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REVIEW

Blockchain-Based Land Tenure Systems: A Conceptual Model for Using Decentralized Technologies in Managing Land Rights and Ownership Disputes

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ABSTRACT

This study develops a conceptual framework for applying blockchain technology to land tenure systems, with the goal of enhancing transparency, equity, and dispute resolution. Land governance in many regions is plagued by fragmented records, legal pluralism, and the systemic exclusion of marginalized groups. Blockchain's decentralized and immutable architecture offers significant promise for reform, yet its practical application requires more than technical innovation. Through a qualitative, literature-based methodology, the study synthesizes findings from global case examples to identify recurring challenges and enabling conditions for blockchain-enabled land systems. Key dimensions analyzed include legal recognition, participatory governance, digital identity, and geospatial data integration. The proposed framework comprises five interrelated components: a permissioned blockchain ledger, smart contracts mechanism, digital identity and access control, geospatial data integration, and inclusive governance architecture. Unlike techno-centric approaches, the model foregrounds social inclusion, legal interoperability, and the recognition of customary and collective land rights. It is theoretically grounded in legal pluralism, socio-technical systems theory, and data justice. Case examples from countries such as Georgia, Bangladesh, and Kenya demonstrate the framework's relevance across varied contexts. The study contributes to the emerging discourse on digital land governance by proposing a justice-oriented, modular design that is adaptable to urban, rural, and post-conflict settings. It also cautions against premature or top-down adoption, emphasizing the importance of local engagement, institutional capacity, and legal harmonization in ensuring long-term success.

Keywords: Blockchain; Land Tenure; Land Governance; Decentralization; Transparency; Equity; Legal Pluralism

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1. Introduction

Secure land tenure is a cornerstone of social stability, economic development, and environmental sustainability [1]. However, in many parts of the world, land ownership systems remain fragmented, opaque, and vulnerable to manipulation [2]. Insecure or unclear land rights can lead to disputes, corruption, forced evictions, and a lack of investment in land productivity [3]. Marginalized groups, such as women, indigenous peoples, and smallholder farmers, are often disproportionately affected by these systemic weaknesses. As land governance becomes increasingly critical in the context of rapid urbanization, climate change, and global development goals, the need for innovative, transparent, and equitable systems of land management has never been greater [4].

Weak land tenure, characterized by insecure, poorly defined, or easily contested land rights, creates significant socio-political consequences including increased conflict, social inequality, political manipulation, and undermined livelihoods. These effects are particularly severe in regions where land serves as a primary asset and source of livelihood. Weak land tenure systems disproportionately harm the poorest and most vulnerable populations, increasing poverty and economic exclusion by making it difficult for them to secure their main asset, that is, land [5–7]. Insecure land tenure serves as a major driver of land-related disputes, tensions, and sometimes violent conflict, as uncertainty over land rights fuels competition and grievances [5,7–9].

Political authorities can deliberately manipulate weak tenure regimes to control rural populations and reinforce state power, as demonstrated in Zimbabwe and Uganda [10]. Corruption, rent-seeking, and lack of accountability in land governance further erode trust in institutions and perpetuate inequalities [5,7,10]. Additionally, dual systems combining customary and formal approaches create confusion and contestation, complicating access and control over land [8,11].

Blockchain technology, originally developed as the foundation for decentralized cryptocurrencies, has recently emerged as a transformative tool with applications well beyond finance to include land and natural resource management [12,13]. Its core features, immutability, decentralization, transparency, and automated trust through smart contracts, offer compelling potential for reforming land tenure systems [14]. A blockchain-based approach to land administration can help to eliminate fraud, increase access to records, reduce transaction costs, and empower communities by making ownership data tamper-proof and publicly verifiable [15].

To combat social inequality and exclusion, blockchain can democratize access to land registration systems by reducing costs and simplifying processes, making it easier for poor and vulnerable populations to formalize their land rights. Digital land certificates stored on blockchain can provide secure, verifiable proof of ownership that is accessible even to those without traditional documentation. Regarding conflict reduction, blockchain's transparent and immutable ledger can provide clear, indisputable records of land ownership and transaction history, reducing disputes over land rights. The technology can also facilitate better integration of customary and formal land tenure systems by creating digital records that recognize and protect traditional land rights within formal legal frameworks. For political manipulation concerns, blockchain's decentralized nature can reduce government control over land records, making it more difficult for political authorities to manipulate land tenure for political gain. The technology can also enhance accountability by creating transparent, auditable records of all land-related decisions and transactions. However, blockchain implementation faces challenges including digital literacy requirements, infrastructure needs, and the necessity of integrating with existing local authority structures and social organizations to avoid unintended negative outcomes [8,11].

Statement of the Problem

Despite land being a foundational asset for economic development, social stability, and environmental sustainability, many land tenure systems around the world remain opaque, fragmented, and prone to disputes. Challenges such as lack of transparency, corruption, and limited accessibility to reliable land re-

cords disproportionately affect marginalized groups. Moreover, the coexistence of statutory, customary, and informal land tenure systems, commonly referred to as legal pluralism, creates governance complexities that conventional digitalization efforts often fail to address. Existing approaches to land reform tend to prioritize technical efficiency over inclusivity, often excluding indigenous practices and vulnerable populations. This study addresses a critical gap by proposing a conceptual framework for blockchain-based land governance that integrates legal pluralism, participatory mechanisms, and technological decentralization to support equitable and transparent land rights systems.

Unlike purely technical frameworks, the model outlined here places a strong emphasis on social inclusion, legal interoperability, and the role of local governance. It also explores how such systems can be designed not only to secure formal land rights but also to recognize customary and collective tenure arrangements. By addressing both technological and socio-political dimensions, the paper aims to contribute to a more holistic understanding of how decentralized technologies can support just and accountable land governance.

2. Thematic Synthesis

2.1. Current Land Tenure Systems

Land tenure systems play a crucial role in managing land rights and usage, with significant implications for economic development, social stability, and environmental sustainability. These systems can be broadly categorized into formal and informal, as well as customary and statutory types, each with distinct characteristics and challenges. Formal tenure systems are typically recognized by legal frameworks and involve documented land rights, such as titles or deeds, often associated with statutory laws intended to provide clear ownership and security of tenure [16,17]. In contrast, informal tenure systems lack formal legal recognition and documentation, commonly arising in urban areas with rapid population growth leading to informal settlements; despite lacking formal recognition, these systems can still provide security through social and community networks [17,18].

Customary tenure systems are based on traditional practices and norms, often managed by local communities or tribal authorities, predominantly in rural areas, and can vary significantly between regions [16,19]. Statutory tenure systems, established by national or regional governments and governed by formal laws and regulations, aim to provide standardized land rights and are frequently used in urban and peri-urban areas [16,19].

Common issues in land tenure systems include corruption and unclear ownership. Corruption manifests as bribery, favoritism, and manipulation of land records, undermining trust in formal institutions [17,20]. Unclear ownership is particularly problematic in areas with overlapping formal and customary claims, leading to conflicts and hindering effective land management and development [20,21]. Inefficiencies can arise from bureaucratic processes, insufficient capacity in land registries, and inadequate legal frameworks, delaying land transactions and reducing investment in land development [18,22]. Land tenure conflicts are common, especially in peri-urban areas where rapid urbanization leads to compulsory land acquisitions, involving disputes over land rights, power dynamics, and legal frameworks [20].

Addressing land tenure-related conflicts requires comprehensive understanding of underlying causes and developing integrated solutions that consider social, economic, and legal dimensions [20,23]. Future research and policy development should focus on improving efficiency of land tenure systems, enhancing tenure security, and ensuring equitable access to land resources by updating land knowledge, strengthening local land management institutions, and adopting pro-poor tenure policies [21,24].

2.2. Blockchain Fundamentals

Blockchain technology represents a revolutionary digital innovation defined by its decentralized architecture, immutable record-keeping, and transparent operations. This technology has garnered considerable attention for its transformative potential across various industries, particularly in governance, where it offers secure and efficient methods for recording, sharing, and

verifying information [25].

The core properties of blockchain include decentralization, which distributes control across multiple nodes rather than concentrating it in a single entity, thereby enhancing security and reducing fraud risk [26–28]. Additionally, blockchain's immutability ensures that once data is recorded, it cannot be altered or deleted, creating a permanent and tamper-proof record that maintains data integrity and builds trust in digital transactions [26,28,29]. Furthermore, blockchain provides transparency by maintaining a public ledger visible to all participants, facilitating easier auditing and verification of data [27,30,31].

In governance applications, blockchain's unique attributes enable new organizational structures and decision-making processes. Smart contracts and decentralized autonomous organizations (DAOs) utilize blockchain's transparency and immutability to automate and secure agreements, reducing dependence on intermediaries and improving coordination among stakeholders [30,32]. Traditional governance models can be renewed through blockchain by eliminating information asymmetries and enabling horizontal coordination, achieved through smart contracts that automate contractual clauses and DAOs that facilitate decentralized decision-making [30,32].

The potential applications of blockchain extend across both public and private sectors, including financial services, healthcare, and supply chain management. By offering a secure and transparent platform, blockchain can optimize operations, decrease costs, and foster accountability in sectors vulnerable to corruption and data manipulation [27,31].

Despite its promising capabilities, blockchain technology faces several challenges, including scalability limitations, privacy concerns, interoperability issues, and regulatory uncertainties. Addressing these obstacles is essential for blockchain's widespread adoption in governance and other sectors [29,31,33]. Future research must explore integration strategies and develop solutions to these challenges to ensure blockchain continues as a key driver of innovation in the digital era [31].

2.3. Digital Rights and Social Justice in the Blockchain

Blockchain's decentralized and immutable ledger can serve as a powerful tool for securing land tenure and ensuring that land ownership records are tamper-proof and accessible [34]. This is especially relevant in contexts where formal documentation is lacking and digital rights are fragmented. By automating legal processes and reducing reliance on intermediaries, blockchain may lower the barriers for marginalized populations to claim and protect their land rights [35].

Despite these benefits, blockchain's deployment in land systems risks reinforcing existing inequalities if not carefully managed. Issues such as accurate data entry, digital literacy, and institutional readiness are significant hurdles [34]. The use of permissioned or private distributed ledger technologies may also limit transparency and public oversight, raising concerns about digital disenfranchisement. Furthermore, the need to reconcile blockchain with legal frameworks on digital identity, privacy, and human rights remains unresolved [35].

The tokenization of land assets can potentially widen economic disparities. While blockchain enables the fractional ownership and trading of land, it can also facilitate speculative investments that displace vulnerable communities. This dynamic raises urgent questions about whether digital systems are structured to uphold the principle of equitable access or primarily serve market-driven interests [36]. Integrating data justice into the design of blockchain solutions is essential to ensure that digital rights, particularly the right to access and control one's own land-related data, are upheld [37].

Blockchain technologies such as DRMChain illustrate how digital rights, especially for creative and intellectual content, can be protected through tamper-resistant systems [38]. However, in the context of land governance, such systems must be designed to balance the rights of users, landowners, and communities. The integration of privacy-preserving features and equitable access controls is key to aligning blockchain-based digital rights management with social justice principles [39].

To ensure blockchain promotes social justice in

land governance, supportive policy and institutional frameworks are essential. Legal harmonization, stakeholder engagement, and regulatory oversight must guide the integration of blockchain into land title systems [40]. Policies must also address how digital rights are defined, protected, and contested within decentralized land systems.

Technological adoption must be coupled with inclusive practices that address socio-cultural dynamics. For instance, user interfaces must be designed with local literacy levels and digital access in mind. Stakeholder engagement in the co-design of blockchain platforms can enhance trust and legitimacy, aligning technological innovation with democratic governance of land and data [41]. Emphasizing the social construction of technology helps shift the focus from efficiency to empowerment, especially for marginalized groups.

2.4. Some Previous Applications

In 2016, the Republic of Georgia's National Agency of Public Registry (NAPR) partnered with Bitfury to develop a blockchain-based land registry system. By 2018, over 1.5 million land titles had been registered on the blockchain, demonstrating the scalability and effectiveness of the solution. The project utilized a hybrid blockchain approach, combining public and private elements to ensure data privacy and security [42]. This initiative aimed to enhance transparency, reduce fraud, and streamline land transactions in the country [43,44].

Hybrid blockchain-based solutions for land title management in Bangladesh were proposed by various authors [45–47]. These systems offer data synchronization, transparency, and immutable records management. They aim to reduce the number of required travels, lower the overall cost of information processing, and provide easy access to vital information. Studies highlighted above indicate the potential of blockchain adoption to improve the land title digitization efforts in Bangladesh.

Seso Global conducted a pilot project in Cape Town, South Africa, to build a blockchain-based property register. The register aimed to show the history of ownership of properties, enable property owners to maintain their data, and allow the government and other service providers to view and validate transactions [48]. This initiative sought to provide a foundation for the government to formalize land ownership records and enable households to access rights associated with formal property ownership prior to official registration [49,50].

In Brazil, Ubitquity collaborated with the municipality of Pelotas in the state of Rio Grande do Sul to implement a blockchain-based land registry system. The pilot aimed to demonstrate how blockchain technology could improve the quality of record-keeping and increase efficiency within local laws. Results indicate the successful registration of a property on the blockchain and highlighted the potential of tokenization in land transaction recording [51,52].

Sweden's land registry authority, Lantmäteriet, partnered with ChromaWay to explore the use of blockchain for real estate transactions [53]. The pilot project aimed to streamline the process of buying and selling real estate while ensuring the security and transparency of land records [54]. The initiative sought to reduce transaction times and costs associated with property transfers.

In India, blockchain technology is explored for land records management to tackle issues like minimal transparency, incoherent data sets, and delays in the current system. A proposed system design using blockchain aims to make land titles tamper-proof and provide conclusive ownership rights. The use of smart contracts and a decentralized application is suggested to enhance efficiency, safety, and scalability in land registry and title management [55,56].

A secure title deed registration model using blockchain has been implemented in Kenya to address inconsistencies in land transactions due to the lack of a universal National Land Information Management System. The model, based on Ethereum, enables secure and transparent land transactions without a central authority, providing a verifiable trail of records visible to all parties involved [57].

A decentralized, transparent, and immutable ledger that can prevent common problems in traditional land revenue systems, such as double-spending and single points of failure is a great advantage for land management [14,58]. These implementations indicate that

blockchain technology offers significant potential for improving land management systems by addressing issues such as forgery, misrepresentation, and human-induced anomalies in records.

2.5. Gaps in Literature

Despite growing scholarly and policy interest in blockchain applications for land governance, a critical gap persists in how the technology is conceptualized and studied within existing literature. Most current research and pilot implementations adopt a predominantly techno-centric perspective, focusing heavily on the technical architecture, cryptographic protocols, and efficiency gains offered by decentralized ledgers. While such analyses are valuable, they often operate in isolation from the complex socio-political and legal environments in which land tenure systems are embedded. As a result, many proposed solutions overlook the structural power dynamics, historical injustices, and culturally embedded land relations that shape tenure systems on the ground. The literature rarely interrogates how blockchain systems might reinforce or disrupt existing inequalities, nor does it adequately address the challenge of integrating customary tenure norms, plural legal systems, or informal settlements into digital frameworks. Furthermore, questions around trust-building, legitimacy, and institutional adaptation are frequently sidelined in favor of technical scalability and automation. This disconnect between technological optimism and socio-political realities limits both the practical utility and ethical grounding of many blockchain-based interventions in land governance. Bridging this gap requires an interdisciplinary approach that situates technological innovation within the broader context of legal pluralism, community participation, and governance reform.

3. Methodology

The research is structured as a conceptual analysis aimed at theory-building and model development. The primary objective is to propose a context-sensitive, justice-oriented framework for implementing decentralized technologies in land tenure systems. To this end, the study integrates:

- Descriptive review of global implementations of blockchain in land administration;
- Comparative analysis of regional challenges in land governance (e.g., legal pluralism, access, corruption);
- Normative synthesis of equity, transparency, and participatory governance principles drawn from relevant scholarly literature and international policy guidelines.

3.1. Data Sources and Selection

The analysis draws upon over 70 peer-reviewed articles, institutional reports, and documented pilot projects spanning a wide range of geographical contexts. Sources were selected based on their:

- Relevance to land tenure, blockchain governance, or decentralization;
- Empirical depth (e.g., reported outcomes from implementation);
- Theoretical insight into socio-technical systems and legal pluralism.

To identify relevant literature, a structured search was conducted using the following keywords and Boolean combinations: *"blockchain AND land tenure," "decentralized land registry," "digital identity AND property rights," "smart contracts AND governance,"* and *"legal pluralism AND land management."* Inclusion criteria prioritized peer-reviewed articles, case studies, and institutional reports published in English between 2000 and 2024 that focused on blockchain applications in land governance, digital rights, or socio-technical system design. Studies were excluded if they lacked substantive discussion of land tenure systems or if they focused solely on cryptocurrency without governance context. Approximately 40 articles were retrieved from Scopus, 15 from Web of Science, 10 from Google Scholar, and another 10 from institutional repositories such as FAO, UN-Habitat, and OECD. Miscellaneous additional sources were referred to fill gaps in understanding or to addressing concerns raised during the review process. These databases were selected for their complementary strengths: Scopus and Web of Science for their academic rigor and metadata quality; Google Scholar

for its broader coverage of interdisciplinary grey literature; and institutional repositories for high-impact policy and implementation reports relevant to land and development contexts.

3.2. Analytical Strategy

This study adopted a multi-phase qualitative synthesis strategy aligned with methods used in prior blockchain governance analyses [29,34] and socio-technical systems research [59], employing thematic coding and comparative case mapping to inform model development. The process began with a critical literature review to identify persistent governance challenges in traditional land tenure systems, including issues of fragmentation, fraud, and the exclusion of marginalized groups. Following this problem identification phase, researchers conducted thematic coding to extract key themes related to blockchain functionality such as immutability, smart contracts, and decentralization, while also examining land governance needs including dispute resolution, documentation, and legal recognition, alongside equity concerns encompassing customary rights, gender considerations, and digital divides.

The analysis then proceeded with comparative mapping through cross-case analysis of blockchain-based pilot projects to identify patterns, successes, and gaps, which served to evaluate feasibility and scalability across diverse contexts including urban, rural, post-conflict, and transboundary environments. These findings were subsequently synthesized to construct a layered conceptual framework that outlines essential components such as ledger architecture, smart contracts, digital identity systems, and dispute resolution mechanisms, while also considering contextual variables and implementation pathways. Finally, the developed model underwent normative alignment assessment against broader values of transparency, inclusion, and legal pluralism, incorporating critical elements of data justice, stakeholder participation, and adaptive governance principles.

A diagram depicting the workflow behind this study is presented below in **Figure 1**.

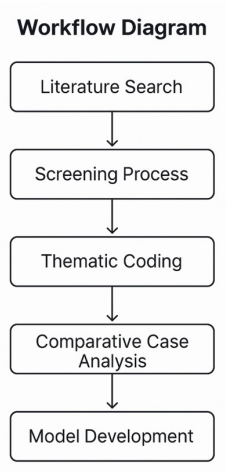

Figure 1. Workflow diagram.

4. Findings

The literature allows us to identify a number of related themes and synthesize them into a conceptual model of land tenure system built around the blockchains. The conceptual framework that we propose consists of the following layers and relationships:

4.1. Blockchain Ledger Layer

At the core of the system is a permissioned blockchain ledger that serves as the primary repository of land ownership data, transaction history, and tenure rights.

- Permissioned vs. Public Blockchain: A permissioned ledger allows for better control over participant access, ensuring that sensitive ownership data is available to authorized actors such as local authorities, surveyors, and certified notaries.
- Immutability and Auditability: Every transaction, from inheritance to land sales to land use conversions, is recorded in a way that cannot be altered retroactively. This promotes transparency and auditability for all stakeholders.
- Interoperability with Existing Cadastres: The system can function alongside or as an overlay to current land registries, ensuring a gradual and non-disruptive transition.

4.2. Smart Contracts Mechanism

Smart contracts are programmable scripts embedded in the blockchain that automatically enforce the terms of land transactions once preconditions are met.

- Automation of Transactions: Smart contracts can automate processes such as land transfers, lease agreements, tax payments, and inheritance procedures, reducing bureaucratic delays and corruption.
- Customary Rights Recognition: Smart contracts can be tailored to respect and encode customary norms or community-defined rules, ensuring cultural and legal plurality.
- Conditional Transfers: Enable land reversion or conditional ownership based on factors such as environmental compliance or community service.

4.3. Digital Identity and Access Control

Secure and verifiable digital identities (DIDs) are essential for validating ownership, preventing fraud, and protecting privacy.

- Biometric and Mobile Identity Integration: Use of biometrics, mobile phones, or national ID systems to establish unique digital identities, especially in rural or undocumented communities.
- Multi-Stakeholder Verification: Land transactions may require digital endorsements from multiple actors (e.g., community elders, land officials, banks) based on pre-agreed protocols.
- Role-Based Access Control: Different actors (e.g., citizens, officials, NGOs) are granted tiered access rights to the ledger, ensuring privacy while maintaining transparency.

4.4. Geospatial and Land Parcel Integration

Land tenure is spatial in nature, and the blockchain system must be tightly integrated with geospatial data sources.

- Linkage with GIS and Remote Sensing: Each land record is spatially linked to georeferenced parcel boundaries, stored off-chain but verifiable via on-chain hashes.
- Land Use History and Mapping: Chronological records of land use changes, ownership transitions, or environmental status can be traced through time.
- Decentralized Survey Validation: Community mapping or crowdsourced land surveys can be validated by consensus mechanisms or third-party oracles.

4.5. Dispute Resolution and Governance Architecture

To be effective and trusted, the system must include institutional and social mechanisms for resolving disputes and ensuring equitable governance.

- Layered Dispute Mechanisms: A multi-tiered system can incorporate community arbitration, smart contract mediation, and formal court appeal processes.
- Consensus Protocols for Community-Led Decisions: Disputes over customary boundaries or resource access can be resolved via community voting or delegated consensus.
- Governance Tokens or Reputation Scores: Local stakeholders may participate in land governance using non-financial incentives (e.g., governance rights, reputation systems).

4.6. Equity and Justice Integration

The conceptual model embeds equity and justice as foundational principles, rather than as afterthoughts.

- Inclusion of Marginalized Groups: System design must account for the unique barriers faced by women, indigenous populations, and people without formal documentation.
- Plural Legal Recognition: Recognizes and incorporates statutory, customary, and religious tenure systems under a unified technical framework.
- Participatory Design: Stakeholders, especially from vulnerable communities, are engaged

from the outset in system co-design, testing, and feedback loops.

4.7. Systemic Synergies and Potential Applications

The blockchain-based system can interface with broader socio-economic and ecological systems, unlocking multiple benefits:

- Land-Based Financing: Tokenized land assets may be used as collateral for credit, enabling financial inclusion.
- Environmental Stewardship: Land rights may be tied to conservation obligations or ecosystem service payments.
- Conflict Prevention and Peacebuilding: Transparent and verifiable land records can prevent disputes and promote reconciliation in post-conflict zones.

Figure 2 below depicts this framework diagrammatically.

4.8. Theoretical Grounding of the Model

The conceptual model presented in this study is grounded in interdisciplinary theoretical perspectives that bridge technology, law, and governance. At its core, the model draws on Legal Pluralism Theory [60], which recognizes the coexistence of multiple legal systems such as formal statutory law, customary norms, and religious practices within a single social field. This theoretical lens underscores the need for land governance systems to acknowledge and operationalize diverse forms of land rights rather than imposing a singular legal regime. By embedding customizable smart contracts and multi-stakeholder dispute resolution mechanisms, the proposed model accommodates legal diversity and fosters inclusive governance, particularly in rural and indigenous communities where formal titling systems may not be predominant or trusted.

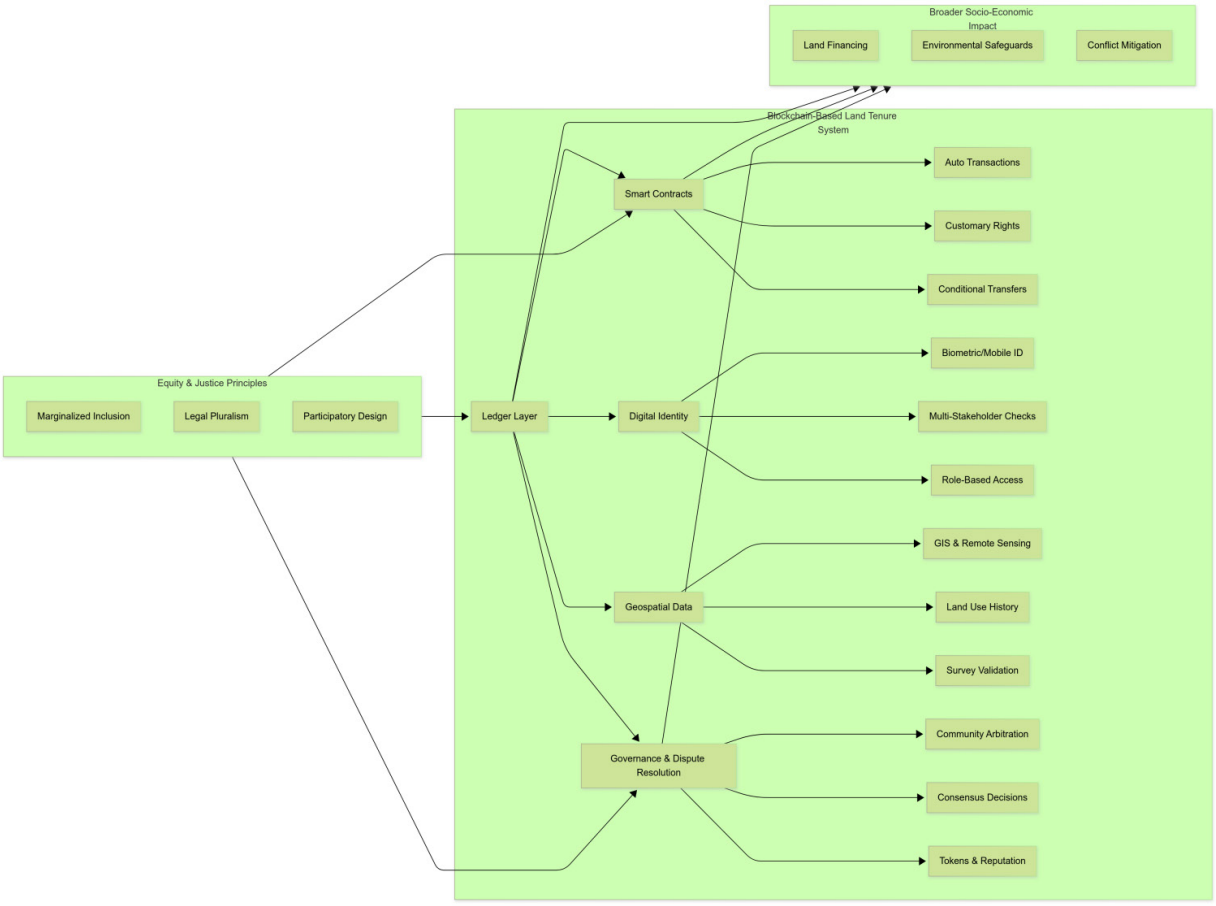

Figure 2. A conceptual diagram of Blockchain-based land tenure systems.

The model is also informed by Socio-Technical Systems Theory [59], which emphasizes the co-evolution of technology and social institutions. From this perspective, blockchain is not simply a neutral tool for automating land records; it is a socio-technical artifact whose design and implementation must reflect the values, needs, and power structures of the communities it serves. The integration of participatory design processes, role-based access controls, and justice-oriented governance layers in the framework reflects this alignment. Furthermore, the model incorporates principles from Data Justice Theory [37], particularly in its attention to transparency, privacy, and equitable access to digital infrastructure. By grounding the technological design in these theoretical foundations, the model aims to be both socially legitimate and practically adaptive across diverse institutional and geographic contexts.

4.9. Implementation

The successful deployment of a blockchain-based land tenure system depends heavily on the contextual realities of each region. Variations in legal structures, socio-political institutions, land governance traditions, and technological infrastructure necessitate flexible approaches to implementation. Broadly speaking the sequence of steps outlined in **Figure 3** must be followed.

It is important to emphasize how the conceptual framework may be adapted to diverse environments while preserving its core values of transparency, decentralization, and equity.

In highly urbanized contexts with existing formal land registry systems, a state-led approach to blockchain integration can enhance the efficiency and transparency of administrative processes. In such settings, government agencies can begin by digitizing land records and anchoring them to a permissioned blockchain. This ledger can be designed to support smart contracts that automate title transfers and link ownership to verified digital identities. Urban property transactions would benefit from reduced bureaucracy, increased trust in land records, and better access to land-related data. However, challenges may include resistance from entrenched bureaucracies and the need for legal reforms to recognize blockchain-based records as admissible evidence in courts.

In contrast, rural regions where customary tenure systems dominate present a different set of priorities. Here, implementation would be more effective if led by communities themselves, with strong facilitation from local NGOs or decentralized government bodies. The process would involve participatory land mapping exercises, recognition of community land governance structures, and the encoding of customary tenure rules into smart contracts. Digital identities could be issued through biometric tools to individuals and households that have historically lacked documentation. This approach would empower rural populations to assert their land rights, provide a verifiable digital trail of tenure claims, and reduce vulnerability to elite land grabs. However, low levels of digital literacy, limited access to internet infrastructure, and internal power asymmetries within communities could hinder equitable implementation.

In post-conflict or disaster recovery zones, where land records are often destroyed or manipulated, blockchain offers a powerful means to restore trust and legitimacy. Governments and international agencies could work with local actors to reconstruct tenure histories using a combination of satellite imagery, oral testimony, and community validation processes. Once reconstructed, these tenure claims could be registered on a tamper-proof blockchain platform and linked to provisional digital land titles. Such a system would not only support peacebuilding efforts and reconciliation but also help to prevent secondary land conflicts over restitution or resettlement. Nevertheless, the success of this approach would hinge on the presence of impartial dispute resolution mechanisms and the capacity of state or transitional authorities to support the process.

Figure 3. Recommended steps in the blockchain-based land tenure implementation.

In contexts with significant private sector involvement, such as agricultural investment corridors or special economic zones, a hybrid model involving public–private partnerships could be viable. Governments could provide the legal framework and institutional oversight, while private technology firms and land service providers develop and maintain the blockchain infrastructure. Civil society organizations would play a critical role in representing community interests and ensuring that implementation is inclusive and accountable. This model enables scalability and technical innovation but raises concerns over the commercialization of land rights and the marginalization of weaker stakeholders if governance safeguards are not in place.

In transboundary regions, such as cross-border rangelands, refugee resettlement areas, or shared watershed zones, a regional blockchain platform could serve as a cooperative land governance tool. Such a platform would enable multiple jurisdictions to record and verify land rights across borders using a common, interoperable ledger. Seasonal or migratory land use claims could be encoded using smart contracts that recognize temporal and collective rights. This kind of supranational system would enhance coordination among countries, reduce inter-ethnic or inter-state disputes over land, and support joint environmental stewardship. However, this approach would require substantial legal harmonization, regional diplomacy, and agreements on data sovereignty.

Each of these scenarios demonstrates the conceptual model's flexibility and relevance across different socio-political landscapes. By designing modular and participatory blockchain systems that are responsive to local needs and norms, policymakers and technologists can create transformative land governance mechanisms that are both innovative and just.

5. Discussion

5.1. Policy Recommendations

Effective implementation of blockchain-based land tenure systems requires not only technological readiness but also deep institutional reform, legal alignment, and stakeholder engagement. The following policy recommendations are designed to support differentiated deployment strategies tailored to varying governance contexts and to ensure that the proposed model serves principles of equity, transparency, and inclusion.

5.1.1. Urban and Formal Registry Contexts

In urban areas with existing statutory land systems, governments should prioritize comprehensive legal reforms to recognize blockchain-based records and smart contracts as admissible legal evidence in court proceedings. This legal foundation must be accompanied by strategic public-private partnerships designed to digitize and migrate existing land records onto permissioned blockchain networks, ensuring data integrity throughout the transition process. Establishing robust interoperability standards becomes crucial for enabling blockchain systems to seamlessly connect with existing geographic information systems, tax databases, and urban planning platforms. Furthermore, implementing comprehensive audit mechanisms and open application programming interfaces will enhance public accountability while reducing the bureaucratic opacity that often characterizes traditional land administration systems.

5.1.2. Rural and Customary Tenure Contexts

Where customary and informal tenure arrangements predominate, particularly in rural regions, policy frameworks must first recognize customary land rights within national legislation, incorporating specific provisions that enable these rights to be encoded into smart contracts without undermining their traditional foundations. Governments should actively support community-led land mapping initiatives and facilitate local governance integration through participatory methodologies that respect existing social structures and decision-making processes. Investment in comprehensive digital literacy programs becomes essential, alongside the development of mobile-based access solutions and biometric digital identity systems that can function effectively in areas with limited technological infrastructure. Most importantly, blockchain system design must support flexible and evolving tenure arrangements that

can adapt to changing community needs without erasing established communal norms and practices.

5.1.3. Post-Conflict and Transitional Settings

In conflict-affected regions or disaster recovery zones where traditional land records may have been destroyed or compromised, establishing transitional legal frameworks becomes paramount. These frameworks should permit provisional blockchain-based title claims that can be validated through a combination of community testimony and satellite data analysis. Creating multi-stakeholder dispute resolution boards that effectively combine traditional dispute resolution mechanisms, formal legal processes, and blockchain-based verification systems will help ensure legitimacy across different segments of society. The involvement of neutral third parties, including non-governmental organizations and United Nations agencies, can provide crucial validation for the reconstruction of complex tenure histories. Throughout these processes, prioritizing data sovereignty, informed consent, and systematic trust-building measures becomes essential for successful digital reconstruction of land rights systems.

5.1.4. Cross-Border and Shared Resource Contexts

In transboundary contexts or areas characterized by migratory land use patterns, developing regional blockchain consortia offers a pathway for managing shared ledgers that span multiple jurisdictions while respecting national sovereignty. This approach requires harmonizing legal definitions of tenure, ownership, and use rights across member states to ensure consistent interpretation and enforcement of blockchain-recorded rights. Promoting cross-border trust-building through decentralized consensus mechanisms and established dispute resolution protocols will help manage conflicts that inevitably arise in shared resource contexts while maintaining the integrity of the distributed ledger system.

5.1.5. Institutional and Governance Recommendations

Across all implementation contexts, establishing strong institutional foundations remains essential for successful blockchain-based land tenure systems. Policymakers should prioritize building multi-level land governance bodies that meaningfully include civil society organizations, technical experts, and authentic community representatives in decision-making processes. Launching carefully designed regulatory sandboxes allows governments to pilot blockchain systems in safe, controlled environments where innovations can be tested without risking widespread disruption to existing land rights. Requiring open-source standards and comprehensive public documentation prevents problematic vendor lock-in situations while ensuring ongoing civic oversight of these critical systems. Finally, integrating robust monitoring and evaluation mechanisms directly into blockchain infrastructure enables continuous assessment of equity outcomes, access patterns, and error correction capacity over time, ensuring that these systems serve their intended beneficiaries effectively.

5.2. Challenges and Limitations

While blockchain-based land tenure systems offer significant promise, their practical implementation faces substantial technical, legal, social, and political challenges that require careful examination to avoid techno-optimism and guide responsible deployment strategies.

The integration of blockchain technology with existing legal and institutional frameworks presents a primary challenge, as land law in many countries remains deeply entrenched in historical precedent and bureaucratic procedures. Legislative reforms are essential to recognize digitally signed smart contracts and distributed ledgers as legitimate legal evidence; without such recognition, blockchain systems risk operating in a legal vacuum as parallel records rather than formally enforceable systems.

Technical infrastructure constraints prove particularly acute in low-income or rural settings where limited internet access, electricity, and digital literacy create barriers to effective blockchain deployment. While mobile-based solutions and offline-first architecture may mitigate some limitations, they cannot fully resolve the exclusion of marginalized populations who have historically been denied access to technological systems. Additionally, incomplete or outdated land mapping in many contexts complicates the process of anchoring accurate geospatial data to blockchain ledgers.

Social and cultural dimensions introduce further complications, as land tenure systems are often embedded in customary, religious, or communal norms that resist formalization. Translating plural legal arrangements into programmable smart contracts risks flattening the inherent nuance and flexibility of such systems. Blockchain's immutability, while preventing fraud, becomes problematic when errors enter the system or when tenure arrangements require updates due to changing social circumstances such as inheritance disputes or family negotiations.

Environmental considerations also pose limitations, as blockchain systems that privilege private, individualized land rights could undermine collective resource management or incentivize harmful land commodification, particularly where communal tenure has historically supported sustainable practices.

Governance and power asymmetries present another critical limitation, as blockchain introduction does not automatically eliminate elite capture, political interference, or corruption. Without adequate safeguards, such systems could exacerbate existing inequalities by reinforcing claims of those with means and technological knowledge while further marginalizing women, indigenous peoples, and informal settlers through top-down implementation approaches.

The tension between efficiency and equity represents a fundamental challenge in blockchain land systems. While automation and immutable records can streamline transactions and reduce bureaucratic inefficiencies, these efficiency gains may inadvertently compromise fairness. Smart contracts can accelerate land transfers but may bypass crucial community consultation processes or fail to accommodate nuanced customary claims if not designed with local context in mind. The technology's rigidity may prevent adaptive dispute resolution requiring social negotiation, necessitating the design of "slow lanes" such as layered dispute resolution mechanisms, community endorsements, or conditional smart contracts to balance speed with inclusiveness and justice.

Finally, questions of trust, scalability, and long-term sustainability remain unresolved. While blockchain creates trust in trustless environments, its adoption depends on perceived legitimacy among local users, institutions, and governments. Ensuring this legitimacy requires continuous engagement, capacity building, and institutional support that are often under-resourced in pilot implementations. Moreover, scalability challenges extend beyond technical considerations to encompass political dimensions, as land tenure reform inevitably intersects with sovereignty, identity, and historical justice concerns.

6. Conclusions

This study sets out to explore how blockchain technology can be conceptually integrated into land tenure systems to enhance transparency, equity, and dispute resolution. Recognizing the persistent challenges of fragmented land records, legal pluralism, and exclusion of marginalized populations, the paper developed a layered conceptual framework grounded in socio-technical and legal theory. Drawing on global literature and implementation cases, the model emphasizes decentralization, participatory governance, digital identity, and the recognition of diverse land rights systems.

The proposed framework makes three key contributions: first, it aligns technical architecture with the social and legal complexities of land governance; second, it offers implementation pathways adaptable to varied contexts, from urban formal registries to rural customary systems and post-conflict zones; and third, it introduces a justice-centered approach that prioritizes human agency and legal pluralism over automation alone. This model offers a foundation for stakeholders, including policymakers, technologists, and civil society, to design blockchain-based land systems that are not

only efficient but also inclusive and legitimate.

As digital transformation accelerates across sectors, land remains a uniquely sensitive and contested asset. The integration of blockchain into land governance must therefore be approached with caution, care, and broad consultation. Future research should focus on pilot implementations of this framework, mechanisms for community validation and trust-building, and iterative policy design responsive to local needs. Ultimately, this study calls for a shift from techno-solutionism to a more grounded, participatory paradigm in land technology design, where innovation is a tool for justice, not displacement.

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Conflicts of Interest

The authors declare no conflict of interest.

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