copy [65,66]. A consensus is achieved through practical Byzantine fault tolerance agreement (PBFT) [67]; however, sometimes, Hyperledger Fabric also allows no consensus [8,68]. PBFT provides the peers with full control to protect the rest of the network peers from double-spending attacks, which could occur through forcing a block [7,68]. Moreover, PBFT offers privacy through providing less transparency over the network, which is more appropriate for governmental work than full transparency [9].

Hyperledger Fabric offers control over the consensus mechanism, which enables performance improvements and scalability, as a fewer number of peers are required to accept a block [8]. The main components of Hyperledger Fabric are as follows [35,69]:

1. Blockchain: Hyperledger Fabric is a private blockchain that can maintain the blockchain access control levels. Its architecture is flexible and scalable [70] in order to address a broad area of applications [71].
2. Nodes: There are two node kinds—anchor peers, which receive the blocks of data from the network and deliver them to the rest of the nodes, and endorser peers, which receive the clients' smart contract requests to emulate and verify a transaction of the smart contract [72].
3. A channel: This is communication link that connects several nodes privately within the Hyperledger [64]. Each channel possesses a separate ledger.
4. Orderer: This is considered to be the backbone of the Hyperledger Fabric network and guarantees the ledger's consistency [72].
5. Endorsement policy: The set of rules that determine the nodes that are responsible for registering the transaction approval [73].
6. Consensus mechanism: This is a technique that is executed via the Orderer to allow the parties to ensure the sequence of the nodes' approval, in addition to ensuring the order, validation, and commitment of transactions [74].
7. Chaincode: This is the smart contract that executes transactions [75] and reflects them to the shared ledger [76]. It is a code that contains the rules, conditions, and business logistics for managing the land ledger. It is implemented using a distinct docker container to keep it separated from the other operations [69].
8. MSP: The Membership Service Provider (MSP) is subsystem that administrates identities and authenticates clients using Public Key Infrastructure (PKI) in order to join the blockchain network [33].
9. Hyperledger policies: These are a set of rules that are stored in the genesis block, which governs accessing or updating the network. Any changes that could affect the participants are approved through a majority vote [72].
10. Application Programming Interface: Independent front-end applications that allow blockchain technology operations for the users are enabled through the REST API or Software Development Kit (SDK) of Hyperledger Fabric, or the SDK of the Fabric

Gateway, based on an organization's requirements [77]. Hyperledger Fabric released a number of SDKs such as Java, Go, and Nod.js, to support several programming languages [78].

4.2. Hyperledger Fabric Transaction Flow

This section illustrates how a transaction flows in a Hyperledger Fabric network [35,71,79]:

1. Propose: A transaction is proposed by the client through an application to several connected endorser nodes, based on the endorsing strategy that defines how many endorsing nodes are required.
2. Execute: All endorsers are required to execute the proposed transaction by collecting read/write responses in order to be added to the proposed transaction; therefore, the signatures of all endorsers would be needed.
3. Respond: The resulting transactions are revised and revalidated when the endorsers communicate together again; then, the read/write responses are asynchronously transmitted to the client.
4. Order: When the client receives enough endorsements, the network has to send the transaction to the ordering service. Several nodes over the network submit their transactions together to the ordering service, which defines the order of the transactions and guarantees that the same order is visible to all network nodes.
5. Deliver: The ordering service submits a block containing the transactions grouped in ordered manner to all of the network nodes.
6. Validate: After all nodes have received a new block that contains the ordered transactions, some of these transactions are flagged as being incorrect as they have not been endorsed enough: such transactions are then directly rejected by the network nodes.
7. Notify: The block containing the set of correct transactions, which are confirmed by all of the peers, is then added to the blockchain and a notification of the addition is announced via block events.

The Hyperledger Fabric protocol distinguishes between two kinds of peers: a validating peer is a node on the network responsible for running the consensus, validating transactions, and maintaining the ledger. On the other hand, a non-validating peer is a node that functions as a proxy to connect clients (issuing transactions) to validating peers. A non-validating peer does not execute transactions, but it may verify them [80]. Figure 2 below shows the transaction flow as defined by the official Hyperledger Fabric docs.

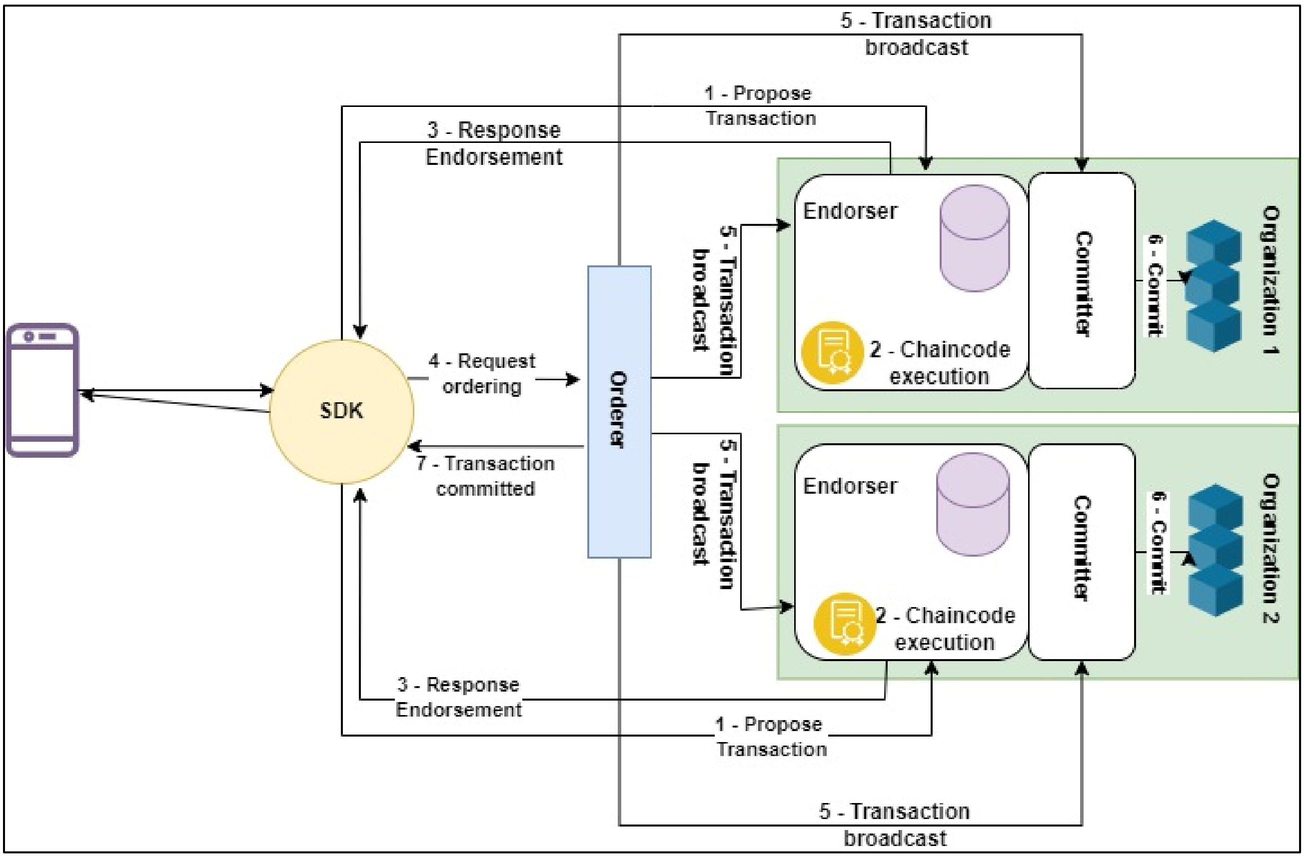

Figure 2. Hyperledger Fabric transaction flow sequence diagram.

5. Model Design

One of the key findings is the concern of transparency and data openness that could result from adopting blockchain technology; this could be attributed to the significance and sensitivity of land's value from the social, historical, and financial aspects [81]. Thus, there is a discernible preference for private blockchain technology, as it allows for certain constraints, potentially offering a safer transition from a fully centralized authority, such as with Hyperledger Fabric. The selection of a blockchain technology that has permission could be considered as an intermediate step between a centralized system and the full openness of the public blockchain technology. However, this preference may be somewhat idealistic at present, given the limited knowledge of blockchain technology among citizens and their lack of confidence in managing their property registration procedures without assistance from Land Registration Authority personnel.

In this section, the development and operational principles of a blockchain-based land registration system (BLRS) are illustrated. Our proposed Hyperledger Fabric architecture designed for efficient land registration data management encompasses aspects such as data storage and exchange between land registration service providers to optimize services for citizens. Hyperledger Fabric was chosen for this study due to its provisions for privacy, scalability, transaction efficiency, interoperability, and fine-grained access control over land registration records [82]. This selection notably reduces the turnaround time for data storage and sharing, enhances decision-making processes related to land issues and transactions, and lowers the overall costs. Furthermore, the efficiency of Hyperledger Fabric surpasses that of other public blockchains, with the capability to execute more than 3500 transactions per second [83].

The proposed architecture facilitates the creation of private permissioned blockchains, wherein various stakeholders and their end-users are identified, registered, and interconnected through distinct channels. This approach ensures maximum privacy, confidentiality, data secrecy, and scalability. Furthermore, the architecture incorporates secure and transparent Byzantine-fault-tolerant (BFT) consensus algorithms to guarantee the secure and reliable communication and exchange of land record-related data among a consortium of stakeholders [9].

5.1. System Architecture

A private blockchain network should be established, comprising three distinct nodes: the UPA, the LRA, and financial institutions (banks). Each of these nodes will be responsible for maintaining a synchronized copy of the land ledger. To automate operational procedures, chaincodes will be deployed for process automation. Given that anonymity is incongruent with the operational requirements of governmental networks—specifically the need to manage sensitive data—authentication protocols are essential. Hence, individual identifiers, hierarchical levels, and accountabilities must be clearly defined. User interaction with the blockchain system will necessitate registration and login via an API, accessible through web and mobile applications.

The initial transaction responsible for generating the block holds a unique significance as it represents the land. This transaction is to be initiated by the UPA. Upon initiation, it will be encompassed with a distinct number and certain specifications, serving as the land base block. Subsequent to any transfer of land ownership, the transaction will be recorded, and the blockchain will be updated.

This BLRS proposes the implementation of a distributed set of nodes to establish system decentralization. Specifically, each registration office will host a dedicated node. Furthermore, there will be nodes positioned at the apex of both the LRA and the UPA. This configuration ensures a robust and decentralized network. To fortify system security, each block contains a cryptographic hash of the preceding block's data. This design mitigates the potential for any tampering attempts, as any such manipulation would be readily detected.

The proposed system architecture, as depicted in Figure 3, embodies a decentralized framework of five layers, involving three parties, all operating within a unified channel.

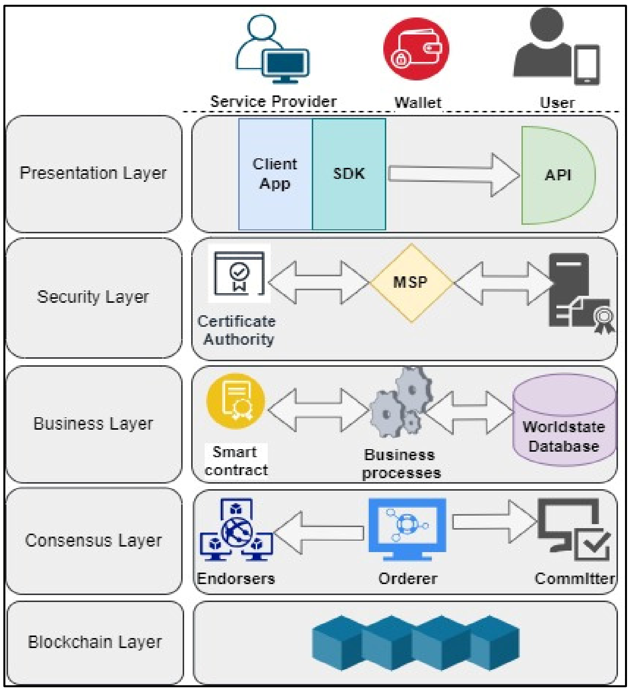

Figure 3. The proposed BLRS architecture.

The architecture of the BLRS comprises three primary levels: an operational level (the UPA, LRA, bank, and citizen), business level (the MSP, world state, Hyperledger SDK, APIs, and smart contracts), and storage level (the blockchain of the BLRS).

The BLRS's operational level includes the main parties (the UPA, the LRA, the bank), who all share the same data in the blockchain and can access an updated version of the land ledger in the world state database through the unified channel. This channel is governed by the MSP to control the access, while the transactions and processes are managed by smart contracts after passing the required verifications. The data are stored in the blockchain after running all of the required verifications and obtaining all of the required approvals to guarantee immutability.

The owner and the buyer can also access the BLRS after being enrolled through the MSP; once an owner or buyer logs in, his/her wallet is displayed. The wallet is a workspace that contains all of the owner's assets and it is where he/she is able to track his/her land and manage processes such as putting his/her land up for sale.

UPA: Two UPA operations could rely on the BLRS: either assigning land to a citizen, or verifying a document such as a survey report. The UPA could be connected to a separate channel that includes other parties such as the survey office.

LRA: The LPA generates certificates, transfers ownership, and approves changing land statuses, for example, for a sale. Moreover, the LRA is responsible for document verifications. It also orders the bank to reserve/un-reserve money.

Bank: The bank is responsible for all financial processes and verifications.

Citizen: If the citizen is new owner who is permitted a land by the UPA, he/she will access the BLRS to register the land by filling in the required form, provide the requested documents, pay the fees, and finally receive the ownership certificate. If the citizen already owns a piece of land and is looking to sell it, he/she asks for a selling certificate and pays the fees, which could lead to his/her land being put up for sale. Once he/she accepts one of the offers, he/she waits for a bank notification regarding receiving his/her money, which will be transferred to his/her account once the ownership transfer is completed. If the citizen is a buyer, he/she offers a price for the desired land after revising its specifications, pays the money, which would be reserved by the bank until the land ownership is transferred under his/her name, and receives the ownership certificate.

5.2. Hyperledger Fabric Network Setup

One of the pivotal attributes of Hyperledger Fabric lies in its utilization of private channels, enabling sets of nodes to engage in communication while safeguarding the confidentiality of their transaction details from the broader network [82]. Each channel maintains its separate ledger, blockchain, and world states, complete with segregated namespaces [84]. Additionally, applications and smart contracts have the capability to communicate through different channels, thereby enabling the exchange of ledger information [85]. This affords organizations the opportunity to enhance the confidentiality and security of their transactions, all while capitalizing on the advantages of a shared ledger [86].

As land registration is a vital component of the government's public sector, the proposed system is envisaged to fall under governmental jurisdiction, encompassing its establishment, execution, and monitoring, as well as the authorization and auditing of every user. In the initial phase, it is imperative to identify all participants, which, in turn, will facilitate the definition of transaction sequences in alignment with the workflow. Consequently, five key stakeholders have been delineated: the landowner, the purchaser, the LRA, the UPA, and the financial institution. The sequential approvals of all of these parties are essential for the seamless execution of the entire process.

To construct a network comprising these three entities—the UPA, the LRA, and the bank, each of which is equipped with a single peer (Peer0)—the following components are established:

- An organization designated for the Orderer (OrderOrg), housing a solitary Orderer node.
- Three distinct organizations (the UPA, the LRA, and the bank), each equipped with a single peer.

The network encompasses two channels: ChannelAll (inclusive of the UPA, the LRA, and the bank) and ChannelLands (specifically for the UPA and LRA) (see Figure 4). This configuration ensures that ChannelAll serves the collaborative purposes of the UPA, LRA, and bank, while ChannelLands exclusively facilitates communication between the UPA and LRA.

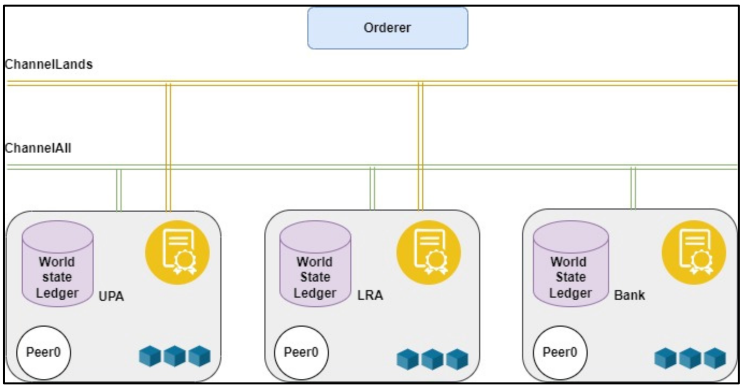

Figure 4. The proposed BLRS Hyperledger network.

5.3. Ledger's World State

The world state holds the present value of an object's attributes as a unique ledger state, as it can be challenging to traverse the entire blockchain to ascertain the current value of an object [87,88].

The ledger's world state encompasses two distinct states. The first state is known as key-value, for example (LAND1, Soba123), where key = LAND1 and value = Soba123. The second state presents a more intricate structure, for example (LAND1, {location:Soba123, area = 300, owner = Ali}), where key = LAND1 and value = {location:Soba123, area = 300, owner = Ali}. Both states exist at version 0, a version which will be incremented with each subsequent state alteration, effectively preventing concurrent updates.

The world state receives transactions containing alterations, submitted by applications through the Hyperledger Fabric SDK for eventual commitment by the blockchain [88]. Essentially, an application invokes a smart contract and awaits notification once the transaction is confirmed within the blockchain, contingent on its validity [89]. Notably, transaction changes lead to an update in the world state only if they have been authenticated by the necessary set of endorsers.

Presently, the available choices for the world state database encompass LevelDB and CouchDB [87]. LevelDB serves as the default choice, proving especially suitable when the ledger states adopt a straightforward key-value pair structure. It is closely integrated with a network node, residing within the same operating system process [62].

CouchDB emerges as a particularly fitting option when the ledger states are organized as JSON documents. This preference arises from CouchDB's robust support for intricate queries and the manipulation of diverse data types commonly encountered in business transactions [62]. From an implementation standpoint, CouchDB operates within a separate operating system process, yet maintains a one-to-one correspondence with a peer node instance [90].

5.4. Chaincodes

The chaincode constitutes a collection of smart contracts. Each of these contracts encapsulates executable logic responsible for generating new records that are subsequently appended to the ledger [65]. A smart contract establishes the operational rules between different organizations in an executable code [53]. Applications trigger a smart contract to initiate transactions, the details of which are then permanently recorded on the ledger [91]. These contracts delineate the operational model governing all interactions between transacting entities [72].

The provided code below exemplifies how two organizations, the UPA and LRA, have defined a smart contract concerning land operations, including queries, transfers, and updates. Applications from these organizations invoke this smart contract to execute a predefined step within a business process, such as transferring the ownership of a specific piece of land from the UPA to the LRA. Presented below in Table 3, Table 4 are description of the smart contract pertaining to land queries, transfers, and updates.

Table 3. Land's contract functions.

Land *contract*
create *(Id, Latit, Longt, Area, Owner, Square):* *this.Id = Id;* *this.Latitude = Latit;* *this.Longtitude, Longt;* *this. Area = Area;* *this. Owner = Owner;* *this.Square = Square;*
query *(land):* *get (land);* *return land;*
transfer *(land, buyer, seller):* *get (land);* *land.owner = buyer* *put (land);* *return land;*
update *(land, properties):* *get (land);* *land.area = properties.area-value;* *put (land);* *return land;*

Table 4. Land's contract definition.

Land *interface*
Transactions*:* *create;* *query;* *transfer;* *update;*
Endorsement Policy*:* *UPA AND LRA*

A smart contract can be automatically executed to conduct processes, provided that all predefined requisite conditions are met and duly sanctioned in accordance with the endorsement policy linked to the chaincode [53,82]. For instance, this includes verifying that the land is not mortgaged, validating the buyer's identity, and confirming that the associated fees have been paid. The endorsement policy holds paramount importance, as it delineates which entities within a blockchain network must authenticate the smart contract transaction for it to be deemed valid [91]. For instance, this may involve the UPA survey representative, the LRA registrar, and the LRA accountant.

Smart contracts encompass a range of APIs designed to engage with the world state, facilitating the creation, retrieval, modification, or deletion of business objects. Simultaneously, the blockchain maintains an unalterable record of these transactions [92]. For instance, the chaincode interacts with the ledger through the PutState and GetState APIs, allowing for the writing and retrieval of state information.

5.5. BLRS Consensus Mechanism

The proposed system integrates a communication channel that links the LRA and LPA, facilitating secure information sharing and exchange, as illustrated in Figure 5. Following this integration, the LRA user initiates the revocation process for the BLRS client application, prompting the application to propose a transaction and send it to the endorser. Once the chaincodes are executed, the endorser sends back the response. Upon successful endorsement, the BLRS client application transmits the transaction to the Orderer. Subsequently, the Orderer broadcasts the transaction to all anchor peers within both the LRA and LPA networks. Each anchor peer then distributes the transaction to all peers within its organization for validation and eventual commitment. In this manner, all decisions regarding the acceptance or rejection of any transaction are shared among the participants and reached through a consensus. Similarly, all copies of the ledgers will consistently maintain the most current version.

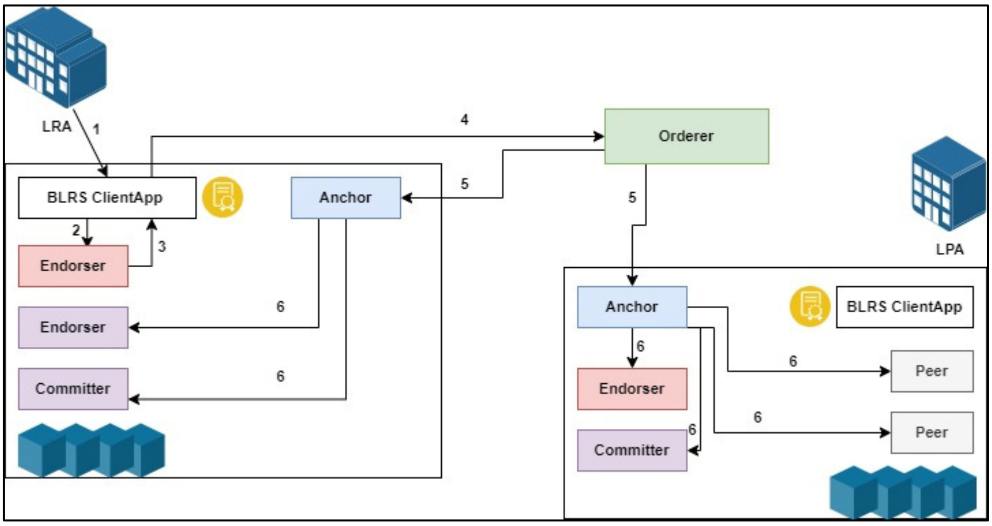

Figure 5. BLRS consensus mechanism.

6. Core Algorithms

The utilization of a private permissioned blockchain proves advantageous in ensuring owners' privacy and confidentiality, particularly concerning their asset-related private details. This blockchain type addresses specific security and interoperability vulnerabilities and challenges, thereby overcoming the barriers present in existing land registration systems. It serves as a bridge between existing land registration systems, facilitating the creation of immutable, auditable, scalable, and interoperable systems for the efficient management of land registration records within the land administration sector. The subsequent section illustrates and expounds a blockchain-enabled efficient land registration system, elucidating the secure workflow of land registry records and activities.

This study addresses two specific cases, having eliminated redundant validation steps. The first involves the assignment of land to a citizen by the UPA, followed by the completion of registration by the LRA. The second case pertains to the sale of land by the owner, resulting in the transfer of ownership to the buyer.

The process of land assignment encompasses all requisite validations and approvals. Furthermore, it ensures that the data's status and transactions are accessible to participant nodes via private channels, readily available for referencing when needed. Additionally, each parcel of land maintains a comprehensive history, tracing its ownership from government possession to its current proprietor. Both the assignment and selling processes are explained in detail in this section and followed by a flow chart for illustration (Figures 6 and 7). Moreover, each of them is followed by pseudo algorithm (Algorithm 1, Algorithm 2) to explain the whole process.

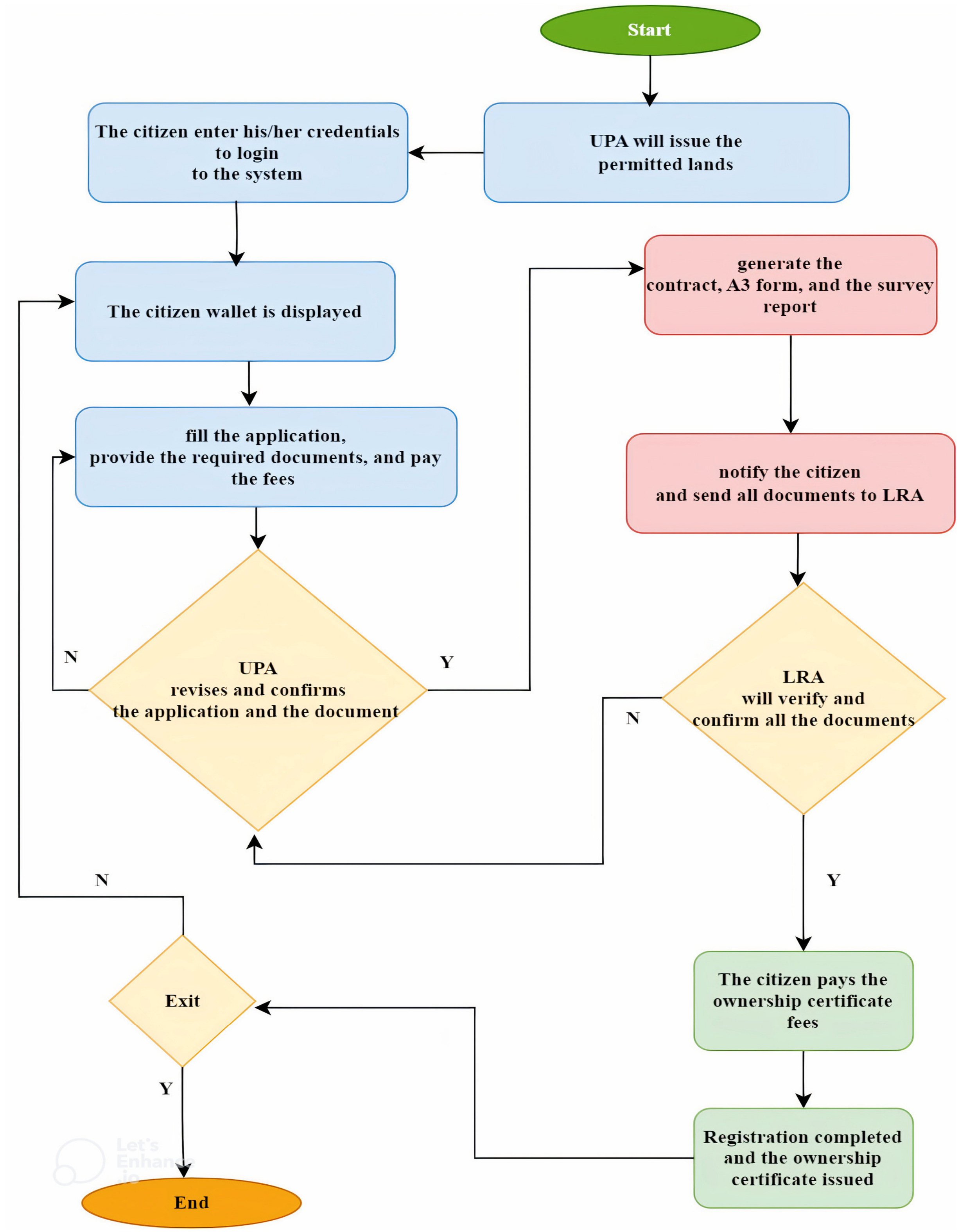

Figure 6. Land registration dataflow diagram.

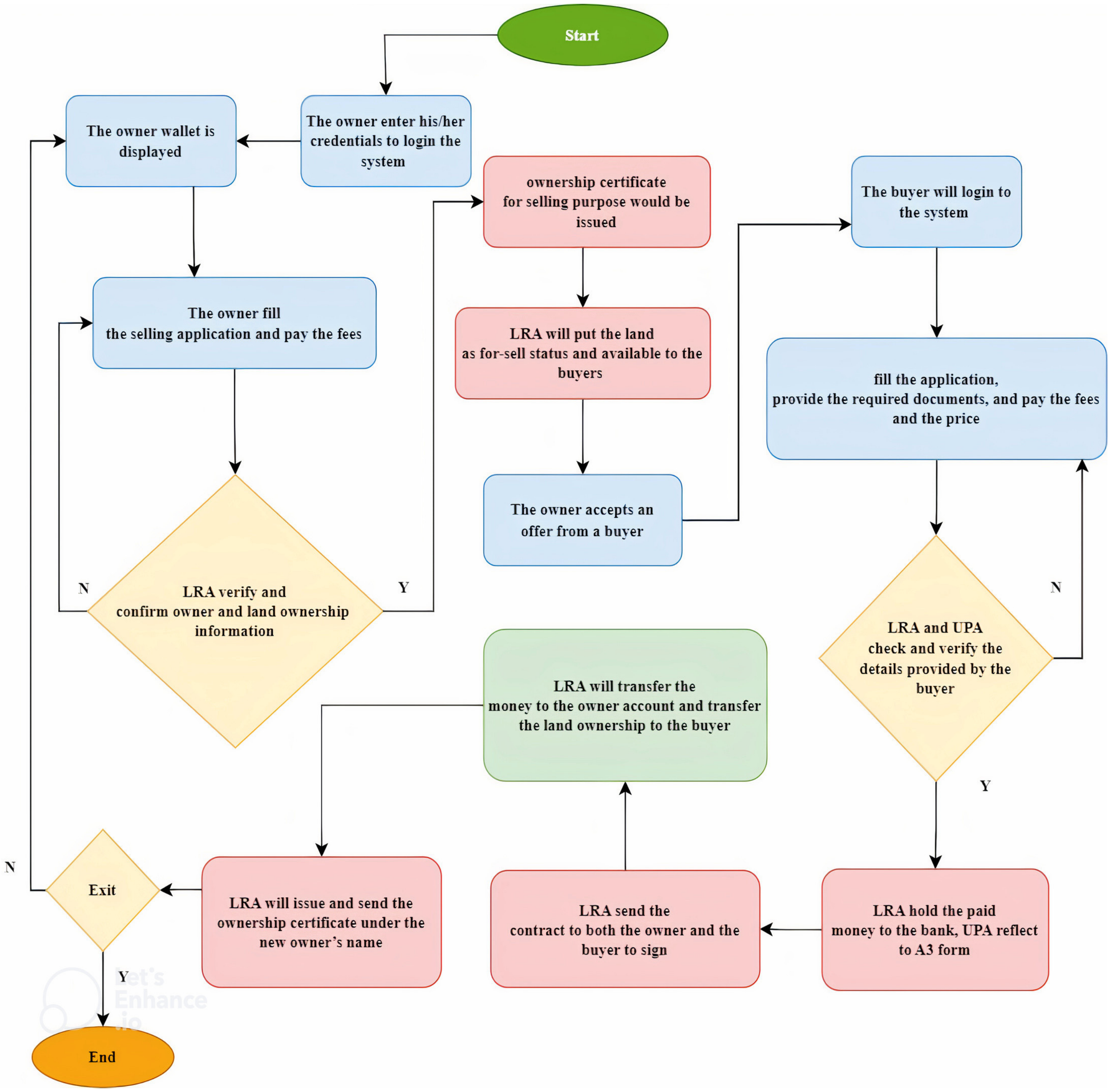

Figure 7. Land sale dataflow diagram.

6.1. Land Assignment Process

The functionality of the process of land assignment will be conducted as follow:

- All chaincodes are subject to oversight by governmental sectors.
- Initially, the system will grant authorization to the Land Registration Authority (LRA), the Urban Planning Authority (UPA), and the Authorized Bank (AB) as nodes of the system through the Membership Service Provider (MSP).
- The UPA will allocate land to citizens based on established legal, organizational, and social criteria. Consequently, the system will grant citizens access as users through the Membership Service Provider (MSP).
- The citizen will log in to the system. The display would show his/her wallet. One of the links in the owner's wallet would be the application for the land that is permitted to the owner by the UPA. The owner should complete the application and

furnish it with the requisite documents, make the necessary payments, and attach the corresponding receipts.

- The UPA will review and validate the application and accompanying documentation submitted by the citizen. Subsequently, it will generate the contract, an A3 form that is one of the main land deed documents, and the survey report. The system will then notify the citizen and forward all relevant documents to the LRA.
- The LRA will authenticate and validate all documents, and instruct the citizen to remit the fees for issuance of the ownership certificate.
- The citizen will log in to make the payment and attach the receipt. Consequently, the LRA smart contract will be triggered to finalize the registration and issue the ownership certificate. The certificate will be duly signed and stamped, and a copy will be dispatched to the citizen/owner.

Algorithm 1. Registration.

```
Procedure InitiateRegistration(User, selectedLand, registrationForm, requiredDocuments, registrationFees)
UPA.Check(userForm, userDocuments, userPayment)
if form approved and documents approved and payment approved then
        UPA issues contract
        UPA issues A3Form
        UPA generate survey report
        CommitOwnership (User, selectedLand, contract, A3Form, surveyReport)
        NotifyUser("Your land has been successfully registred.")
else
        NotifyUser("Registration could not be initiated." + Error message)
end if
end Procedure

Procedure CommitOwnership (User, selectedLand, contract, A3Form, surveyReport)
ProposeTransaction (User, selectedLand, contract, A3Form, surveyReport)
if Committed is successful then
        User pays OwnershipCertificateFees
        if paymentStatus is successful then
                LRA issues ownership certificate
                LRA sends the ownership certificate to User
                NotifyUser("Your ownership certificate has been issued and sent to you.")
        else
                NotifyUser("Payment for ownership certificate failed.")
        end if
else
        DisplayMessage(ErrorMessage)
end if
end Procedure
```

6.2. Land Sale Process

The functionality of the process of land sale will be conducted as follow:

- After successfully logging in to his/her wallet, the owner initiates the land sale process by completing the selling application and paying the necessary fees to request an ownership certificate for the purpose of selling their land.
- The LRA undertakes a thorough verification and validation of the owner's identity and land ownership information. Subsequently, an ownership certificate, specifically for selling purposes, is issued with a 2-week validity period. The land is then categorized as being available for sale, along with its listed price, for potential buyers to peruse.

- Upon acceptance of an offer made by the owner, the LRA prompts the buyer to complete their application, submit the requisite documents, and make the payment for both the price of the land and the associated fees.
- The buyer logs in to complete the application, provide the necessary documents, and pay the required fees and the cost of the land. Consequently, the LRA securely holds the funds and performs a meticulous validation of the details furnished by the buyer in conjunction with the UPA.
- The application is then ratified by both the UPA and LRA. The UPA subsequently updates the A3 form accordingly. In tandem, the LRA dispatches the contract to both the owner and the buyer, requesting their respective signatures.
- The LRA proceeds to transfer the funds to the owner's account and initiates the formal transfer of land ownership to the buyer. Moreover, the LRA issues and dispatches the ownership certificate under the new owner's name.

Algorithm 2. Sale.

```
Procedure PutLandForSell (User, selectedLand)
    CheckLandStatus(User, selectedLand)
    if (LandStatus == "Free") then
        User pays fees
        if FeesPayment is successful then
            selectedLand.Status = "For-Sell"
            LRA issues ForSellCertificate
            NotifyUser("Ownership certificate for sell purpose has been issued and sent to you.")
        else
            NotifyUser("The payment is failed.")
        end if
    else
        NotifyUser("The land is restricted not allowed to sell.")
    end if
end Procedure

Peocedure LandSellAgreement (selectedLand, User, SelectedOffer)
    Buyer fills SellForm (selectedLand)
    Buyer uploads required documents
    Buyer pays the sell fees and the land price
    if SellForm approved and documents approved and payment approved then
        Money is put on hold
        UPA updates A3Form and survey report
        LRA sends contract for Buyer and User to confirm and sign
        if ContractStatus is successful then
            TransferOwnership (Buyer, selectedLand, requiredDocuments, Fees)
            Money is transfered to the Users's Account (User, LandPrice)
        else
            DisplayMessage("Sell Process is not completed." + Error)
        end if
    else
        NotifyUser("Approval is not completed." + Error)
    end if
end Procedure
```

7. Discussion

Blockchain technology ensures that the majority of network nodes validate the information blocks stored on the ledger before posting, adhering to established and agreed-upon rules [93]. A notable strength of blockchain lies in the immutability, reliability, security, and trustworthiness of stored blocks, deriving trust from the verification and validation processes undertaken by the majority of network nodes and eliminating single points of failure. Blockchain facilitates the building of trust among various land management entities by storing immutable records, employing consensus mechanisms, using private keys, and leveraging decentralized networks for secure and transparent communication among parties in the land registration data management system.

The land registry handles highly sensitive data that require secure management, encompassing various personal and sensitive information such as names, addresses, national identification numbers, land data, and historical land records. These data hold significant value for citizens and government entities like the Urban Planning and Land Registration Authorities. However, the potential public exposure of such sensitive personal information poses substantial privacy and security risks to landowners and land registration service providers. Hence, there is an urgent need for innovative technologies to address privacy, information sharing, and security challenges in land registration processes. Blockchain technology emerges as a promising solution, aiming to offer transparency, security, information sharing, and privacy through consensus-driven decentralized data management within peer-to-peer distributed computing systems.

It is imperative to establish a clear definition of how the workflow, procedures, and service presentation will be adjusted when implementing blockchain technology to preempt any potential confusion in the future. Equally important is the delineation of the tools and methods to be employed, especially security tools, to allay fears and concerns, instilling confidence in citizens regarding the blockchain system. The proposed land registration system should prioritize the establishment of an intimate and close relationship between the government and its citizens, aiming to provide a reliable, trustworthy, and user-friendly service. Government services must align with citizen needs, maintain affordability, ensure simplicity in the procedures, and expedite service delivery.

Anticipated changes in the business processes, workflow, and service procedures due to the new system necessitate careful examination. Therefore, there is a requirement to proactively anticipate and study these changes, accounting for all socio-technical factors that could impact the introduction of blockchain technology. Initiating a discussion on blockchain technology-related issues becomes crucial to identify its benefits and align them with existing services provided at land registration offices.

Resistance persists in introducing this technology, and concerns about the risks associated with the theft or loss of citizens' information are prevalent, especially among top management respondents. Consequently, education, training, and awareness programs targeted at top leadership groups are imperative as part of government reform efforts. The introduction of blockchain technology mandates skilled and knowledgeable employees proficient in blockchain technology to develop, implement, and support solutions, thereby elevating the level of digital innovation. Furthermore, providing education, training, and certification resources is essential to enhance the awareness of blockchain technology and its associated benefits.

Smart contracts exhibit extensive capabilities and are capable of supplanting manual contracts, payment receipts, and agreements [94]. Furthermore, their utilization enables the automation of various processes, thereby enhancing efficiency through reducing the business process steps and minimizing human involvement. However, given that smart contracts represent a nascent technology, limited individuals possess prior knowledge of them. Consequently, it is imperative to explore the socio-technical factors influencing the adoption and use of smart contracts. Additionally, the implementation of awareness programs becomes essential to enhance familiarity with this tool.

User accounts necessitate creation by an administrative user affiliated with a relevant governmental institution. Each user is granted restricted access with qualifications commensurate with their roles and privileges. The anticipated enhancements in security methods involve replacing current measures with more precise and effective tools, particularly with services anticipated to be offered through diverse ICT platforms, such as mobile and web applications. Novel service access methods include the use of one or more fingerprints, real-time verification codes, real-time links, secret-question passwords, and real-time photos.

In the new system, specific Application Programming Interfaces (APIs) can be employed to verify data outside the network by sending requisite values to different institutions and obtaining results. For example, verification of passports or identity cards can be conducted through the Sudanese civil registry API, while disputed documents and petitions can be verified through the land prosecution API. Legal documents can be authenticated through the courts' API, and mortgage documents can be verified using bank APIs.

The establishment of new governance necessitates legal, organizational, and social sustainability, ensuring that decisions and changes do not compromise the social, economic, and environmental requirements of the community. Smart contracts, integral components of blockchain technology, can uphold these standards and laws through inscriptions generated during the addressing stage. Recognized by all stakeholders, these smart contracts autonomously execute at predetermined trigger times, ensuring optimal conditions without human interference.

Government policies and decisions pertaining to land must adhere to principles of transparency and be open to all community groups. Despite the decentralized nature of land administration in Sudan, the susceptibility of its offices to risks such as manipulation, damage, and loss arises due to their subjection to the central headquarters in Khartoum. The addressing stage delineates the necessary organizational, legal, and technical changes essential for reforming land administration in Sudan. Blockchain technology, for instance, provides a decentralized immutable land ledger to mitigate these risks, ensuring privacy, security, and an equal level of trust for both rural and urban regions, thereby safeguarding human rights.

Furthermore, blockchain technology facilitates information sharing to ensure that all involved stakeholders, particularly women and vulnerable citizens, can interact efficiently [95].

In response to these challenges, this study proposes a comprehensive evaluation framework comprising expert reviews, simulations, case studies, stakeholder feedback, and security and privacy assessments. This holistic approach aims to validate the effectiveness and scalability of the proposed system, ensuring alignment with the diverse requirements of stakeholders, including landowners, government bodies, and legal authorities.

8. Conclusions

As blockchain technology gains global attention, organizational adaptation informed by co-learning and information sharing becomes crucial for realizing its full potential in governance and beyond. This study sought to develop a blockchain-based land registration system for resource-constrained countries with diverse cultural contexts.

This study demonstrates the transformative potential of blockchain technology, particularly through a permissioned Hyperledger Fabric platform, in revolutionizing land registration systems. By enabling secure, transparent, and immutable information sharing, the proposed system promotes collaboration among stakeholders, ensures data integrity, and enhances operational efficiency. Addressing technical challenges, privacy measures, and deployment obstacles underscores the need for an adaptive system design that respects local legal frameworks and cultural contexts. The implementation of blockchain-based systems signifies a paradigm shift in digital government services, offering enhanced productivity and service quality. However, this advancement requires a reassessment of current legislation and practices to accommodate new technologies.

This study was grounded in an examination of the prevailing practices and services provided by land registration in Sudan, particularly during the transitional period that ensued after the Sudanese revolution in 2019. This context is of utmost significance, given that all governmental institutions were undergoing extensive revisions and scrutiny. These revisions were executed using the current ideal policy system without taking into account the social aspects of individuals, including their ages, cultures, and academic backgrounds relating to these processes and to what extent they are ready to deal with such technology. Also, due to space limitation, an evaluation of the proposed prototype is yet to be conducted.

There is a need to implement this system in the real world and evaluate the results to understand the effects of using blockchain technology in the public sector context. Therefore, more research is required to reform the other governmental institutions with blockchain technology to come up with an integrated information technology setup that could be accessed through a unified portal. In addition, artificial intelligence can also be integrated in the future for further smooth working processes. With regard to new legislations, NFTs are also now emerging as options and are expected to be explored in the future.

This study evaluates a distinct new artefact, diverging from computer science's focus on quantifying algorithmic efficiency. Instead, it adopts an Information Systems evaluation perspective, which emphasizes a broader evaluation that extends beyond computational performance. This approach focuses on the artefact's adoption, user engagement, and impact within an ecosystem: in this instance, a digital government ecosystem. The evaluation of this artefact is therefore an area for further research.

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