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BACP-LRS: Blockchain and IPFS-based Land Record System

Insaf Boumezbeur [1], **Abdelhalim Benoughidene** [1], **Imane Harkat** [1], **Farah Boutouatou** [1], **Dounia Keddari** [1], **Karim Zarour** [2]

[1] Centre de Recherche en Aménagement du Territoire (CRAT), Campus Zouaghi Slimane, Constantine, Algeria
[2] LIRE Laboratory, Faculty of Information and Communication Technology, Constantine 2 University – Abdelhamid Mehri, Constantine, Algeria

Corresponding author: Insaf Boumezbeur (insaf.boumezbeur@crat.dz)

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Abstract

Background: Land records have traditionally derived their credibility from a central database of local government records, with copies issued to land owners. Physical records are the only credible source of any information related to land ownership that has been in existence for a long time. However, physical records are prone to manipulation and fraud. Recently, some academic research has begun to address the potential use of blockchain technology to improve the security and reliability of land registration processes.

Objective: The purpose of the present work is to propose an architecture for blockchain-based access control for distribution, ensuring information privacy. We take advantage of the benefits of blockchain technology in improving land record management while granting access to electronic data through user permissions.

Methods: This approach replicates cryptographic primitives, while smart contracts are used to assist land record owners and users in interacting with each other using the Ethereum blockchain in the proposed system. The approach includes performance evaluation by the execution of a smart contract and security analysis to check the system robustness.

Results: The performance evaluation and security analysis prove the proposed blockchain architecture to be secure and feasible for practical implementation in managing land records.

Conclusion: The research proves how the application of blockchain technology can significantly enhance both security and reliability in land registration processes, giving credibility to tamper-resistant systems for maintaining information about land ownership.

Index Terms

Blockchain; Interplanetary file system; IPFS; Smart contract; Ethereum; Land record; Encryption.

1 INTRODUCTION

Urbanization, public administration and other aspects of life rely on technology settings with distinct features and uses. Because of urbanization and modernity, people are adopting new technologies that have evolved throughout our lives, from utilizing remote controllers to manage various smart home products to managing various events. The most typical method of keeping cadastral records is by a tangible representation of the land borders. Each stakeholder has a copy of the records, which are kept centrally in a municipal repository, and is unaware of the existence of any surrounding assets; the information solely relates to their own asset. Land registration is a process in which a government entity documents ownership and land-related rights.

This technique provides proof of ownership, facilitates transactions and deters fraud. However, out-of-date land register systems cause delays in the certification of ownership, obstruct legal transactions and, in the worst scenario, may allow abuse of land (Deininger & Feder, 2009).

The World Bank estimates that 70% of the world's population does not have access to land titles (World Bank, 2017). According to UN-Habitat (2016), less than 10% of land in urban areas in Africa is properly registered, creating substantial challenges in urban planning and development. Over 90% of rural land in Sub-Saharan Africa is unregistered, which contributes to recurrent land conflicts affecting over a billion people (Alden Wily, 2018). According to UN-Habitat (2020), approximately 1 billion people worldwide live in informal settlements, which have uncertain land tenure and limited access to essential amenities. In India, around 23% of rural households are landless, and landlessness is strongly associated with poverty (NSSO, 2019).

The existence of land rights is critical for governments to charge taxes, provide services and create territorial jurisdictions. It may also affect residents' access to economic opportunities. The World Bank has been spearheading efforts to enhance land registration in several countries and funds numerous initiatives to reform out-of-date registration systems because of the importance of land registration for economic growth (Heider & Connelly, 2016).

Land record systems sometimes rely on antiquated, manual, paper-based methods and databases that are vulnerable to destruction, forgeries and inaccuracies, making it impossible to maintain deadlines and service level agreements among the several parties involved. This might cause delays in ownership transfers, compromising ownership rights and even resulting in land or border conflicts. Traditional land registers, which rely on paper records, are prone to loss, destruction, alteration or manipulation (Lemieux, 2017). In high-income countries, property registration takes an average of 23 days, compared to 47 days in low-income ones (World Bank, 2020). If someone tries to sell an unregistered property and loses or destroys the paper title documents, registering the property might be exceedingly difficult. The centralized system for registering land is time-consuming, with the procedure possibly taking months and leaving a void during which different legal concerns might occur.

The current system of land transactions presents problems in terms of accountability, transparency, security and efficiency (Gupta et al., 2019). These problems can be solved with a blockchain-based approach by building a safe, dependable and unalterable platform. It can make it easier for stakeholders to share data via smart contracts, monitor service level agreements in real time and keep an ownership database or "golden record" that is only accessible to authorized users. By cross-referencing the false documents with the golden database, this system can detect forgeries. A tamper-proof master source can be used to generate dynamic factors including ownership, mortgage information, litigation status and property tax information.

In recent years, blockchain technology has been used in a variety of countries. Blockchain technology can improve the security and openness of land records by putting land-related data on the blockchain. Blockchain technology also speeds up property identification while enhancing transaction trust and accuracy by allowing stakeholders to digitally monitor transactions (Shuaib et al., 2020). This technology can address concerns associated with centralized, paper-based land management systems, such as accountability, efficiency, transparency and security. Blockchains are basically immutable, which implies that property recorded on them cannot be modified, which is crucial for creating trust in the system (IBM, 2024).

This article describes a secure land record sharing system based on blockchain and the InterPlanetary File System (IPFS), which provides a decentralized and verifiable alternative to effective and transparent land record administration. The proposed architecture ensures data integrity and accessibility by combining blockchain transaction logging and IPFS distributed file storage. This technology solves the limitations of conventional land registration systems, providing landowners, buyers and administrators with more security, confidentiality and reliability. By automating tasks using smart contracts, the system enables frictionless property transfers and reliable record verification, resulting in a comprehensive and time-tested financial management solution. The remaining sections of this paper are structured as follows. Section 2 provides context for the proposal. Section 3 presents an overview of related studies. Section 4 discusses the system architecture, workflow and smart contract. Section 5 presents the proposal performance results. Section 6 discusses the results and Section 7 concludes the paper.

2 BACKGROUND

2.1 Land records

Land record administration is an essential part of documenting and maintaining land ownership information. Figure 1 depicts the organization of a land record, which is made up of several key components that offer comprehensive recording of property facts. First, basic property information is entered, including the unique identifier, physical address and legal description of each parcel based on official documents. Owner information includes the property owners' names as well as contact information such as addresses, phone numbers and email addresses. The transaction history section records all property-related transactions, including dates, transaction types (e.g., purchase, sale and transfer) and parties involved. Legal documents consist of title deeds, which establish legal ownership, deeds of sale, which record transactions and transfers, and any easements or other usage restrictions. Financial information includes property sale price, loan details, paid or unpaid taxes; geographic data (cadastral plans, maps and precise GPS coordinates) are used to ensure that the property is displayed correctly in space.

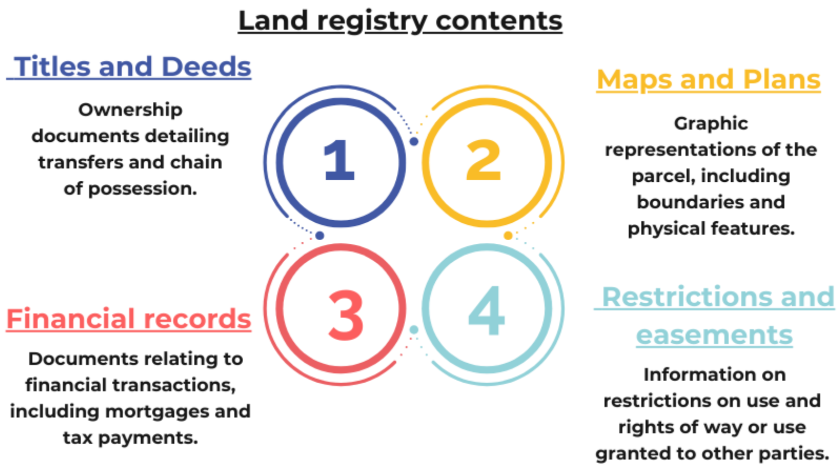

Figure 1. *Land record content.*

2.2 Blockchain technology

Blockchain technology, introduced by Nakamoto in 2008 with the bitcoin proposal (Nakamoto, 2008), is a decentralized ledger technology that provides a unique method of storing and recording transactional data without the supervision of a central authority. It functions as a shared, immutable ledger for recording transactions and monitoring assets in a corporate network. Blockchain uses append-only blockchain technology to store data in blocks that are connected together. Because each block of data is encrypted and cannot be altered, the technology is a major disruptor in a range of industries, including payments, cybersecurity and healthcare. Blockchain technology has been used to store data other than bitcoin. Today, it may be used to create activities, protect healthcare data, give transparency for the food supply chain and fundamentally alter how we deal with ownership and data on a broad scale (Becher, 2024).

In a nutshell, blockchain technology is a distributed, decentralized ledger that securely maintains ownership records for digital assets. It offers a novel way of managing assets and recording transactions across a wide range of industries. Beyond cryptocurrencies, its uses have grown, with huge potential to transform other industries. As seen in Figure 2, each block in a blockchain includes transaction information, a timestamp, a nonce number (a one-time random or semi-random integer) and a reference hash to the preceding block. The block is then digitally signed with a hash value generated by a hashing algorithm.

By combining transaction data (timestamp, nonce and hash of the previous block), the hash function is generated in the form of a unique encrypted chain of a specified length. It is not difficult to interpret the entry from the hash chain since it acts as the block's digital signature. A solid chain of blocks is created by combining the contents of the current block with the hash of the preceding block. This layout allows users to easily monitor and recognize changes made to preceding blocks. When a block is modified, a new hash is generated. The connection between the two blocks is broken and the change is noticed since the previous block's hash was used to produce the succeeding blocks' hashes. Blocks cannot be removed from the blockchain, only added. This means that the blockchain was created as an immutable collection of records and is an ever-growing data structure (Shen & Pena-Mora, 2018). When a node has completed the proof-of-work (PoW) and solved the computational dilemma, it broadcasts the new block to the network, along with any new transactions. Other network nodes check the new block's history and signature. If the majority of nodes agree on the block's history and signature, it is added to the chain. According to Laurence (2023), adding a new block to the chain using this consensus validation approach improves the verification of previous blocks, and thus the whole blockchain.

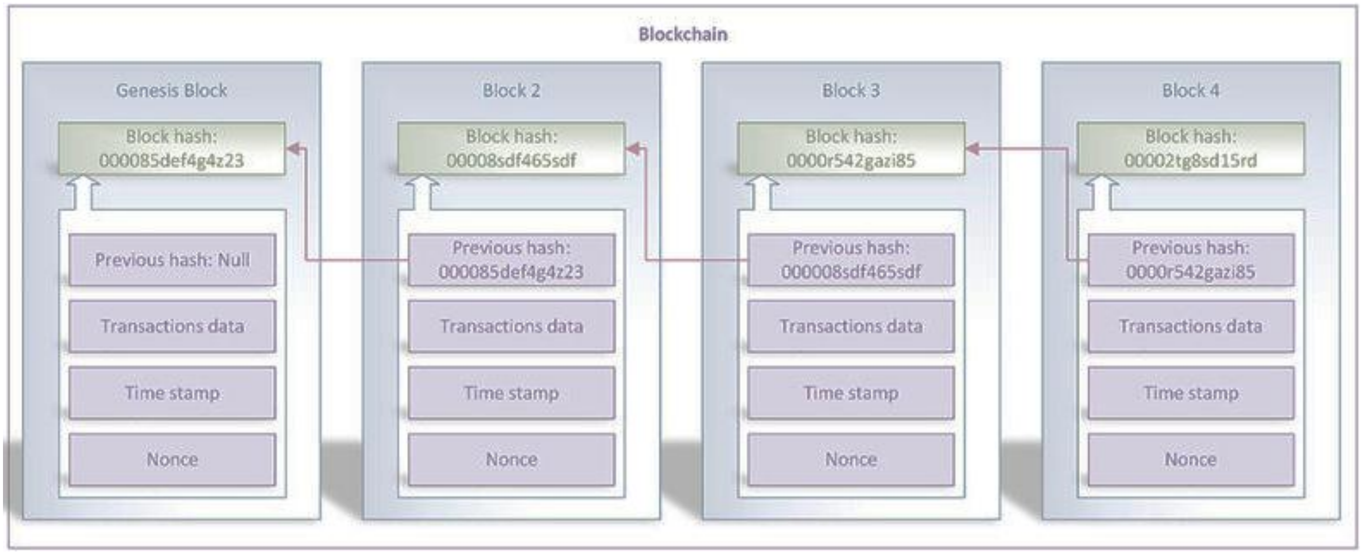

Figure 2. *Structure of blockchain. Source: (Farnaghi & Mansourian, 2020).*

2.3 Ethereum, ether and smart contract

Ethereum is a distributed computer network with a blockchain that may be used for a variety of purposes, as opposed to bitcoin, which is solely a cryptocurrency and a decentralized payment network. Although Ethereum and bitcoin are regularly likened to each other, their broader purposes distinguish them greatly. Ether is a monetary unit developed by Ethereum, a decentralized computing platform. One of the primary benefits of the Ethereum blockchain is the ability for programmers to build "smart contracts". These contracts are automatically carried out according to their code (Hoffman, 2018). It is a collection of functions and state-related data stored at a specific address on the Ethereum blockchain. As a form of an Ethereum account, smart contracts may be the subject of transactions and have a balance. They are, however, network-deployed and executed according to a program rather than the user's instructions. Then, user accounts may engage with smart contracts by submitting transactions that carry out smart contract activities.

According to the Ethereum.org developers' documentation on smart contracts, interactions with them are irreversible and cannot be undone by default (Ethereum Foundation, 2024). As a result, anyone with access to a copy of the blockchain may read the smart contract code and confirm that it was properly performed (Boumezbeur & Zarour, 2022). Yatsenko (2021) identified four key reasons for customer trust in smart contracts: openness, cost-effectiveness, accuracy and confidence. Transparency is ensured because smart contracts, like ordinary blockchain transactions, are fully accessible to all network users, allowing all parties to read the terms and circumstances of the agreement. They are cost-effective because they eliminate the need for further agreement validation, saving money on unnecessary expenses. Smart contracts are accurate because they always adhere to the terms specified in the code. Finally, the fact that smart contracts may only be executed if specific conditions are met boosts confidence by lowering the risk of fraud or manipulation.

2.4 Blockchain versus traditional systems

When comparing centralized systems with distributed blockchain systems, there are a few key differences and aspects to examine. Figure 3 shows the distinction between centralized and distributed systems. In centralized systems, a single authority or agency oversees all components. A centralized authority makes decisions in a network and all data are stored on a single server or database (Blockchain Council, 2024). This design is referred to as a single point of failure since any problem in the central system can cause outages throughout the system. On the other hand, centralized systems may be implemented rapidly and simply. Distributed systems, particularly those built with blockchain technology, are decentralized. In a dispersed network, no single entity has total control of the system. Blockchain technology facilitates decentralization by validating and recording transactions over a distributed network of nodes, removing the need for a central authority. Distributed systems are safer and more reliable than centralized systems due to their decentralization. They are less prone to single points of failure and can continue to function even when one or more network nodes fail. The redundancy of storing and processing data across several nodes may make them more complex to configure and operate, necessitating extra resources (Notepub, 2021; Bitstamp, 2022).

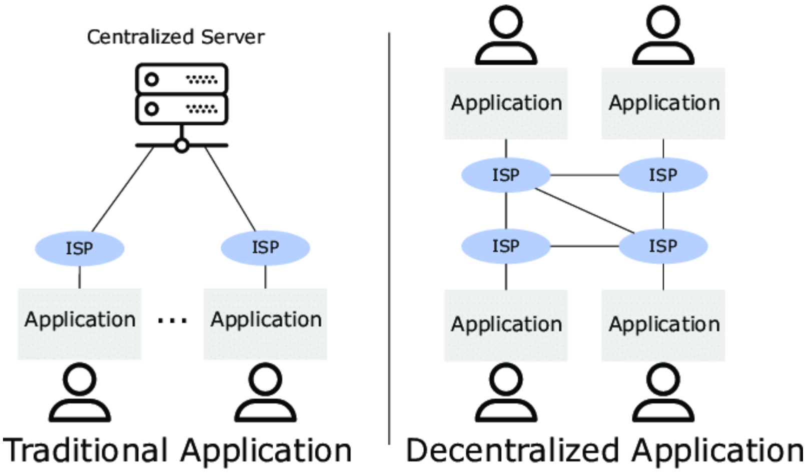

Figure 3. *Traditional versus decentralized application. Source: (Kaynak et al., 2019).*

2.5 Role of blockchain in collaborative urban planning

Blockchain technology can help with many aspects of urban development and planning. Blockchain technology, with its transparency, immutability and distributed consensus, has the potential to revolutionize urban planning and development through public participation. Two key barriers to urban planning and development are a lack of openness in public decision-making and the efficacy of present institutions for encouraging connections between civil society and local governments. Blockchain technology has the potential to address these issues by creating a transparent, traceable and verifiable record of all previous transactions, reducing the risk of corruption and data manipulation while increasing public organizations' accountability to local communities (Belfer Center for Science and International Affairs, 2022). The concept of "tokenization", or city tokens, is a novel application of blockchain technology in urban planning. Tokens are digital assets created using blockchain technology that may be used to store value or represent rights to assets such as property ownership and voting power. It may encourage citizen participation and convert infrastructure projects into community-funded urban development initiatives. In addition, the usage of blockchain-based technologies is an opportunity to help develop smart cities. As an example, the Smart Dubai effort is creating blockchain-based applications for finance, education and transportation (World Economic Forum, 2021).

Despite the enormous potential, it is vital to recognize that incorporating blockchain in urban planning presents more than just technological problems. It is more sociotechnical in character, demanding the creation of separate institutional frameworks capable of efficiently using the potential of the technology to serve the public good while avoiding recognized dangers and drawbacks for the benefit of the population. To summarize, blockchain technology has the potential to revolutionize urban planning and development by enhancing transparency, accountability and public participation. However, while deploying blockchain solutions in this setting, sociotechnical problems should be prioritized, as well as the requirement for human-centred procedures and trustworthy business processes (Belfer Center for Science and International Affairs, 2022).

2.6 Blockchain in land records

Blockchain can track all land data and play a critical role in identifying ownership. Proprietorships can be created efficiently; ownership transfers can be completed in less time and records can be correctly kept. X-Road is Estonia's way of sustaining a contemporary state. Within it, the e-Land Register is an online tool that provides land ownership and parcel information. It is linked to a geographical information system (GIS), which delivers real-time geographic data via X-Road. It also fosters openness by releasing data on sellers and buyers (Umrao et al., 2022). The Brazilian government has started a pilot project with blockchain company Ubiquiti to increase the efficiency and quality of record-keeping in compliance with local legislation. Property registration has been done successfully utilizing a blockchain network that contains a real estate register. This project shows how blockchain-based transactions employ tokenization to determine the authenticity of ledger-based transactions (Nunes, 2004). In the United States, blockchain has been employed in the real estate industry. The Medici Land Governance project has been working on a worldwide land blockchain record to help with land management by providing a reliable public record of property ownership. In South Burlington, Vermont, the initiative worked with Propy Inc. to test real estate transfers on the blockchain, which eliminated all paperwork. The major goal is to lower the costs of keeping real estate data by using a blockchain-based solution.

The Honduran government will become the second country to embrace blockchain technology, collaborating with FACTOM, a blockchain innovation startup, to create a permanent and secure land record system based on blockchain. The administration has already confronted fraudulent land titling instances. The government utilizes blockchain to handle data, boost transaction transparency and assign mineral rights. The pilot programme aims to put all of the country's land titles on blockchain (Umrao et al., 2022). Dubai's government has been developing a blockchain-based land record system as part of its bigger "Smart Dubai" initiative. The system aims to increase the efficiency and security of real estate transactions, as part of Dubai's goal to create a blockchain-powered city by 2020 (Smart Dubai, 2019). The Swiss government developed the first corporation-based blockchain endeavour. This project allows a variety of stakeholders, including a bank, seller, buyer, entrepreneur and notary, to automate their operations using smart contracts and the hyperledger blockchain. This initiative was part of the Digital Switzerland Challenge. The goal was to provide an alternative approach by digitizing records throughout the country.

3 LITERATURE REVIEW

Dewangan & Chandrakar (2024) proposed a geolocation-based land register system that employs blockchain technology to enhance security, transparency and efficiency. The system has three steps: maintaining existing owner records, making new entries via smart devices and confirming records. By using blockchain technology, the system reduces personal data exposure, avoids fraud and assures safe transactions, providing a contemporary and privacy-preserving method of land registration.

Sidharthan & Balasaraswathi (2024) provided a solution based on Ethereum blockchain, IPFS, smart contracts and the Sepolia TestNet. This strategy improves security and trust by implementing decentralized, tamper-resistant procedures and automating jobs using smart contracts. By incorporating IPFS for decentralized document storage, the solution increases data quality and accessibility, with the goal of making land registration in India safer and more efficient.

Banerjee et al. (2022) proposed a land record system based on blockchain and the InterPlanetary File System (IPFS) technology to solve concerns such as inconsistent data and a lack of transparency in land ownership, particularly in developing countries such as India. The proposed solution guarantees that land records are immutable and transparent, with all facts available via the blockchain network. Smart contracts are used to handle ownership transfers and verify agreements, making transactions more efficient. This method improves the accuracy and speed of the land registration procedure, making it more secure and efficient.

Alam et al. (2022) demonstrated a three-stage blockchain-based land title administration system for Bangladesh, which provides data synchronization, transparency and simplicity of access. They developed a prototype system using Ethereum and described a detailed architecture for smart contracts.

Sahai and Pandey (2020) introduced blockchain and smart contracts as a valuable tool for any application that requires trust and integrity. Land record upkeep and registration are required for processing. It prevents fraud and saves time in the registering procedure. Blockchain employs smart contracts to automate the whole process through the application, establish an immutable register and prevent land fraud. However, the authors did not explore stakeholder registration or verification. They also did not explore a scalable approach for storing images and documents in the system.

Thakur et al. (2020) developed a blockchain-based, tamper-proof system that provides valid and conclusive rights to owning land titling, with a focus on smart contracts. They developed a platform to confirm that the land being purchased is the correct parcel and that the seller is indisputably the owner, thus decreasing disputes and counterfeiting.

Ashiquzzaman et al. (2021) described an Ethereum-based land register system for Bangladesh. It featured a variety of players, including buyers, sellers and banks. However, the authors did not address the problem of how the government would participate in and supervise the system. There is also no explanation as to how land information is preserved or how land transfers take place.

Rouhani and Deters (2019) concentrated on the security issues surrounding blockchain applications. The authors thoroughly examined and proposed the notion of a smart contract with a decentralized system, including security measures, various tools and performance optimization approaches. Security using a smart contract produce better outcomes in a distributed blockchain environment, and work on a lightweight consensus method to improve the usage of blockchain applications.

Krishnapriya & Sarath (2020) utilized blockchain to create a land registration system that allowed quick land record maintenance while also protecting land transactions from threats. It employed the SHA256 algorithm to secure land record transactions and elliptic curve cryptography (ECC) for signatures. The approach was tested with just 12 nodes and 200 transactions and it relied on a proof of work (PoW) consensus process, which might be resource-intensive.

The system presented by Sharma et al. (2021) is built on Ethereum and addresses a number of difficulties that exist in the existing system. They employed IPFS for decentralized storage and proposed a verification module that uses third parties to validate documents. However, they did not address a variety of land ownership transfer issues, such as land partitioning, hereditary causes or documenting the history of transfers for a specific property.

4 SYSTEM MODEL

This section describes the architecture and workflow for our proposal a blockchain and IPFS-based land record system (BACP-LRS = Blockchain Access Control Proposed Land Record System). Table 1 highlights the fundamental abbreviations used throughout this paper.

Table 1. *Abbreviations.*

Abbreviation	Description
LR	Land record
L_{ID}	Land record ID
AES	Advanced encryption standard
RSA	Rivest-Shamir-Adleman
SK	Symmetric key
PuK	Public key
PrK	Private key
OI	Owner ID
C_{LR}	Ciphertext
CK	Encryption key
SIG	Digital signature
C_{ID}	Resulting hash
MD	Message digest

4.1 System architecture

The proposed architecture for a privacy-preserving and access control strategy for sharing land data with blockchain and IPFS technologies prioritizes security, transparency and efficiency. The system combines blockchain, which guarantees the integrity and immutability of land transactions, with IPFS, which allows safe, distributed storage of land records. Smart contract connectivity simplifies the verification and validation processes, whilst user interfaces (web portals or mobile applications) make access to systems and engagement easier. The basic network design, built around P2P protocols, enables decentralized safe communication among the system parts. This flexible, scalable solution aims to solve the inadequacies of current land registration systems by offering a more dependable and trustworthy alternative. The proposed framework contains five layers, namely a user interface (UI) layer, an application layer, a blockchain layer, a storage layer and a network layer. The role of each layer and each entity is defined as follows and the architecture is presented in Figure 4.

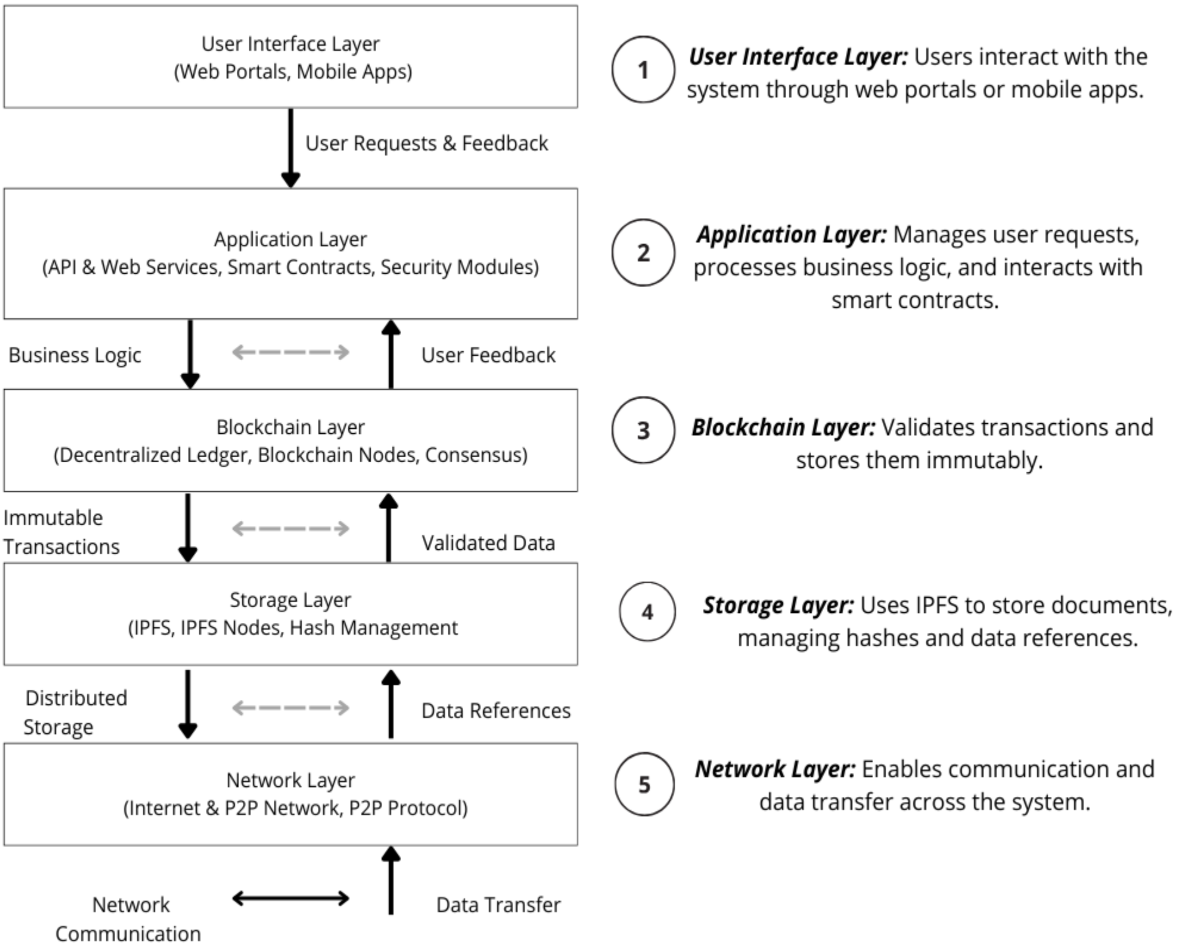

Figure 4. *BACP-LRS architecture.*

- *Layer 1: User interface (UI) layer*
    - Users, including landlords, buyers and administrators, communicate with the system through web portals and mobile applications.
- *Layer 2: Application layer*
    - APIs and web services connect user interfaces to commercial logic and data layers.
    - Smart contracts allow the blockchain to facilitate land transactions, check records and monitor property transfers.
    - Security components manage user authentication, authorization and data encryption.
- *Layer 3: Blockchain layer*
    - Blockchain nodes are servers that authenticate transactions and manage the distributed register.
    - Consensus is a transaction verification method comparable to proof of work (PoW) and proof of stake (PoS).

- *Layer 4: Storage layer*
  - IPFS is a distributed file system that stores land records. It is a decentralized distributed file storage and transmission technology designed to alleviate some of the challenges associated with file storage. IPFS saves files by distributing them over several network nodes and allows users to access them using content addressing instead of traditional location-based addresses. This allows users to access files by a hash of their contents rather than URL addresses. IPFS nodes are computers that store, distribute and retrieve data across an IPFS network.
  - Hash management is the use of hashes to verify documents saved on IPFS.
- *Layer 5: Network layer*
  - Blockchain nodes and IPFS are connected via the internet and P2P network.
  - P2P protocols provide decentralized communication.

4.1.1 Threat model and security goals for BACP-LRS

This threat model, jointly with the accompanying security goals, aims to offer a complete security foundation for a blockchain-based land record system that uses IPFS. By addressing identified dangers and adopting strong security mechanisms, the system is able to protect the privacy, integrity, availability and overall security of land data. Table 2 illustrates the threat model and security goals for BACP-LRS.

Table 2. *Threat model and security goals for BACP-LRS.*

Security goals	Threat	Impact
Unauthorized access	Sensitive land records being accessed by unauthorized users	Data breaches, loss of confidentiality and probably fraudulent activities that result from this
Data tampering	Land records being tampered with by malicious intent	Data integrity compromises, disputes in land ownership and potential legal consequences
Data loss	Possible loss of land records due to node failure or corruption	Unavailability of crucial land records, possible legal complications and disruption of operations
Denial of service (DoS) attacks	Attackers overloading the system with extraneous requests	System unavailability, reduced performance and inability to provide services
Identity theft	Impostors stealing the identity of users to access systems without proper authorization	Unauthorized transactions, financial losses and possible legal consequences
Smart contract exploits	Smart contract vulnerability exploitation	Unauthorized transactions, loss of funds and a possible system compromise

4.1.2 Security goals

In accordance with this architecture, ensuring absolute security is critical. This section outlines particular security objectives and the actions required to achieve them, as shown in Table 3. These objectives cover critical issues such as data privacy, integrity and availability, as well as strong authentication, authorization and non-repudiation procedures. Furthermore, smart contract security, attack resistance and data redundancy and backup are prioritized to assure the system robustness and dependability.

Table 3. *Security goals.*

Security goals	Objective	Measure
Privacy of data	Ensure that land records, which are sensitive, are accessible to persons with authority.	Strong authentication and authorization is enforced. Encryption for data both in transit and at rest is implemented.
Data integrity	Ensure that the land records cannot be tampered with or altered maliciously.	Immutability feature of blockchain is used to ensure integrity of data. Digital signatures and cryptographic hashing is performed.
Data availability	Ensure that land records are accessible at all times to users with authority.	Data redundancy through a distributed network-IPFS for storage. Techniques for the detection and mitigation of DoS attacks.

Security goals	Objective	Measure
Non-repudiation	Achieve traceability to source about actions subjected to the system.	Digital signatures evidence the origin and integrity of transactions.
Smart contract security	Smart contracts should be correctly and securely operating.	State-of-the-art testing and auditing of smart contracts. Best practices for secure smart contract development.
Data redundancy and backup	There shall not be any data loss due to system failure.	Distributed and redundant storage by IPFS. Regular data backup and recovery procedure implementation.

4.2 Scheme workflow

In this part, we describe in full the process of the proposed BACP-LRS scheme for sharing land data while preserving confidentiality, which employs blockchain and IPFS technologies. The idea allows landowners to manage their own land records. It secures the transfer of land records using cryptographic techniques and blockchain technology, as seen in the steps below. Figure 5 illustrates the proposed scheme in detail.

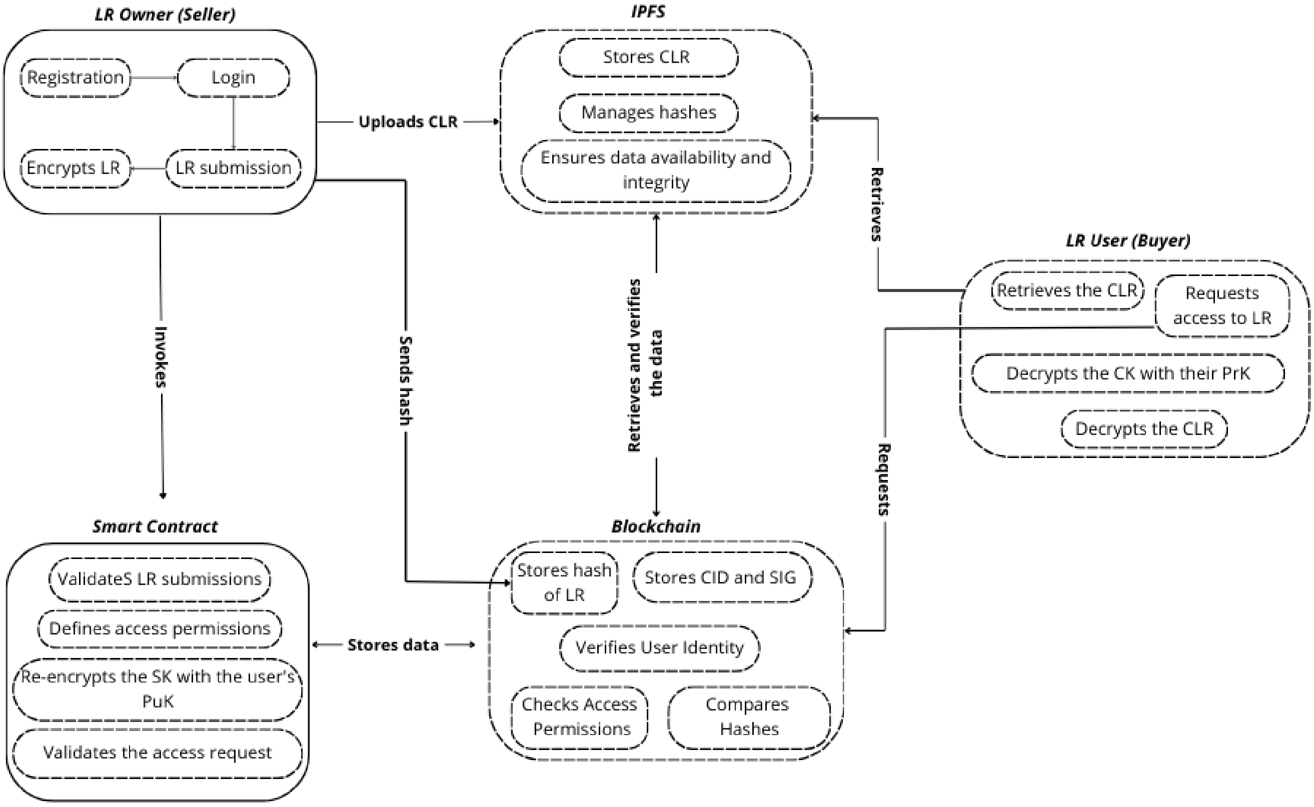

Figure 5. *System workflow.*

4.2.1 System setup

The proposed system setup for a privacy-preserving land registration considers a multi-layer approach for sharing data securely and efficiently. Users register through a web or mobile interface and it creates a unique account for each user. A symmetric key (SK) generated for each land owner is used for encrypting the land records, whereas RSA key pairs are used for secure sharing and signing of data. Then the encrypted land records are stored in the IPFS nodes, which are identified by a unique cryptographic hash (CID), which is linked with the blockchain. In the standard architecture, access control is provided by re-encryption of the SK with users' public keys. Ensuring confidentiality in a layer-based architecture integrated with blockchain and IPFS for security, transparency and controlled data sharing is possible with this. To implement the proposed scheme, users must register with unique accounts and create their keys. The steps are detailed below according to the layers.

a. User interface layer

- **User registration:** Landowners, buyers and administrators access the system via web portals or mobile applications to register unique accounts.

b. Application and business logic layer

- **Symmetric key (SK) generation:** A 128-bit symmetric key (SK) is generated for each landowner. This symmetric key is derived from the SHA-1 hash function used by the SHA1PRNG pseudo-random number generation algorithm (PRNG). The hash function generates a sequence of random numbers and the advanced encryption standard (AES) SK is used to encrypt land records.

- **Obtaining key pairs (PuK, PrK):** Each blockchain user obtains a key pair (public key PuK and private key PrK) by hashing a random number (RN) using the SHA-256 hash function to facilitate data-sharing transactions. The Rivest-Shamir-Adleman (RSA) asymmetric encryption key pair is used to encrypt the SK and sign the original land registration.

c. Blockchain layer

- **Data storage on blockchain:** Once all the keys have been generated, the landowner proceeds as follows:
  - Encrypt land records (LR): The landowner encrypts the land records using the symmetric key to obtain the ciphertext (C_{LR}), then encrypts the symmetric key using the public key (PuK) to obtain the encrypted key (CK), as illustrated in the following equations:

$$C_{LR}= EncLR\ (LR_i\ (I \in [1;4]),\ SK) \qquad (1)$$

$$CK= EncKey\ (SK,\ PuK) \qquad (2)$$

- **Creating and signing the hash:**
  - The landowner creates a hash of the encrypted land record for signing, as shown in Equation (3), where MD is the message digest. The private key is then used to sign the MD and the encrypted hash is the digital signature (SIG). Once the signing algorithm is complete, the owner sends the encrypted land record (C_{LR}) to IPFS distributed storage, as described in Equation (4).

$$MD=H(C_{LR}) \qquad (3)$$

$$SIG= (MD,\ PrK) \qquad (4)$$

- **Sending encrypted keys and signatures:**
  - The landowner sends both the SIG and the encrypted keys (CK) to the blockchain. He also sends access authorizations to the smart contract.

d. Storage layer

- **IPFS nodes:** The encrypted land records (C_{LR}) are stored on IPFS nodes, which are computers participating in the IPFS network. These nodes store, share and retrieve the files.
- **Hash management:**
  - Each file stored in IPFS is given a unique cryptographic hash. This hash serves as an address for the file and ensures data integrity.
  - When a land record is uploaded to IPFS, the resulting hash (C_{ID}) is recorded on the blockchain, linking the blockchain transaction with the IPFS-stored file.
  - To retrieve a file, the system uses the hash (C_{ID}) to locate the file on the IPFS network.

e. Network and infrastructure layer

- **Data sharing and access control:**
  - **Public key storage:** All users' public keys are stored in the system database.
  - **Access authorization:** If A (the landowner) wishes to share the data with B (add B to the list of approved users), the symmetrical key (SK) is re-encrypted with B's public key.
  - **Data access:** When B needs access to the data, he can decrypt it using his private key. Since only B has access to his private key, no one else can decrypt the data.
  - **Security assurance:** By following this scheme, the land registration system ensures maximum confidentiality and security, while enabling efficient and controlled sharing of land registrations.

By following this layered scheme, the land registration system ensures maximum confidentiality and security, while enabling efficient and controlled sharing of land registrations. The storage and sharing process are shown in Algorithms 1 and 2.

Algorithm 1. *Land registration and encryption process.*

```
Input Owner ID (OI), Land Details (LD)
     if Document Verification is correct then
        landDet = createLandDetailsStruct(LD)
        LID = createLandId(landDet, OI)
        SK = generateSymmetricKey() //Step 1: Generate cryptographic keys
        (PuK, PrK) = generateRSAKeys()
        CLR = encryptLandRecords(LD, SK)//Step2:Encrypt land records and symmetric key
        CK = encryptSymmetricKey(SK, PuK)
        MD = createHash(CLR)//Step 3: Create and sign hash
        SIG = signHash(MD, PrK)
        storeOnIPFS(CLR)//Step 4: Store encrypted data
        storeOnBlockchain(SIG, CK)
        if Land is under some court dispute then //Step 5: Check legal status
            Remove Owner’s Access to Status Change of Land
        else
            Grant Owner’s Access to Status Change of Land
        Append OI to ownerHistory(LID) //Step 6: Update records
        Append LID to ownerList(OI)
        return LID
     else
        return "Error in Documents"
```

Algorithm 2. *Land record sharing process.*

```
Input Owner ID (OI), Land ID (LID), Requester ID (RQI), Requester Public Key (RQPUB)

     if not verifyAccessRights (RQI, L_ID) then //Step 1: Request Access
          return "Access Denied"
        CLR =retrieveEncryptedLandRecord (L_ID)// Step 2: Retrieve Encrypted Data
        CK = retrieveEncryptedSymmetricKey (L_ID)
        SK = decryptSymmetricKey (CK, OI_PrK)// Step 3: Decrypt Symmetric Key
        RSK = encryptSymmetricKey (SK, RQPUB)//Step 4: Re-encrypt Symmetric Key
        MD = createHash (C_LR) //Step 5: Create Hash for Integrity
        SIG = signHash (MD, OI_PrK)// Step 6: Sign Hash
        sendToRequester (C_LR, RSK, SIG)// Step 7: Send Data to Requester
        SK = decryptSymmetricKey (RSK, RQ_PrK)// Step 8: Requester Decrypts Data
        LD = decryptLandRecords (C_LR, SK)
        MD2 = createHash (C_LR)// Step 9: Verify Integrity
        Verified_MD = verifySignature (SIG, OI_PuK)
        if MD2 == Verified_MD then
              return LD
     else
        return "Data Integrity Check Failed"
```

4.2.2 Detailed structure of a land record blockchain block

This section presents a comprehensive illustration of how a blockchain block may appear in our proposed BACP-LRS system. We incorporate a variety of items such as land record details, cryptographic information and metadata. We also include a graphic illustration of the block structure, as seen in Figure 6. This structure allows the land record system to maintain a secure, immutable record of land transactions and ownership, ensuring data integrity and transparency.

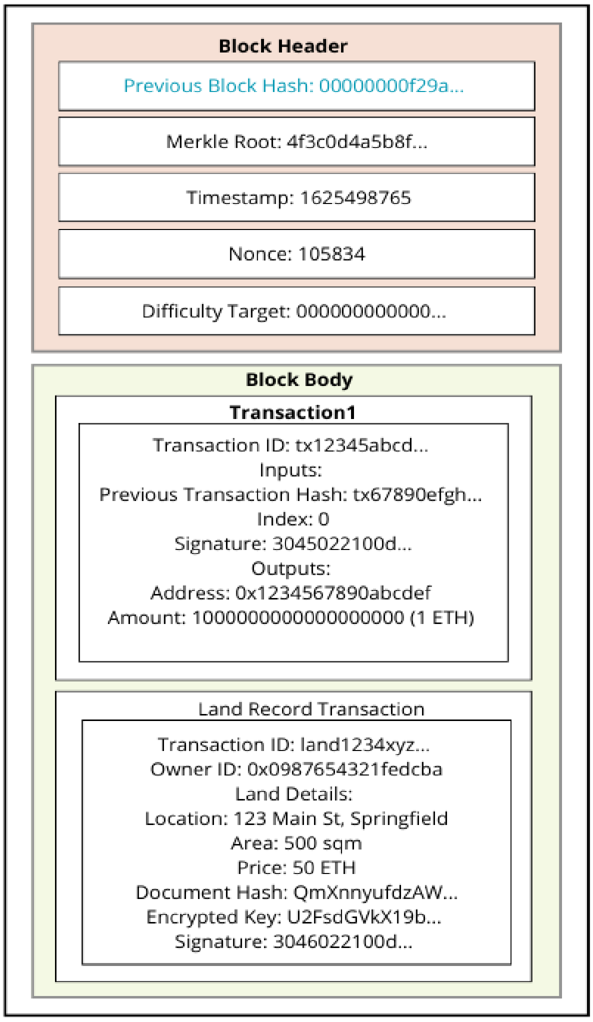

Figure 6. *Detailed structure of a land record blockchain block.*

4.3 Smart contract implementation

Our proposal includes several smart contracts that benefit from the transparency, security and immutability of the blockchain. Each contract plays an important role in ensuring the recording, transfer and transparent sharing of land records, as well as the integrity of data and owner control. The explanations below provide an overview of the specific functions of each contract.

LandRecord contract

LandRecord is the primary contract responsible for registering land records on blockchain. It manages the creation of new land entries, stores encrypted land details and connects these records to landowners.

- *registerLand*: This function allows the owner to register new land registrations by supplying information such as location, area and price, as well as the hash of the encrypted document. It sends a unique identification for the land parcel.
- *getLandDetails*: This function retrieves the details of a land parcel for a given identifier.
- *getEncryptedKey*: This function returns the encrypted key associated with a land record.
- getSignature: This function allows the user to retrieve the digital signature associated with the land record.

PropertyTransfer contract

The ***PropertyTransfer*** contract ensures the secure transfer of property between parties. It ensures that all requirements are met prior to updating the ownership.

- *initiateTransfer*: This function initiates the transfer procedure by verifying the requester's identifying information and ensuring that the parcel is eligible for transfer.
- *finalizeTransfer*: After verification, this function completes the transfer by updating the owner in the ***LandRecord*** contract.

LandSharing contract

The ***LandSharing*** contract allows the sharing of ownership documents with authorized third parties, such as potential buyers, while ensuring the document integrity and confidentiality.

- *requestAccess*: This function allows a third party to request access to land records. The request is subject to the owner's approval.
- *grantAccess*: The land owner uses this function to grant access by encrypting the symmetric key with the requester's public key and sharing it.
- *retrieveSharedRecord*: This function allows the user to fetch the encrypted document and the encrypted symmetric key.

LegalStatus contract

The ***LegalStatus*** contract allows the management and monitoring of the legal status of a property, particularly in cases of litigation or other legal obligations. It ensures that no unauthorized transactions occur during the legal proceedings.

- *updateLegalStatus*: This function updates the legal status of a land parcel by indicating whether it is the subject of a lawsuit.
- *checkLegalStatus*: This function verifies the current legal status of the parcel to ensure that it complies with legal requirements.

5 PERFORMANCE

The performance of BACP-LRS system is presented in this section.

5.1 Experimental setup

To evaluate the performance of the proposed framework, we have implemented it on a Windows 10 system with an 11th Gen Intel(R) Core (TM) i7-1165G7 @ 2.80GHz processor and 16.0 GB of RAM. The implementation is based on Java and Solidity, the programming language for Ethereum smart contracts. Our application programming interfaces communicate with Ethereum as the blockchain technology and IPFS for distributed storage. The system performance was tested using these configurations to evaluate the framework efficiency and effectiveness in the land registration process.

5.2 Experimental results

The suggested system was evaluated in the following cases. Below are the detailed descriptions and results of each experiment.

5.2.1 Smart contract costs

To evaluate and analyse the gas costs associated with the various operations of the different smart contracts, offering insight into the financial consequences of deploying and executing the contracts on the Ethereum network, the BACP-LRS smart contracts were placed on a test network and each function was run many times to measure gas usage. The experiment aimed to determine the efficiency and profitability of contract operations. As shown in Figures 8 and 9 and Table 4, we found that deploying smart contracts consumes a large amount of gas, highlighting the difficulty of the deployment process. The deployment costs is the amount of gas necessary to first deploy each smart contract to the Ethereum network. Gas costs apply to services such as *registerLand*, *shareLandRecord*, *registerLegalStatus* and others that require state changes in the blockchain. Functions such as *getLandDetails*, *getEncryptedKey*, *getSignature*, *checkLegalStatus* and *retrieveSharedRecord* are read-only and do not require gas. The deployment costs vary depending on the complexity and size of each smart contract. The more functions and data structures a contract has, the more gas is needed to deploy it.

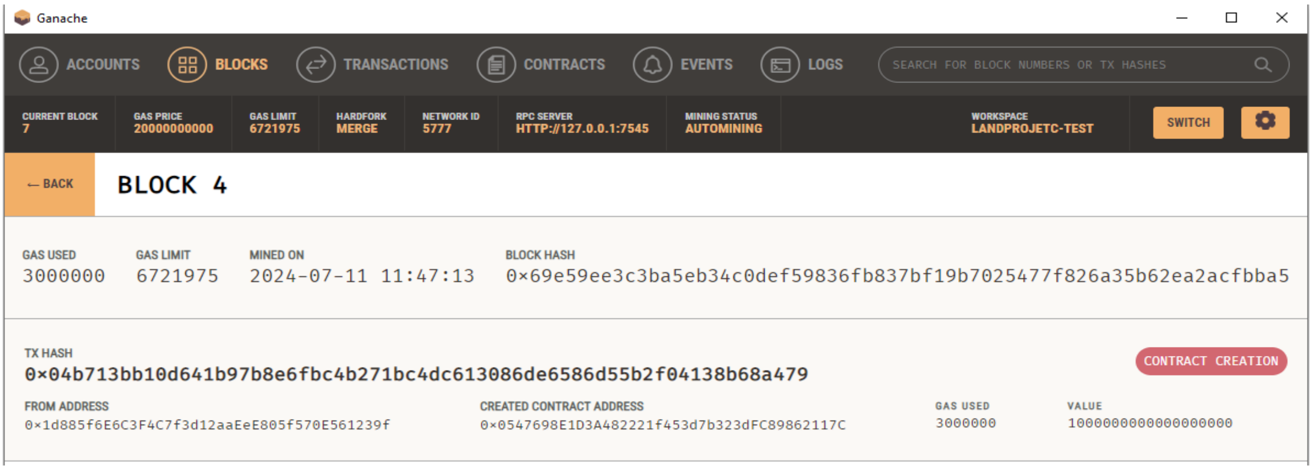

Figure 7*. Ethereum smart contract block.*

Table 4. *Gas costs of deployment of land register smart contracts and their functions.*

Contract function	Task	Gas (Gwei)	Description
***LandRecord* contract**			
LandRecord	Deployment	210,000	Deploys the *LandRecord* smart contract on the Ethereum network.
registerLand	Execution	100,000	Creates a new land record on the blockchain.
shareLandRecord	Execution	75,000	Shares an encrypted land record with the requester.
getLandDetails	Execution	0	Retrieves information about a certain land record.
getEncryptedKey	Execution	0	Obtains the encrypted symmetric key for a land record.
getSignature	Execution	0	Retrieves the signature for a land record.
***PropertyTransfer* contract**			
PropertyTransfer	Deployment	230,000	Deploys the *PropertyTransfer* smart contract on the Ethereum network.
initiateTransfer	Execution	110,000	Initiates the transfer of ownership of a land record.
finalizeTransfer	Execution	90,000	When all prerequisites are completed, the transfer of ownership is finalized.
retrieveSharedRecord	Execution	0	Retrieves a shared record of a land transfer.
***LandSharing* contract**			
LandSharing	Deployment	215,000	Deploys the *LandSharing* smart contract on the Ethereum network.
shareLandRecord	Execution	80,000	Allows the owner to safely share their land record with a requester.
getSharedLandDetails	Execution	0	Allows the requester to view shared land information following verification.
validateSharedRecord	Execution	85,000	Using a signature, validates the shared land record integrity.
***LegalStatus* contract**			
LegalStatus	Deployment	220,000	Deploys the *LegalStatus* smart contract on the Ethereum network.
registerLegalStatus	Execution	95,000	Registers the legal status of a land record.
updateLegalStatus	Execution	85,000	Updates the legal status of a land record.
checkLegalStatus	Execution	0	Returns the legal status of a land record.

OwnershipTransfer has the greatest deployment costs since its ownership transfer operations need more complicated logic and state changes. *LegalStatusRecord* also has somewhat higher deployment costs since it manages more legal status data, necessitating larger blockchain storage allocation. *LandRecord* and *LandSharing* have reduced deployment costs since their functionalities prioritize data storage and sharing over complicated state transitions. *RegisterLand* is the largest gas charge in this contract since it includes saving new data (location, area, price, document hash) on the blockchain, which uses a lot of gas. *ShareLandRecord* uses less gas because it largely updates and shares an existing record. *GetLandDetails*, *getEncryptedKey* and *getSignature* are read-only functions that do not affect the state of the blockchain; therefore, they do not use any gas. *RegisterLegalStatus* and *UpdateLegalStatus* incur gas costs since they create or modify data on the legal status of a property. *CheckLegalStatus* is a read-only function; thus, it does not consume any gas. *InitiateTransfer* has a greater gas cost since it begins the process of transferring ownership, which necessitates the creation of new records and the potential interaction with other data. *FinalizeTransfer* uses significantly less gas because it completes an existing transfer, but it still affects the state, resulting in a large gas cost. *RetrieveSharedRecord* is a read-only function, therefore it does not use any gas. Figure 7 shows the block in the Ganache Ethereum.

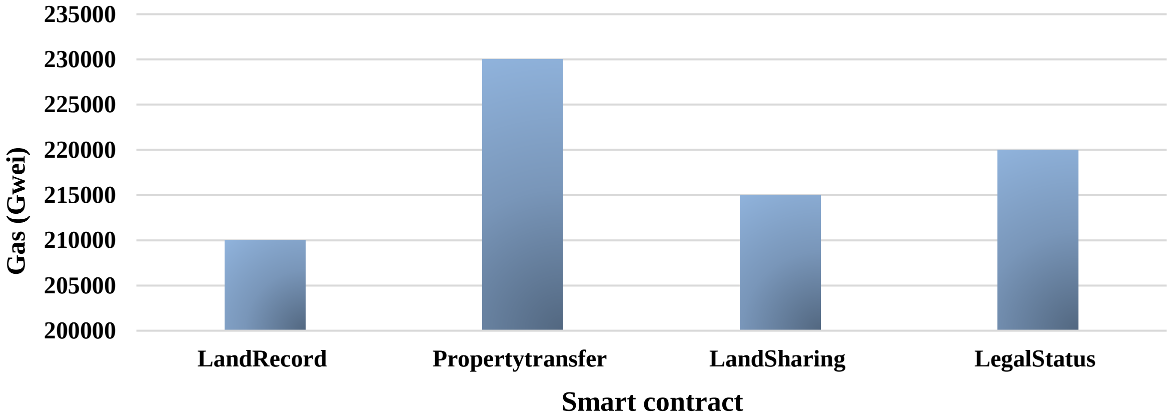

Figure 8. *Gas costs of deployment of smart contracts.*

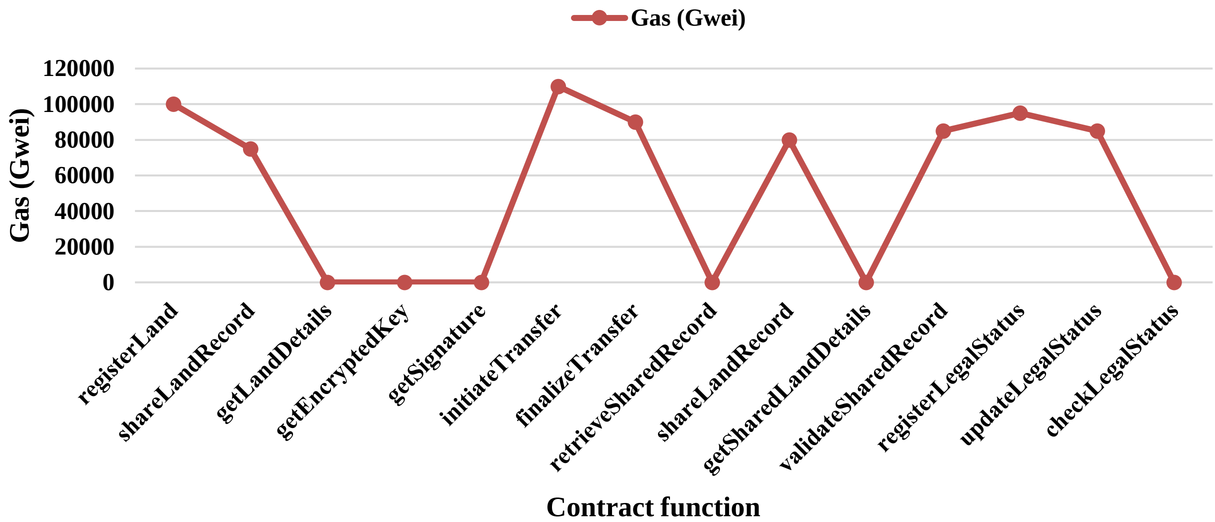

Figure 9. *Gas costs of contract functions.*

6 DISCUSSION

6.1 Limitations and challenges of traditional land registration systems

Conventional methods of land registration are limited by a number of bounds and issues. Among the most considerable concerns, one must mention that of centralization. Very often, such systems are kept by one or a few institutions, such as property register offices or government agencies. Inasmuch as users must rely on the integrity of the central entity, the system opens up to corruption, internal fraud and human error.

Another serious issue can be fraud and data tampering. Land papers can be forged, altered or manipulated by dishonest people, leading to land fraud. This has been a big headache for many countries, ending up in courts of law and financial losses to the real owners. In addition, the existing systems are not transparent. Information is usually not available publicly or is difficult to verify, making it problematic for stakeholders to inquire into ownership history and validity of transactions. Lack of transparency along these lines breeds a breakdown in the trust of the system. Adding inefficiency and bureaucracy to these processes creates even more distrust. Sometimes, the administrative procedure for the registration, transferring or certification of property is circuitous, cumbersome and involves many stages and papers. All these delays and bureaucratic obstacles raise costs and frustrate users, decreasing the overall effectiveness of the system. Another major disadvantage is high costs. The charges for the registration and transfer of property, including administrative and notary charges, are sometimes unreasonably high. Because of this, clients have been discouraged from registering or transferring ownership of their properties and illicit transactions become more possible. Traditional ways of maintaining land records are vulnerable to disasters. Records often remain in the form of paper documents or are maintained within centralized systems that can easily be destroyed by natural calamities, fires and other devastating events. These accidents may lead to partial or total loss of such information, which can never be replaced. Besides, land records generally have limited availability during office hours and may require physical visits to the register office. Thus, this limited access reduces the probability of the users receiving or verifying any information outside office hours or remotely, which reduces the accessibility and efficiency in the system.

6.2 Blockchain and IPFS-based solutions

Systems utilizing blockchain and IPFS have a great number of advantages compared to traditional ways of land registration. Firstly, there is the issue of decentralization. Using a decentralized blockchain for storing land transactions removes the need for any authoritative centre of trust. This minimizes a set of risks from corruption and fraud while making systems more resilient. Both methods make data a great deal more tamper-proof. Records of the hash values are stored on the blockchain, while actual documents are stored on the IPFS. In doing so, these records become tamper-proof and unchangeable once they are saved; this is a massive upgrade in data security and integrity.

Another main advantage relates to transparency. Ownership history and transactions connected with it can be viewed by everyone due to the fact that they are clearly and publicly recorded on the blockchain. Such transparency breeds trust in the system. Efficiency and automation are provided by smart contracts. In this respect, smart contracts allow automated processes regarding property registration and transfer. This reduces the level of complexity, time and expenses involved in traditional administrative procedures. Lower costs are another advantage. The application of smart contracts to record registrations and automate processes significantly cuts administrative and transaction costs, making the system more accessible for all.

Finally, using IPFS for decentralized document storage increases the resilience of the system. This ensures that records are distributed across several nodes, minimizing data loss and ensuring continuous availability. Traditional recording technologies are limited in terms of security, transparency, efficiency and expenses. The implementation of blockchain and IPFS technology has the potential to significantly improve these characteristics, providing a more secure, transparent, efficient and accessible system for managing land records. Table 5 illustrates the advantages of blockchain and IPFS technologies in addressing the limitations of traditional land registration systems.

Table 5. *Blockchain and IPFS technologies versus traditional land registration systems.*

Aspect	Traditional land registration methods	Blockchain and IPFS-based solutions	BACP-LRS
Centralization	Records are maintained by one or a few institutions.	A decentralized system does not need any central authority; therefore, corruption and fraud are considerably reduced.	Decentralized, with even better peer-to-peer validation that reduces reliance upon a central entity.
Integrity and trust issues	Depends on central entities that can easily be prone to corruption, fraud and other human errors.	Decentralization enhances resilience of a system and trust in it while reducing the risks of corruption and fraud.	Sophisticated algorithms of consensus ensure integrity and are more trustworthy.
Fraud and data tampering	Land papers can be forged, altered or manipulated, which again results in fraud cases and other legal issues.	Data are immutable on the blockchain; thus, the document hash is stored on the blockchain and actual documents on the IPFS; therefore, tampering cannot take place.	Adding multi-signature authentication to enhance security and make it tamper-proof.

Aspect	Traditional land registration methods	Blockchain and IPFS-based solutions	BACP-LRS
Lack of transparency	Details are not publicly available or hard to verify.	Transparent, publicly available history of past ownership and transactions on the blockchain; improved transparency.	Real-time transparency and audit trails for all stakeholders, while access can be restricted by improved privacy.
Inefficiency and bureaucracy	Inconvincible and complicated administrative procedure for registration, transfer or certification.	Smart contracts automate and simplify the process of registration and transfers in order to reduce complexity and consume less time.	Smart contracts ensure that the end-to-end registration and transfer process is optimized for security, allowing speedy and tamper-proof execution of transactions.
High costs	Administrative and notary fees are included in these expensive registration and transfer fees.	Digitization and automation by smart contracts reduce the costs.	Because of optimized smart contracts and the use of decentralized, low-cost storage, transaction fees are low.
Vulnerability to disasters	Records may get lost in natural calamities, fires or other devastating situations.	IPFS facilitates decentralized storage of data that minimizes the chances of data loss and increases data availability over time.	Improved data redundancy by multi-site storing and disaster recovery procedures.
Limited access	Limited to office hours and physical visits to register offices.	Blockchain and IPFS enable access to records remotely, making access easier.	Decentralized access control lets users securely access and share land records from anywhere, without dependence on a centralized authority.

6.3 Comparison of BACP-LRS with related works

As shown in Table 6, the proposed method distinguishes itself from prior relevant research in the field of land registration by containing various critical enhancements. Unlike previous systems that rely solely on blockchain technology, our approach includes IPFS for decentralized storage. This characteristic not only improves data security by reducing the danger of centralized storage failures, but it also assures the continuous availability of land records, which is a significant improvement over earlier systems that did not use IPFS. In addition, the BACP-LRS includes data encryption, which was missing in the comparison studies. It has a complex encryption system that improves data security and privacy. Each landowner is given a 128-bit symmetric key (SK) generated using the SHA-1 hash technique and the SHA1PRNG pseudo-random number producing process. This SK, encrypted with AES, adequately safeguards land records. In addition, the system generates key pairs for each blockchain user by hashing a random number using the SHA-256 hash algorithm. These RSA asymmetric encryption keys are necessary for encrypting and digitally signing the initial land records. This multilayer encryption technology provides high levels of data protection and management, distinguishing the proposed system from previous studies that lacked such broad security features. Encrypting land records gives an extra layer of security, securing essential information and ensuring that only authorized users have access to it, eliminating potential threats that other systems may overlook.

Table 6. *Comparison of BACP-LRS with related works.*

Feature	Gupta et al. (2019)	Shuaib et al. (2020)	Biswas et al. (2021)	Umrao et al. (2022)	Zein and Twinomurinzi (2024)	*Proposed BACP-LRS*
Blockchain	✓	✓	✓	✓	✓	✓
IPFS	×	×	×	×	×	✓
Data encryption	×	×	×	×	×	✓
Smart contract	✓	✓	×	✓	✓	✓
User control	×	×	×	×	×	✓

Another key strength of the BACP-LRS is the incorporation of smart contracts, which, as in most other works, help automate procedures such as land transfers, improving efficiency and reducing the chance of human error. Nevertheless, what differentiates our proposal is a focus on individual control, which none of the other approaches provide. Our system enhances privacy and security by enabling users to determine who has access to and can distribute their land data, while also enhancing user trust. This user-centric approach closes an important gap in existing systems, making our proposed solution not only more secure and transparent, but additionally more responsive to end-user preferences and concerns.

7 CONCLUSION

In this paper, we proposed a secure and effective land record management system based on blockchain and IPFS technologies. Our multi-layered architecture protects the integrity, confidentiality and accessibility of property data while allowing smooth interaction among various stakeholders such as landowners, buyers and administrators. The system employs smart contracts to automate critical operations such as land registration, verification and data exchange, lowering fraud risk and increasing transparency. The use of IPFS for distributed storage offers a comprehensive solution for handling massive volumes of land records while assuring security and retrieval efficiency. The use of symmetric and asymmetric encryption techniques ensures that sensitive information is only available to authorized users, protecting the privacy and security of personal data.

We also handle data integrity and non-repudiation issues by utilizing digital signatures and cryptographic hashing, which give verifiable proof of document authenticity and integrity. Because of the decentralized structure of blockchain, data are immutable and tamper-proof, resulting in a large ledger of reliable and transparent transactions. Overall, this system represents a significant advancement in the field of domain name management, providing an evolving and secure architecture that can be used on a global scale. Future work will focus on improving the system evolution, incorporating advanced features such as automated dispute resolution, and exploring the potential of emerging blockchain technologies to improve the efficiency and security of filing registries.

ADDITIONAL INFORMATION AND DECLARATIONS

Conflict of Interests: The authors declare no conflict of interest.

Author Contributions: I.B.: Conceptualization, Methodology, Writing – Original draft preparation, Writing – Reviewing and Editing. A.B.: Supervision, Writing – Reviewing and Editing. I.H.: Supervision, Writing – Reviewing and Editing. B.F.: Supervision, Writing – Reviewing and Editing. D.K.: Supervision, Writing – Reviewing and Editing. K.Z.: Supervision, Writing – Reviewing and Editing.

Statement on the Use of Artificial Intelligence Tools: The authors declare that they didn't use artificial intelligence tools for text or other media generation in this article.

REFERENCES

Alam, K. M., Rahman, J. A., Tasnim, A., & Akther, A. (2022). A blockchain-based land title management system for Bangladesh. *Journal of King Saud University – Computer and Information Sciences*, 34(6), 3096–3110. https://doi.org/10.1016/j.jksuci.2020.10.011

Alden Wily, L. (2018). The tragedy of public lands: The fate of the commons under global commercial pressure. The International Land Coalition. https://www.landcoalition.org/en/resources/tragedy-public-lands/

Ashiquzzaman, R. I. S., Pipash, H. K., Elme, K. M., & Mahmud, D. M. (2021). Ethereum Based Land Registry System for Bangladesh. International *Journal of Innovative Science and Research Technology*, 6(3), 531–553.

Banerjee, S., Kumar, K., Masulkar, P., Amin, R., & Dwivedi, S. K. (2022). Blockchain and IPFS-based reliable land registry system. *Security and Privacy*, 5(5), e236. https://doi.org/10.1002/spy2.236

Becher, B. (2024). Blockchain: What It Is, How It Works, Why It Matters. *Built In*. https://builtin.com/blockchain

Belfer Center for Science and International Affairs. (2022). The Future of Urban Development: Applying Blockchain for Civic Participation. https://www.belfercenter.org/publication/future-urban-development-applying-blockchain-civic-participation

Biswas, M., Al Faysal, J., & Ahmed, K. A. (2021). Landchain: A blockchain based secured land registration system. In *2021 International Conference on Science & Contemporary Technologies (ICSCT)* (pp. 1-6). IEEE. https://doi.org/10.1109/ICSCT53883.2021.9642505

Bitstamp. (2022). Centralized and Decentralized Networks. *Bitstamp Learn Center*. https://www.bitstamp.net/learn/blockchain/centralized-and-decentralized-networks/

Blockchain Council. (2024). Centralization and Decentralization. *Blockchain Council*. https://www.blockchain-council.org/blockchain/decentralized-vs-centralized/

Boumezbeur, I., & Zarour, K. (2022). Privacy-preserving and access control for sharing electronic health record using blockchain technology. *Acta Informatica Pragensia*, 11(1), 105–122. https://doi.org/10.18267/j.aip.176

Deininger, K., & Feder, G. (2009). Land registration, governance, and development: Evidence and implications for policy. *The World Bank Research Observer*, 24(2), 233–266. https://doi.org/10.1093/wbro/lkp007

Dewangan, N. K., & Chandrakar, P. (2024). Geolocation-Based Smart Land Registry Process with Privacy Preservation Using Blockchain Technology and IPFS. In *Blockchain-based Internet of Things* (pp. 167–184). Chapman and Hall/CRC.

Ethereum Foundation. (2024). Introduction to Smart Contracts. *Ethereum Foundation*. https://ethereum.org/en/developers/docs/smart-contracts/

Farnaghi, M., & Mansourian, A. (2020). Blockchain, an enabling technology for transparent and accountable decentralized public participatory GIS. *Cities*, 105, 102850. https://doi.org/10.1016/j.cities.2020.102850

Gupta, N., Das, M. L., & Nandi, S. (2019). Landledger: Blockchain-powered land property administration system. In *2019 IEEE International conference on advanced networks and telecommunications systems (ANTS),* (pp. 1–6). IEEE. https://doi.org/10.1109/ANTS47819.2019.9118125

Heider, C., & Connelly, A. (2016). Why Land Administration Matters for Development. *World Bank Group*. https://ieg.worldbankgroup.org/blog/why-land-administration-matters-development

Hoffman, C. (2018). What Is Ethereum, and What Are Smart Contracts? *How To Geek*. https://www.howtogeek.com/350322/what-is-ethereum-and-what-are-smart-contracts/

IBM. (2024). What is blockchain?. *IBM*. https://www.ibm.com/topics/blockchain

Kaynak, B., Kaynak, S., & Uygun, Ö. (2019). Cloud manufacturing architecture based on public blockchain technology. *IEEE Access*, 8, 2163–2177. https://doi.org/10.1109/ACCESS.2019.2962232

Krishnapriya, S., & Sarath, G. (2020). Securing land registration using blockchain. *Procedia computer science*, 171, 1708–1715. https://doi.org/10.1016/j.procs.2020.04.183

Laurence, T. (2023). *Blockchain for dummies*. John Wiley & Sons.

Lemieux, V. L. (2017). A typology of blockchain recordkeeping solutions and some reflections on their implications for the future of archival preservation. In *2017 IEEE international conference on big data (Big Data),* (pp. 2271–2278). IEEE. https://doi.org/10.1109/BigData.2017.8258180

Nakamoto, S. (2008). Bitcoin: A peer-to-peer electronic cash system. https://bitcoin.org/bitcoin.pdf

Notepub. (2021). Blockchain – Centralized vs. Decentralized vs. Distributed Systems. *Notepub*. https://notepub.io/notes/blockchain-technology/introduction-to-blockchain/blockchain-comparison-of-centralized-vs-decentralized-vs-distributed-systems/

NSSO. (2019). Situation assessment survey of agricultural households. *Government of India*. https://mospi.gov.in/sites/default/files/publication_reports/Report_587m_0.pdf

Nunes, E. P. (2004). A case study in Brazil: The main challenges faced by land administration. In *Inter-regional Special Forum on The Building of Land Information Policies in the Americas, Aguascalientes, Mexico*. FIG. https://www.fig.net/resources/proceedings/2004/mexico/papers_eng/ts5_nunes_eng.pdf

Rouhani, S., & Deters, R. (2019). Security, performance, and applications of smart contracts: A systematic survey. *IEEE Access*, 7, 50759–50779. https://doi.org/10.1109/ACCESS.2019.2911031

Sahai, A., & Pandey, R. (2020). Smart contract definition for land registry in blockchain. In *2020 IEEE 9th International conference on communication systems and network technologies (CSNT),* (pp. 230–235). IEEE. https://doi.org/10.1109/CSNT48778.2020.9115752

Sharma, R., Galphat, Y., Kithani, E., Tanwani, J., Mangnani, B., & Achhra, N. (2021). Digital land registry system using blockchain. *SSRN*. http://doi.org/10.2139/ssrn.3866088

Shen, C., & Pena-Mora, F. (2018). Blockchain for cities—a systematic literature review. *IEEE Access*, 6, 76787–76819. https://doi.org/10.1109/ACCESS.2018.2880744

Shuaib, M., Daud, S. M., Alam, S., & Khan, W. Z. (2020). Blockchain-based framework for secure and reliable land registry system. TELKOMNIKA, 18(5), 2560–2571. http://doi.org/10.12928/telkomnika.v18i5.15787

Sidharthan, R., & Balasaraswathi, V. R. (2024). Secured Land Registration using Ethereum Blockchain and IPFS. In *2024 3rd International Conference on Applied Artificial Intelligence and Computing (ICAAIC)* (pp. 1449–1454). IEEE. https://doi.org/10.1109/ICAAIC60222.2024.10575276

Smart Dubai. (2019). Dubai blockchain strategy. https://www.smartdubai.ae/initiatives/blockchain

Thakur, V., Doja, M. N., Dwivedi, Y. K., Ahmad, T., & Khadanga, G. (2020). Land records on blockchain for implementation of land titling in India. *International Journal of Information Management*, 52, 101940. https://doi.org/10.1016/j.ijinfomgt.2019.04.013

Umrao, L. S., Patel, S. C., & Kumar, S. (2022). Blockchain-based reliable framework for land registration information system. *International Journal of Technology Diffusion*, 13(1), 1–16. https://doi.org/10.4018/IJTD.300743

UN-Habitat. (2016). World Cities Report 2016: Urbanization and Development – Emerging Futures. U*nited Nations Human Settlements Programme*. https://unhabitat.org/world-cities-report-2016

UN-Habitat. (2020). World cities report 2020: The value of sustainable urbanization. *United Nations Human Settlements Programme*. https://unhabitat.org/world-cities-report-2020-the-value-of-sustainable-urbanization

World Bank. (2017). Enhancing public sector performance: Malaysia's experience with transforming land administration. https://www.worldbank.org/en/country/malaysia/publication/enhancing-public-sector-performance-malaysias-experience

World Bank. (2020). Doing business 2020: Comparing business regulation in 190 economies. *World Bank Group*. https://documents1.worldbank.org/curated/fr/688761571934946384/pdf/Doing-Business-2020-Comparing-Business-Regulation-in-190-Economies.pdf

World Economic Forum. (2021). How blockchain can empower smart cities. *World Economic Forum*. https://www.weforum.org/stories/2021/04/how-blockchain-can-empower-smart-cities-gtgs21/

Yatsenko, M. (2021). Blockchain for Cybersecurity: Benefits, Challenges, and Use Cases. *Apriorit*. https://www.apriorit.com/dev-blog/role-of-blockchain-for-cybersecurity

Zein, M. R., & Twinomurinzi, H. (2024). Information Sharing in Land Registration Using Hyperledger Fabric Blockchain. *Blockchains*, 2(2), 107–133. https://doi.org/10.3390/blockchains2020006

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