Design and Implementation of a Geospatially Enabled Blockchain Application for Land Record Management

Malhar Patel , Enrcomp Solutions Pvt Ltd, Ahmedabad, India
Anjana Vyas , CEPT University (Retd.), Ahmedabad, India
Sweata Katwala , Vadodara Urban Development Authority, Vadodara, India

Keywords: GeoBlockchain, Land Administration, Smart Contracts, Geospatial Technology, Decentralized Ledger Systems

Abstract

In India, land ownership disputes remain a major source of litigation, often resulting from fragmented records, lack of transparency, and outdated administrative processes. This study explores the potential of geospatially enabled blockchain technology to transform land administration into a secure, efficient, and trust based system. By combining the immutability and decentralization of blockchain with the spatial precision of geospatial data, the research proposes a digital framework that enhances the integrity of land transactions and builds stakeholder confidence. The methodology follows a modular system development approach using both software and database life cycle models. Through fact finding, stakeholder interviews, prototyping, and interface development, the system was designed to accommodate various users buyers, sellers, inspectors, and administrators. Key features include cryptographic public private key generation and secure hashing algorithms for transaction protection. A functional prototype was developed using Java and MySQL, integrating GIS capabilities and smart contracts to automate processes and ensure spatial traceability. The system's performance was assessed based on its completeness, usability, and security. Results showed that the blockchain ledger enabled real time synchronization and minimized the risk of fraud, tampering, or duplication. Incorporating spatial data allowed for visual verification of land parcels and ownership histories, improving reliability for both citizens and government agencies.
This research demonstrates how integrating geospatial intelligence with blockchain can modernize land governance, reduce bureaucratic delays, and foster a more transparent and citizen centric system. It presents a promising direction for high performance, scalable digital infrastructure in rapidly developing regions.

1. Introduction

1.1 Blockchain Applications in Land Registry

Over the last decade, research and pilot projects have demonstrated the relevance of blockchain technology for digital land governance, improving the trust and transparency of property registries (Lemieux, 2016) (World Bank, 2017). Platforms such as Ethereum and Hyper ledger allow land authorities to securely store land ownership details, transaction histories, and supporting documents within tamper proof ledgers (Zheng, Xie, Dai, Chen, & Wang, 2018). These systems make direct use of public and private key cryptography, ensuring that only authenticated individuals or institutions are able to execute and verify transactions. The adoption of programmable smart contracts enables conditional transfers of ownership, automatic validation processes, and transparent recording of procedural steps in a property exchange, thereby minimizing opportunities for manual interference or malfeasance (Bashir, 2020). Several notable implementations contribute unique modules such as secure user authentication, inspector mediated validation, and real time status updates demonstrating both the practicality and adaptability of blockchain networks in various regulatory environments.

1.2 Geospatial Information Integration

A defining advancement in contemporary land registry systems is the integration of geospatial data into blockchain frameworks. By embedding cadastral maps, property boundaries, and spatial attributes directly within digital records, these systems offer unprecedented accuracy and authenticity in defining land parcels (de Kruijff & Weigand, 2017). The use of geospatial APIs and mapping interfaces ensures each transaction is explicitly linked to verifiable spatial units crucial in regions with boundary disputes and overlapping claims. Integration with standardized geospatial formats, such as GeoJSON, supports consistent representation of spatial extents and facilitates interaction with enterprise GIS platforms such as ArcGIS (FAO, 2021). This approach enhances the evidentiary value of digital land records and allows for real time visualization and validation by all stakeholders.

1.3 Shortcomings of Conventional Systems

Conventional paper based and standalone digital land registry processes face persistent challenges such as outdated ownership records, lack of a verifiable chain of custody, unauthorized sales, and delays from mutation to registration (Williamson, Enemark, Wallace, & Rajabifard, 2010) (McLaren, 2018). These issues are compounded by the absence of a unified, verifiable interface for stakeholders, often resulting in transaction disputes and legal complications. Human oversight, while essential, can also introduce inconsistencies and errors. Blockchain based systems address these weaknesses by implementing role based access controls, rule driven transaction logic, and immutable audit trails thereby enforcing compliance and enhancing accountability (Lemmen & van Oosterom, 2019).

1.4 Legal and Technical Challenges

Despite their promise, blockchain enabled land registries must overcome legal and technical hurdles. Many jurisdictions require the ability to update or redact records for legitimate administrative or judicial reasons, which conflicts with blockchain's inherent immutability. Cryptographic techniques such as chameleon hashes are being explored to enable controlled redaction without compromising chain integrity (Banasik, Leszczyna, & Szczepański, 2020).

This contribution has been peer-reviewed. The double-blind peer-review was conducted on the basis of the full paper.
https://doi.org/10.5194/isprs-annals-X-5-W2-2025-491-2025

Additionally, achieving interoperability with existing cadastral, legal, and revenue systems remains a significant challenge. Standardizing spatial and alphanumeric metadata, and aligning blockchain features with evolving land governance regulations, are essential for scalable adoption (FAO, 2021) (UN-Habitat & GLTN, 2020).

2. Methodology

The methodology adopted for developing a geospatially enabled blockchain system for land administration combines principles from software engineering, database design, and spatial information systems.

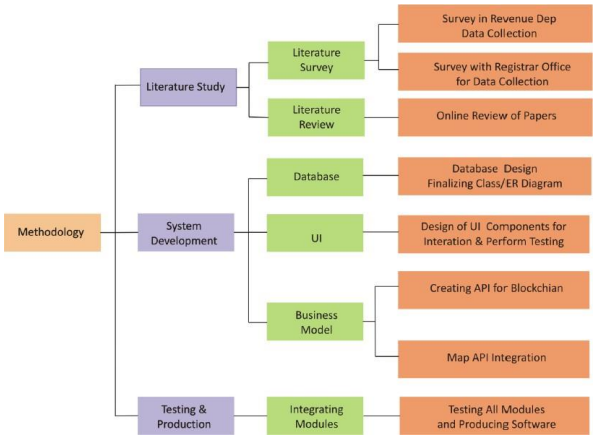

Figure 1: Methodology workflow.

The project follows a comprehensive system development life cycle (SDLC) and incorporates fact finding techniques, user interface prototyping, and rigorous database modelling. The goal was to construct a tamper proof, spatially aware, role based land registry platform using blockchain technology.

2.1 System Development Life Cycles

The software development process followed a modular SDLC approach, consisting of the following stages:

- Requirement Gathering: Stakeholder interviews, document analysis, and field observations were used to gather system specifications.
- Planning: This stage included defining the system scope, selecting technologies (Java, MySQL, HTML5), and identifying security needs.
- Defining Requirements: Detailed requirement documentation was created and validated by supervisors and potential users.
- Designing: Functional design documents and UI wireframes were developed. Special attention was given to spatial data integration and access control mechanisms.
- Building: Backend development was executed using Java (J2EE), incorporating cryptographic libraries and blockchain logic. UI elements were created using HTML5 and CSS.
- Testing: Multiple testing layers were introduced, including unit testing for modules, integration testing for blockchain transactions, and usability testing for the user interface.
- Deployment: The prototype was deployed on a local server with a fully integrated spatial database and blockchain ledger.

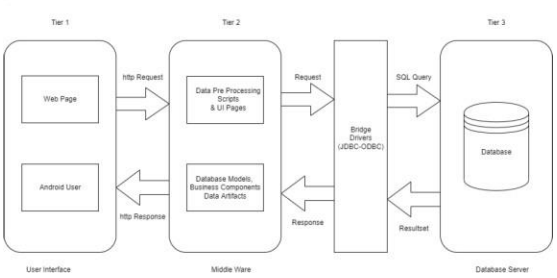

Figure 2: Architecture Diagram Of Current Model.

2.2 Database Development Life Cycle (DDLC)

The backend database was designed following the DDLC methodology, ensuring reliable data modeling and efficient query processing. The major phases included:

- Requirement Analysis & Planning: Identified all required data fields for buyer, seller, property, and transaction records.
- Conceptual Design: Entity relationship diagrams were created, mapping the relationships among users, properties, and blocks.
- Logical and Physical Design: Tables were normalized to avoid redundancy, and indexing strategies were applied to optimize retrieval.
- Implementation: The MySQL database schema was coded using SQL, and Java connectors were used to interface with the application layer.
- Observation & Maintenance: Functional testing of the database was conducted to ensure robustness. Backup and data recovery plans were defined.

2.3 User Interface and Module Development

A clean, intuitive user interface (UI) was essential for ensuring adoption across diverse user groups. The application supports four primary roles .Buyer, Seller, Inspector, and Administrator each with a customized interface and role based access control.

- Buyer Panel: Enables registration, browsing of property listings, submitting purchase requests, and viewing transaction history.
- Seller Panel: Allows property uploads with associated documents, price details, and ownership history.
- Inspector Panel: Validates transactions, reviews documents, and either approves or flags entries. Serves as the key validation node in the blockchain network.
- Admin Panel: A government designated role to manage system users, monitor transactions, and perform security audits.

All modules interact with the blockchain ledger, ensuring that each user action (registration, transaction, validation) creates or appends to a cryptographically secured block.

2.4 Blockchain Transaction Flow

The transaction logic is governed by secure blockchain principles, utilizing hashing algorithms and asymmetric cryptography:

- Key Generation: Public private key pairs are generated for each user during registration. These keys ensure identity verification and secure message exchange.
- Block Formation: Each approved transaction such as a buyer's request or inspector's validation triggers the creation of a new block, linked to the previous one via a secure hash.
- Smart Contracts: Embedded conditions manage the property ownership transfer once pre defined validations are met.
- Hashing Algorithm: SHA based algorithms were used to generate unique identifiers for blocks, ensuring immutability and integrity.

2.5 Integration of Geospatial Information

The system embeds geospatial data such as maps, boundary lines, and parcel coordinates within the blockchain record. This is achieved through:

- Use of standard formats like GeoJSON for spatial attribute consistency.
- Linking cadastral datasets with land registry records at the database level.
- Visualization support via mapping libraries for real time property display on the user dashboard.

By combining geospatial intelligence with blockchain integrity, the model enhances transparency, reduces disputes, and enables verifiable, location aware land administration.

2.6 Fact Finding Techniques

To validate user needs and system feasibility, multiple fact finding techniques were employed:

- Documentation Review: Analysis of current land registry formats and administrative processes.
- Observations: Field visits to registry offices to understand real world workflows.
- Interviews: Conducted with stakeholders including landowners, government officers, and legal experts.
- Questionnaires: Distributed to assess public understanding of digital land systems.
- Prototyping: Early mockups of the UI were shown to users to gather feedback.
- Joint Requirement Planning (JRP): Collaborative sessions were held with technical experts and users to co develop system features.

3. User Interface (UI) Development

The user interface is one of the most critical aspects of any software system, as it shapes the user experience and determines the usability of the platform. In the proposed blockchain enabled land administration system, the interface was designed to be intuitive, responsive, and tailored to the needs of four distinct user roles: Buyer, Seller, Inspector, and Administrator. Each user role has access to specific functionalities, ensuring secure, role based access control while maintaining system transparency.

3.1 Design Principles and Approach

The interface design followed a user centered approach, focusing on simplicity, clarity, and accessibility. The system was built using HTML5, CSS, and JavaServer Pages (JSP), ensuring cross platform compatibility and browser independence. Visual consistency was maintained through standardized color palettes and layout structures. Input fields were designed with appropriate validation to prevent incorrect entries and support secure data handling.

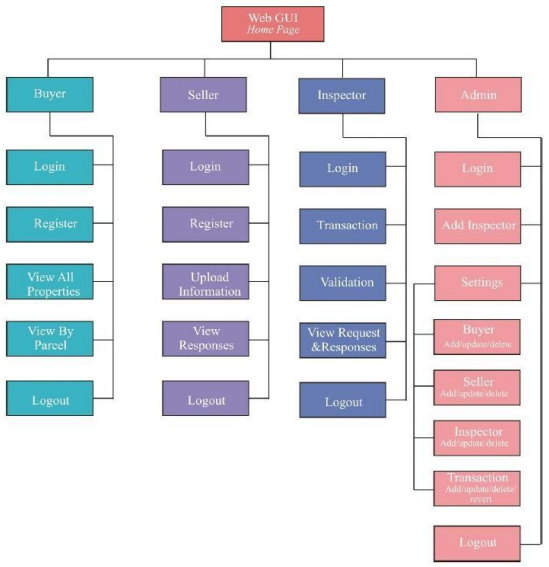

Figure 3 Home Page Flow Work Of Each Panel.

Before development began, wireframes were created for each module and reviewed with stakeholders to incorporate early feedback. These wireframes were then translated into fully functional front end templates integrated with backend services using Java and MySQL

3.2 Buyer Interface

The buyer module offers an end to end workflow that allows users to browse, select, and initiate property purchases seamlessly.Key features of the buyer dashboard include:

- Secure Registration and Login: Buyers can create an account and access the platform using a secure two step authentication process.
- Property Listing Access: Properties are presented in both a searchable list format and an interactive map interface. Each listing includes:
  - Property ID and location
  - Plot dimensions and valuation
  - Documented ownership history
  - Available amenities and inspection status

Property Selection and Interaction: Once a buyer identifies a property of interest, they can:
Click to view detailed descriptions and legal documentation

- Compare multiple listings using filters (e.g., price range, area, verification status)
- Submit a "Purchase Interest Request" which alerts the seller
- Request Management and Tracking: All submitted requests are visible on the buyer's dashboard along

with real time status updates (e.g., "pending", "under inspection", "validated").

- Blockchain Transaction History: Every buyer interaction from registration to final property acquisition is recorded immutably on the blockchain. The buyer can view hashed transaction summaries, timestamps, and inspector approvals in a secure audit log.

This structured workflow simplifies the property search and selection experience, while simultaneously integrating robust legal and technical safeguards behind the scenes.

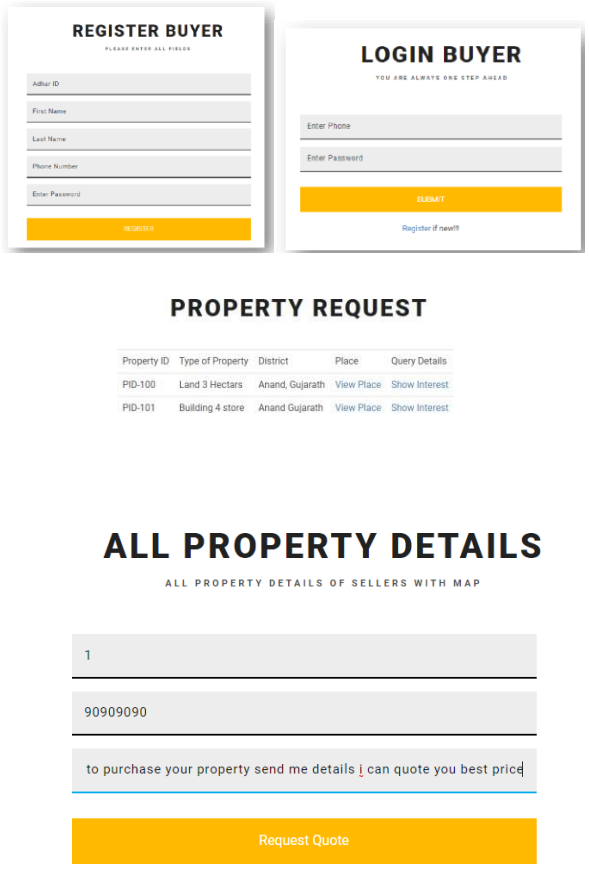

Figure 4 – Buyer Interface.

3.3 Seller Interface

The seller interface is structured to simplify the process of uploading and managing property listings. Through the seller panel, users can:

- Register and verify their identity by uploading scanned documents such as ID proof and ownership certificates
- Upload detailed property information, including location, area, valuation, and history
- Respond to buyer inquiries and initiate smart contract based ownership transfers

All uploads are automatically encrypted and stored securely in the backend, ensuring that sensitive ownership documents are only accessible to authorized parties such as inspectors or administrators.

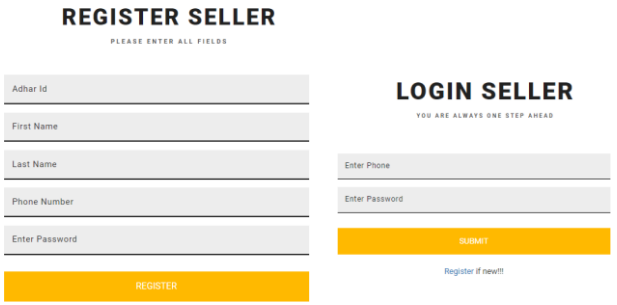

Figure 5 – Seller Registration Interface.

3.4 Inspector Interface

The inspector acts as a neutral validator in the land transaction workflow. Their interface is designed to streamline oversight responsibilities. Key functionalities include:

- Reviewing buyer and seller submissions for completeness and authenticity
- Validating or rejecting transactions by verifying documents and blockchain entries
- Triggering the block creation process for verified transactions
- Monitoring flags or alerts raised due to suspicious activity or incomplete documentation

This interface ensures that inspectors can maintain a transparent and impartial record of all land transactions. Every inspector decision is recorded on chain to maintain accountability and reduce chances of malpractice.

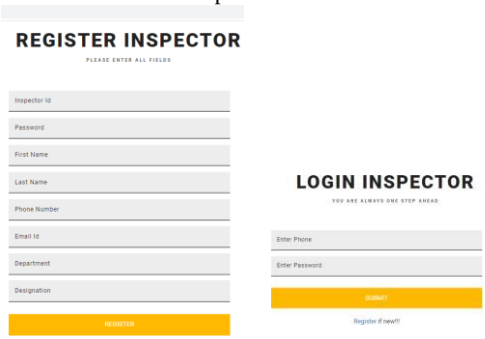

Figure 6 – Inspector Registration Interface.

3.5 Administrator Interface

The administrator (typically a government appointed officer) oversees the entire ecosystem. The admin dashboard provides high level access to:

- Add, edit, or remove users from the platform
- View and audit transaction histories across all user roles
- Manage system configurations and permissions
- Monitor platform usage and security logs

The administrator's role is essential for maintaining regulatory compliance and ensuring that the platform operates according to national land laws and digital governance standards.

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3.6 Interface and User flow

The platform follows a linear and intuitive user flow:

1. Registration and login for all users with individual credentials
2. Role based redirection to user specific dashboards
3. Real time data fetching from the database to populate dashboards
4. Smart contract initiation and block creation upon inspector validation
5. Secure transaction recording with hash based encryption

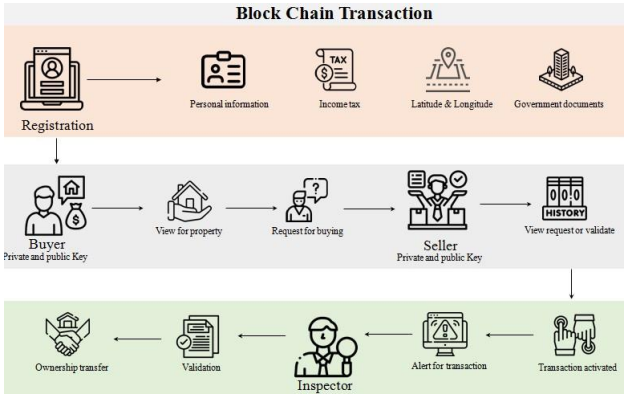

Figure 6 – Blockchain workflow.

The interactive UI also includes visual feedback for users at every step for example, confirmation messages after uploads, success indicators after validation, and alerts for rejected actions. Each user interaction results in a change that is mirrored in the blockchain backend, making the system both reactive and traceable.

4. Transaction Processing

Transaction processing is at the heart of the proposed blockchain based land administration system. Each transaction from property registration to ownership transfer is cryptographically secured, timestamped, and recorded on an immutable ledger. This ensures not only traceability but also verifiability across the entire transaction lifecycle.

4.1 Blockchain Execution Logic

When a buyer expresses interest in a property, the system initiates a transaction request, which includes identifiers for the buyer, the seller, and the property. This request is encapsulated within a data block. Before this block is added to the chain, it undergoes validation by the inspector.
Once verified, the transaction is digitally signed using the buyer's private key and stored as a new block linked to the previous one through a secure hash. The system uses SHA (Secure Hash Algorithm) for generating unique hash values for every block, ensuring data integrity and chain continuity.

4.2 Smart Contract Operations

Smart contracts play a vital role in automating rule based decisions during transactions. For instance, a transfer of ownership only proceeds if:

- Both parties (buyer and seller) are authenticated
- Required documents have been uploaded
- The inspector has validated the transaction

Once all conditions are met, the smart contract triggers automatic updates to the land registry database, which then reflects the new owner's details.

4.3 Cryptographic Key Management

All transaction data is encrypted using asymmetric cryptography. During registration, each user is assigned a pair of public and private keys. These keys are used to encrypt and decrypt messages and documents during transactions. The public key of the buyer encrypts the transaction, and only the corresponding private key can decrypt it, ensuring confidentiality and non repudiation.

4.4 System Logging and Error Handling

Every transaction is logged in both the blockchain ledger and a secondary audit trail. This parallel log ensures that, even in the event of system failure, transaction history can be reconstructed without compromising security. The system also includes validation checkpoints to catch incomplete or fraudulent submissions and notify the relevant user roles accordingly.

5. Conclusion

This research demonstrates the feasibility and value of integrating blockchain technology with geospatial data systems to modernize land administration. The proposed system offers a decentralized, tamper proof, and transparent platform that minimizes human intervention and enhances trust among stakeholders.

Through the use of smart contracts, cryptographic identity management, and spatially referenced records, the platform addresses longstanding challenges such as unauthorized sales, ownership disputes, and procedural delays. The modular UI design ensures accessibility for diverse user roles from property owners to government officials while maintaining strict access control and traceability.

The project also emphasizes interoperability with GIS platforms and adherence to secure software development practices. Its ability to generate real time insights and verifiable audit trails makes it a strong candidate for scalable deployment in urban as well as rural settings.

By securely linking people, property, and process, the proposed geospatially enabled blockchain model paves the way for next generation land governance in India and beyond.

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