Design and Implementation of a Blockchain Integrated

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***Abstract*—Land registry systems are required to maintain a transparent record of the legal ownership of a plot of land. These systems help up efficiently manage property records; however conventional centralized systems are vulnerable to data tampering, limited transparency and inefficient verification processes. This paper presents the design and implementation of a blockchain integrated land registry management system that combines the scalability of relational databases with the immutability and security of blockchain technology. The proposed system employs a dual-layer architecture which consists of a relational database and a blockchain layer. A MySQL database manages high-volume of transactions which include user management, property registration, taxation, document handling, and approval workflows. The Blockchain layer uses solidity smart contracts to ensure immutable property records and secure property transactions. The blockchain module includes a distributed marketplace with escrow bidding and government-level validations to further ensure property transactions security and integrity. The whole service is delivered as a web application built on Flask. The project also uses advanced database management techniques like stored procedures. triggers and indexing in order to provide data consistency and optimized performance. Results demonstrate that the proposed hybrid approach enhances property record transparency, traceability and security as well as supports efficient property management comparable to existing systems.**

***Index Terms*—Blockchain, Land Registry Management System, Smart Contracts, Database Management System, Secure Transactions**

I. INTRODUCTION

Land registries establish legal ownership of plots, enable transactions of properties and also give the state the facts it needs to levy taxes or plan a city. Despite their importance, many of today's registries sit in on office and run on paper heavy processes. This makes them susceptible to data tampering, fraudulent ownership claims, delays in registration and other functions and lack of transparency. These issues are known to be among the pertinent challenges to accelerated land management, especially in areas with extensive land transactions and intricate regulatory workflows [1], [5].

There is a growing interest in blockchain technology as a means to overcome the challenges of trust and integrity pertaining to record management systems. This is because blockchain technology, with its Decentralized System and cryptographic security features, is capable of ensuring the security and integrity of records in such a manner that they would not require any central control or authorization. There have been some recent developments in which blockchain land registration systems have been shown to increase the level of transparency, auditability, and security of protection against unauthorized changes in ownership records [1], [4], [9].

Previous work has offered various solutions from a blockchain perspective, such as hierarchical permissioned blockchains, document verification systems integrated with the blockchain, and decentralized systems designed to simplify governance and facilitate effective governance of property rights [2], [3], [8]. Furthermore, studies have employed surveys and investigations of the current context of land registries to examine the operational issues involved in adopting the concept of blockchain, such as scalability, governance, and adaptability of the system to fit the context and directives of jurisdictions [5]. This implies that, even though the feasibility of adoption is possible, there are issues involved that need further research and development work.

A major weakness of existing systems is the dependency on blockchain technology to store and manage all land information. Blockchain transactions are neither designed for high transaction rates, nor are they designed for complex queries and analysis, which

are required in a large-scale land administration system. The latest trend of research moves towards overcoming this limitation and ensuring a balance between immutability and efficiency, where blockchain technology is to be combined with a traditional database management system [6]. Existing systems lack implementation examples of a closely integrated hybrid technology.

These observations drive the development of a Blockchain integrated Land Registry Management system, which uses both a relational database backend and a blockchain based smart contract layer. This proposed system will enable holistic land registry management functionality like role-based user management, property registration, ownership transfer, government checks and transaction traceability all while providing tamer proof storage of land ownership information through blockchain technology. The hybrid system leverages database technology for efficient data processing and analytics, while blockchain provides secure and immutable record-keeping.

II. RELATED WORK

Using blockchain for land registration and land records management has drawn a significant interest lately because it promises clearer, safer and more trusted property transfers. Current studies are directed towards harnessing the potential offered by blockchain's immutability in preventing changes to land ownership registration by unauthorized persons.

There are several studies that investigate blockchain based frameworks for registering lands to combat irregularities and increase reliability. Models for decentralized recording of lands and maintaining the authenticity of transactions have been identified using blockchain techniques [1], [4], [9]. These solutions show that use of unalterable repositories is helpful in combating irregular activities of data manipulation and illegal ownership transfers in the centralized registry of lands and properties.

Additionally, because blockchain based frameworks must also handle governance and administrative control, the hierarchical and permissioned blockchain structures have also been explored to cater to such requirements. These systems use role-based access to enable government authorities to validate and approve land transactions while benefiting from blockchain transparency [2], [8]. Such models emphasize the need to fit blockchain based land registries into the current legal and institutional frameworks instead of relying on permissionless systems.

Improvements related to document verification and authenticity have been made using the combination of auxiliary technologies with blockchain technology. A combination of blockchain technology with QR codes or digital means of document verification has been proposed to enhance document tracing and ensure document authenticity in land-related documents [3]. Although these technologies strengthen document security, they rarely emphasize document verification and do little to support actual administrative processes, such as taxation, auditing, and conflict resolution.

Several survey and analytical studies have looked into the practical challenges of using blockchain based land registry platforms. These studies highlight scalability issues, complex governance, difficulties in working with old systems, regulatory compliance, and extra performance costs as main barriers to large-scale use [5]. This indicated that the use of blockchain technology alone is not sufficient to address the system needs of the land administration system.

Recently, there has been a focus on the need to incorporate blockchain technology architectures with classical database management systems. This approach aims to balance immutability with efficiency and scalability. Studies on integrating blockchain and databases show that relational databases are more effective for managing high frequency transactions, complex queries, and analytical tasks. In contrast, blockchain is more capable to ensure data integrity and auditability [6]. However, most studies that focus on blockchain and database technology are still at the conceptual level and have no direct implementation to land registration systems.

Several proposed frameworks and experimental systems mainly focus on ownership registration and transfer, while giving little attention to real-world aspects such as multi-level approval workflows, marketplace-based land transactions, escrow mechanisms, and thorough audit logging [7]. Thus, there still appears to be a gap in the implementation of blockchain-based land registry systems.

In conclusion, although there are findings that indicate blockchain-based systems have been effective in managing land registries and their benefits are realized, existing solutions based on these systems are challenged by scalability, database efficiency and

functionality in a practical system process. Therefore, there is a need for a hybrid system that combines the immutable properties and database functionality in a system as proposed in this work.

III. METHODOLOGY

A. System Architecture

The proposed Blockchain Integrated Land Registry Management System is designed using a hybrid architecture that combines a conventional web-based application layer with a relational database backend and a blockchain based smart contract layer. This structure aims to balance operational efficiency, data integrity, and transparency in land registry operations.

Overall, the system has been divided into three main layers. The application layer allows users to interact with a web based interface and provides the backend services required to fulfil tasks related to land registry. The database layer deals with the management of formal data, transaction data, and administrative tasks via a relational database management system. Lastly, the blockchain layer provides immutability to the storage of essential records of ownership and transaction histories through smart contracts. These layers work together so that every step of registering land or transferring ownership is safe, traceable and quick.

A high-level representation of the system architecture is illustrated in Fig. 1.

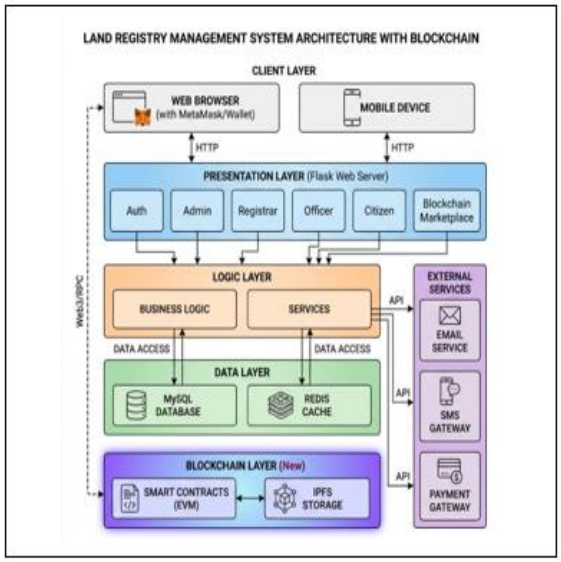

Fig. 1 System Architecture Diagram of the proposed solution

B. System Actors and Roles

The system restricts who can carry out sensitive tasks using a role-based access model that mimics actual land administration. Three categories of users have been identified.

Land Owner (Citizen): This user participates in land transactions, registers properties, files ownership paperwork and starts property transfers. Landowners can view their registered properties and also check the status of transfer requests and approvals.

Government Authority: Government representatives are in charge of approving or rejecting property registrations and transfers, confirming submitted land records and validating ownership claims. Their function guarantees the system's administrative supervision and adherence to the law.

System Administrator: Administrator manages user accounts, system configurations and watches over the operations of the system. Their function does not alter land ownership records and is limited to maintain system integrity.

Accountability is perpetuated by the way responsibilities within actors are clearly separated, preventing unauthorized access to critical operations of the registry.

C. Database Layer

The database layer is the main operating part of the system and is implemented on a relational database management system. The decision to use a relational model is informed by the need to store structured data, perform complex querying, maintain transaction consistency, and perform analytical processing, which are necessary in a large land registry system.

The database schema has key entities like users, properties, ownership records, transaction logs and supporting documents. Normalization techniques help reduce data redundancy and maintain data integrity across related tables. To ensure referential consistency, ownership and transaction relationship are represented using foreign keys.

Stored procedures are used for frequently executed operations like property registration, ownership updates and approval workflows. They help improve performance and reliability. Database triggers are used to track changes by automatically logging updates made to key tables. This allows for auditability in the system. Indexing on frequently queried attributes like property identifiers help speed up query execution.

Transaction management mechanisms ensure atomicity and consistency in multi-step operations. These operations include administrative validation and ownership updates.

D. Blockchain Layer and Smart Contract Design

Important land ownership records are made transparent and immutable by integrating the blockchain layer. Smart contracts store vital records of ownership and the hashes of transactions in the blockchain. This way, it can be ensured that once recorded and verified any kind of alteration will not go unnoticed.

Smart contracts can deal with the following activities: property registration, ownership transfer, and tracing of transactions. In order to keep the system efficient, it adopts an on-chain, off-chain data separation strategy. Necessary identifiers like ownership, and cryptographic hashes are maintained on the blockchain, while property data is kept in the database. This helps to ensure reduced storage space on the blockchain and reduced costs of performing transactions while at the same time upholding the authenticity of the ownership information on the land. Instead of taking the place of the database system, the blockchain layer serves as a reliable verification method.

E. Hybrid Integration Workflow

The hybrid integration workflow specifies the interaction between the database and the blockchain layers for certain critical operations of the system. When a land owner submits a property registration request, the property data and documents are stored in the database. Then, the government authority verifies the request through the application layer.

After that, a related blockchain transaction is automatically performed, and thus an immutable reference to the approved ownership record is stored. The generated identifier of the blockchain transaction is then stored inside the database in order to maintain synchronization between the two levels. Ownership transfer transactions follow a similar process as well, and thus ownership is updated in a consistent manner within both database and blockchain records.

This two-way synchronization makes it possible to efficiently query and manage workflows through the database and ensures that ownership proof and details are tamper-proof using the blockchain. Attempts to alter ownership details without an accompanying record in the blockchain can be detected using integrity checks in the database.

F. Implementation Environment

The proposed system is implemented as a full-stack web application. The backend services are developed using the Python Flask framework. This handles request routing, business logic and communication between system components. The relational database is implemented using MySQL. The database helps manage structured data and transactions.

The blockchain layer is created with the help of Solidity smart contracts that run in a regulated blockchain setting. The communication between the application and blockchain is via the conventional blockchain communication libraries and applications programming interfaces. Under this modular implementation design, one can have the extended or replaced individual components without impacting on the system structure as a whole.

IV. TESTING AND VALIDATION

This section presents the strategy used in testing the proposed Blockchain Integrated Land Registry Management System on its correctness, reliability, and feasibility. Testing was performed on all levels, namely, the database level, application level, and blockchain level, to ensure functionality. Testing was focused on ensuring that there were no defects owing to service deployment.

A. Database layer testing

The relational database layer was tested to ensure data consistency. Unit testing and subsequent query analysis were done on:

- Registration and approval of properties
- Requests for ownership modifications and joint ownership management
- Stored procedure dealing with the business logic
- Automatic status updates and trigger conditions for audit logs

The ACID properties were tested through the execution of parallel transactions with property transactions and tax payments to test isolation and rollback functionality in during failures. In order to confirm the efficacy of the query and ensure effective retrieval for search and analytics operations, query response time was monitored.

B. Application layer testing

The application layer was tested through both manual testing and API level checks. Testing focused on:

- Role-based access control for different system users
- Form validation and error handling
- REST API endpoints for property registration, updates and reporting
- Handling session and authentication process.

Real time notifications based on web sockets were also tested to ensure that users get quick updates on approvals, rejections or changes in transaction status. Edge cases like invalid inputs, unauthorized attempts to access data and duplicate requests were also evaluated.

C. Blockchain layer testing

The blockchain element of the platform was implemented and tested on the Somnia Testnet, a test network that allows an Ethereum-friendly environment ideal for the validation of smart contracts in a financially risk-free setting.

With the focus of the project centred on smart contracts, there was a need to test the contracts. The tests included:

- On-chain registration of land records
- Decentralized marketplace listing and delisting of properties
- Placement of bids using Escrowed Ether
- Ownership transfer requests and government validation processes

All functions of the smart contract had been checked for correctness in matters of state transitions, event emission, and access control. Using the Somnia testnet helped validate real transaction execution, gas usage and behaviour and wallet- based interactions that are almost akin to real world situations.

D. Integrated system testing

End to end testing was necessary to ensure synchronization between off chain database and on chain records. The test cases included:

- Property registration approved in the database and subsequently recorded on the blockchain
- After approval, ownership transfers made through the blockchain marketplace are reflected in the database.
- Confirmation of ownership consistency between off chain data and on chain records.

These tests verify that data is consistent across all the layers of the hybrid architecture while also storing leveraging immutability offered by the blockchain.

E. Test Environment

The system was tested in a controlled development environment with the configuration listed below:

- Backend: Python (Flask)
- Database: MySQL 8.0
- Blockchain Network: Somnia Testnet
- Smart Contracts: Solidity 0.8.x
- Wallet Integration: MetaMask

This setup allowed safe experimentation, repeatable testing, and reliable observation of system behaviour under realistic operating conditions.

V. RESULTS AND DISCUSSIONS

The hybrid model is effective in enabling land registries in a safe, transparent, and effective way, according to the experimental results of the suggested Blockchain Integrated Land Registry Management System. Function, integration, and blockchain testing results on the suggested system unequivocally show that everything operates in a real-world administrative manner.

The system was able to efficiently handle property registration and transfer of ownership through a mix of database driven workflows and blockchain based authentication. The administrative approval was properly enforced to ensure that any change of ownership was actually committed upon successful authentication by government officials. This proves that a role-based system is able to prevent unauthorized changes.

The integration between the relational database and blockchain layer proved to be reliable. For every registered approval and transfer of ownership, transactions on the blockchain technology have been recorded and associated with their database counterparts. This ensured that there was synchronization between the two environments, which made it possible to query with efficiency using the database while providing the record with no room for alterations on the blockchain environment as well. From the study, the hybrid model solves the problem

associated with the use of blockchain technology alone.

The blockchain component's usefulness was further confirmed by deployment and testing on the Somnia Testnet. Smart contracts that had predictable transitions of state and reliable event generation worked correctly in this environment. Because only critical ownership updates, not routine access, were conducted on the blockchain, although it took longer on the blockchain compared to operations on the databases, it did not affect the system usage.

From the performance point of view, the database layer managed administrative tasks and structured queries effectively. The system behaved steadily during several test cycles due to the use of indexing, stored procedures and transaction management. This demonstrates that relational databases are appropriate for handling frequent land registry operations in the suggested architecture.

Despite these advantages, some drawbacks were noted. Considering the dependency of blockchain operations on the state of the network, the verification of ownership can be delayed in times of high usage. In addition, advanced functionalities such as the automatic resolution of disputes and the testing of large-scale deployments were not included in the implementation, even though the system supports the core operations of the land registry.

On the whole, it appears that the findings from the work demonstrate that the proposed system has a well-balanced and practical approach for the future management of land registries. This has been achieved by incorporating the benefits of the database and the immutability offered by the blockchain technology and can be seen as having overcome the problems faced with real world adoption.

VI. CONCLUSION

This paper presented the design and implementation of a Blockchain Integrated Land Registry Management System that combines the efficiency of relational database systems with the immutability and transparency of blockchain technology. The key weaknesses in the conventional land registry systems, including the lack of transparency, unauthorized modifications, and inefficient administrative processes, are overcome by the proposed hybrid model.

The system separates operational data management from immutable ownership verification in order to effectively leverage both database and blockchain technologies. The relational database allows efficient handling of structured data. It can handle complex queries and manage a high volume of operation requests. With the help of smart contracts, the blockchain layer ensures that records of ownership and transactions are tamper proof. This helps avoid scalability and performance issues with fully on chain solutions.

Experimentation and testing, including its deployment to the Somnia Testnet, have shown the system to work well when registering properties and completing the process of property ownership transfer. This is evidence that there is indeed synchronized interaction between the off-chain and on-chain parts of the system, proper enforcement of the approval by roles, and adequate user-friendliness.

Though the existing system implementation targets land registry functionalities, future developments could see the system being expanded to test the deployment on a larger scale, national identity system integration, and automatic dispute resolutions. In addition, system performance improvement and compatibility with the existing land records management system of the government could also be studied for further developments.

Overall, the proposed system combines both blockchain and database to provide a practical and scalable solution for modern land registry management. This system offers improved transparency, integrity and efficient administration.

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