

Reconciling Blockchain Immutability and Statutory Revocation in Land Administration: An Integrated Conceptual Framework

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ABSTRACT

Much of the blockchain-based land administration literature reviewed appears to assume that a registry's primary value lies in its absolute immutability. This assumption is difficult to reconcile with statutory revocation, such as that provided under Section 28 of Nigeria's Land Use Act of 1978. This paper develops a conceptual framework that treats lawful mutability as a primary architectural requirement. Drawing on the Land Administration Domain Model (LADM), a Systems Integration Perspective (SIP) and the identity-gated consensus literature, the framework integrates a five-component technology stack: a permissioned blockchain ledger; Geographic Information System (GIS) spatial verification; Non-Fungible Token (NFT) title representation; a hybrid social oracle for community attestation; and offline-resilient Message Queuing Telemetry Transport (MQTT) messaging. Revocation is modelled as an append-only event rather than a deletion. A title moves through defined statuses (proposal, notice, appeal and revocation), and the transition to "revoked" requires proof of service, a lapsed notice period, the absence of a stay and signatures from separate statutory roles, while community attestations are recorded as evidence and conflicts place the title on hold. A bounded explicit-state check of the specified transition system found no violation of its safety properties and detected four deliberately injected faults. The framework is a conceptual contribution: it has not been implemented, legally approved or empirically evaluated, and recommendations, future research directions and a validation agenda are set out to guide future work.

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INTRODUCTION

Land administration systems in developing economies are frequently characterised by fragmented records, weak interoperability between formal and customary tenure regimes, and verification mechanisms that test claims only after disputes arise (Babalola *et al.*, 2024; Patil, 2026). Customary tenure recognition and formal title transfer are distinct processes. The former documents socially legitimate rights through community consensus and may confer no formal title (Omeke *et al.*, 2025), whereas the latter is a statutory act that changes the official register and normally requires official consent. Conflating the two may create friction when informal claims are forced into registry workflows designed for documented titles. Blockchain technology has been proposed repeatedly as an institutional remedy, on the premise that a cryptographically immutable ledger eliminates record manipulation and unverified third-party interference (Ameyaw & de Vries, 2023; Ansah *et al.*, 2023; Okoli *et al.*, 2024; Seun & Eguavoen, 2022). Immutability, however, raises an unresolved structural tension when it is applied to statutory land governance. In this paper, absolute immutability denotes a data structure in which state transitions are permanently appended and cryptographically unalterable. Land rights, by contrast, are

legally non-absolute in most jurisdictions and remain subject to compulsory acquisition and statutory revocation. In Nigeria, this prerogative is codified in Section 28 of the Land Use Act of 1978, which empowers the State Governor to revoke a right of occupancy for overriding public interest or for breach of statutory conditions (Land Use Act, 1978; Babalola *et al.*, 2024; Okoli *et al.*, 2024). Lawful mutability is defined here as an architectural requirement under which a ledger permits authorised legal changes of state while preserving cryptographic traceability. Reconciling the two concepts requires distinguishing unauthorised record tampering, which immutability prevents, from lawful administrative revocation, which a land registry must support. A scoping review of 84 blockchain land-administration design studies (Section 3.1), informed by earlier reviews of the field (Ansah *et al.*, 2023; Okoli *et al.*, 2024; Yahya *et al.*, 2026), suggests that this tension is common. This pattern is consistent with an unexamined assumption that immutability is an unqualified virtue, although it does not establish why the assumption persists. The corpus also divides across three debates: immutability versus lawful mutability, permissionless versus permissioned governance, and single-technology reliance versus multi-technology sufficiency. Existing studies offer useful insights into smart-contract

design (Chandra *et al.*, 2025; Gadagkar & Begum, 2024) and spatial data integration (Zhao *et al.*, 2022; Johnson *et al.*, 2024), but within the coded corpus they generally evaluate technical choices in isolation and give limited attention to the legal mechanisms required for state-backed revocation. This gap is the focus of the present paper.

The paper therefore develops an integrated conceptual framework that elevates lawful mutability to a primary design requirement for permissioned blockchain land registries. The framework combines five technical components: a permissioned ledger, GIS spatial verification, NFT title representation, a hybrid social oracle and offline-resilient MQTT messaging. To accommodate revocation without compromising cryptographic integrity, revocation is structured as an append-only workflow governed by multi-actor authorisation. The paper makes three contributions. First, it specifies lawful mutability as an explicit design requirement and uses a scoping review to show how the literature treats it. Second, it proposes an integrated architecture and an append-only, role-bound revocation workflow, specified as a transition system with proof of service, appeal and reinstatement paths. Third, it provides a preliminary logical verification of that transition system and a validation agenda. The contribution is conceptual and architectural, and the framework is not deployed, legally approved or empirically evaluated. The remainder of the paper is organised as follows. Section 2 sets out the theoretical foundations (LADM, SIP and identity-gated consensus). Section 3 describes the methodological approach and synthesises the literature. Section 4 presents the framework, including the design goals, layered architecture, revocation workflow, authorisation model and safeguards. Section 5 discusses the theoretical propositions, governance trade-offs and limitations, Section 6 sets out recommendations, future research directions and a validation agenda, and Section 7 concludes.

Theoretical and Conceptual Foundations

The framework combines three building blocks: a domain reference model, a systems integration perspective and a governance mechanism for validating and altering state. The first specifies what the system represents, the second how its components are coordinated, and the third who holds authority to change recorded state. Each is introduced in turn, and Section 2.4 then shows how the three are operationalised together.

The Land Administration Domain Model

The Land Administration Domain Model (LADM), standardised as ISO 19152 (International Organization for Standardization [ISO], 2012), supplies a conceptual vocabulary for land administration. It represents parties, basic administrative units, spatial units, and rights, restrictions and responsibilities (the LA_RRR classes), together with the source documents that evidence them, and thereby promotes semantic consistency and cross-jurisdictional interoperability (Lemmen *et al.*, 2015). Its compatibility with the Social Tenure Domain Model (STDM) is reported to make it suitable for contexts such as Nigeria's, where statutory and customary tenure coexist (Omeke *et al.*, 2025).

Systems Integration Perspective

No single, codified "Information Systems Integration Theory" exists in the literature. Reviews note that integration remains under-theorised and lacks a unified theoretical framework (Chowanetz *et al.*, 2012; Waring & Wainwright, 2000). This paper therefore adopts a Systems Integration

Perspective (SIP) as an analytical framework assembled from established sources, and not as a validated theory in its own right. Hasselbring (2000) characterises information system integration across business, application and technology layers and stresses the autonomy, heterogeneity and distribution of the systems being integrated. Markus and Tanis (2000) show that integrating technical systems is inseparable from organisational and social adaptation. Three design principles are drawn from these sources: (i) layered mediation, meaning that heterogeneous components interact only through defined interfaces at each layer; (ii) shared authoritative state, meaning that independent components must defer to one authoritative record of state; and (iii) socio-technical alignment, meaning that integration must account for institutional roles and legitimacy as well as protocols.

Identity-Gated Consensus and Statutory Revocation Mechanisms

The third building block, identity-gated consensus, draws on the reputation-based consensus literature to theorise how revocation authority can be governed. The framework adopts the identity-gating and role-binding principle of that literature but does not implement reputation scoring, which is treated only as an optional extension (Section 4.6). Rather than tying validator authority to computational work or financial stake, this approach ties decision-making power to verified institutional standing, which is argued to make it better suited to administrative than to purely commercial blockchain contexts (Hasan *et al.*, 2022). Byzantine Fault Tolerance variants built on this principle restrict validator sets to trusted, identity-gated entities. These variants are reported to reduce the communication overhead that limits larger open networks, and they allow consensus to reflect the legal mandate of a registry rather than the more volatile incentives associated with permissionless models (Nugraha *et al.*, 2026; Shava & Mhlanga, 2023).

The same framing can be extended to revocation. If a validator's authority can be withdrawn for administrative malfeasance under a reputation-weighted scheme, the mechanism could in principle be adapted to revoke a title (Hasan *et al.*, 2022). Studies of land registries point in a consistent direction. Hybrid governance configurations use ledger transparency to reduce fraud while retaining institutional control over entry validation (Kalaierasi *et al.*, 2025), and proxy-delegate architectures are intended to keep revocation subordinate to jurisdictional authority by requiring signatures from court-sanctioned entities before a state reversion executes (Langaliya & Gohil, 2021; Panwar *et al.*, 2024). Geographically aware validator selection extends this logic by anchoring administrative overrides to localised jurisdictional proof (Mallya *et al.*, 2025), and protocol-enforced nullification events are argued to allow property disputes to be rectified verifiably without relying on absolute immutability (Gesang & Dirgahayu, 2025). Taken together, these studies suggest that authority-bound correction of ledger state is technically feasible, although the sources reviewed describe it as a design possibility and do not report legal validation.

This reputation-to-revocation link provides the governance rationale for anchoring title-level revocation to statute-defined authority tiers. The initiating, reviewing and authorising officers' sign, and the court or appeal body acts independently of that chain (Section 4.4). The argument is theoretical and not evidence of effectiveness, because none of the sources reviewed implements and tests such a design as a single revocation workflow.

Operationalizing the Three Building Blocks

The three building blocks answer distinct questions. LADM specifies what the system represents (domain semantics), the systems integration perspective specifies how its technical components are coordinated reliably (integration logic), and the identity-gated revocation mechanism specifies who holds

authority to validate or alter state (governance mechanics). Within the coded corpus (Section 3), few studies combine a domain ontology, an integration logic and a statutory revocation mechanism in one architecture, and this combination is therefore adopted as the paper's conceptual foundation (Figure 1).

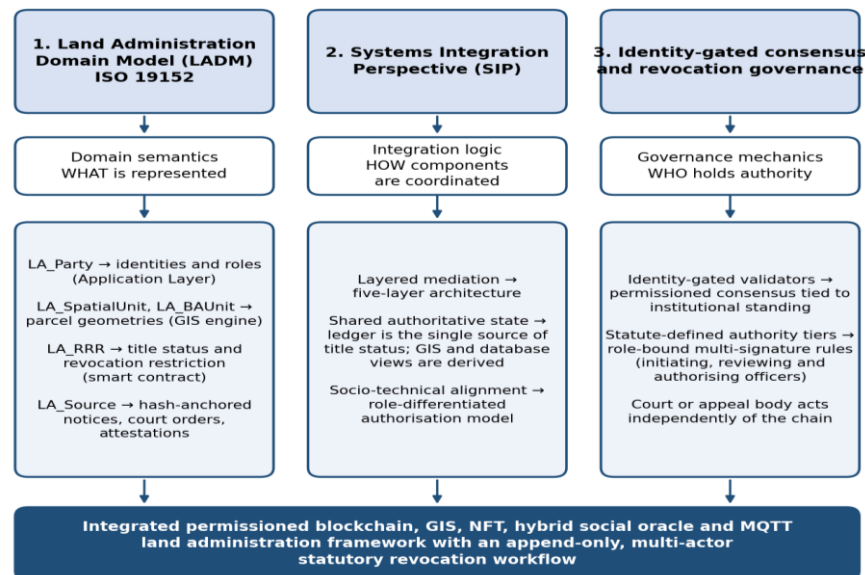


Figure 1: Conceptual foundation of the proposed framework: LADM supplies domain semantics, the systems integration perspective supplies integration logic, and identity-gated consensus, drawing on the reputation-based literature, supplies governance mechanics

The domain semantics are operationalised through the LADM classes. LA_Party is realised as the identities and roles managed in the Application Layer (holders, officers and custodians). LA_SpatialUnit and the basic administrative unit are realised as parcel geometries held by the GIS engine. LA_RRR is realised as the title status held by the smart contract, with statutory revocation modelled as a restriction that changes the right. LA_Source is realised as hash-anchored notices, court orders and community attestations. The integration logic is operationalised through the three SIP principles. Layered mediation determines the five-layer architecture (Section 4.2). Shared authoritative state makes the ledger the single source of title status, from which GIS and database views are derived. Socio-technical alignment determines the role-differentiated authorisation model (Section 4.4).

The governance mechanics are operationalised through identity-gated validation and role-bound signing. Validators are bound to institutional identities, and a revocation is finalised only when the initiating, reviewing and authorising officers have each signed, with the court or appeal body able to stay or set aside the revocation independently (Sections 4.3 and 4.4).

MATERIALS AND METHODS

Search and Selection

The study follows conceptual framework analysis (Jabareen, 2009), supported by design-science principles for specifying and evaluating the proposed artefact (Hevner et al., 2004; Peffers et al., 2007). In Jabareen's terms, data sources were mapped and categorised through the scoping review described in this section. Concepts were then identified,

deconstructed and integrated into the three building blocks of Section 2 and the design goals of Section 4.1. The resulting framework was subjected to partial validation through model-based logical verification (Section 4.8), and legal and stakeholder validation are deferred to the agenda in Section 6.3. The scoping review is not a PRISMA-compliant systematic review. Records were gathered from four databases (Web of Science, Scopus, IEEE Xplore and Google Scholar) and covered peer-reviewed articles, conference papers and institutional reports published between 2018 and 2026. Foundational earlier work (Griggs et al., 2017) was retained as background. The search combined domain terms ("land registry", "land administration", "cadastre", "tenure"), technology terms ("blockchain", "distributed ledger", "smart contract", "NFT") and legal terms ("revocation", "expropriation", "Land Use Act").

The initial search returned 412 records. After duplicate removal and title and abstract screening, 218 records remained, and application of the inclusion criteria produced a final corpus of 84 primary design studies (Figure 2). A study was included if it proposed or evaluated a blockchain-based land-administration design, incorporated spatial or legal tenure records, and stated an explicit architecture. Studies concerned only with cryptocurrency trading or generic supply-chain tracking were excluded. Each included study was coded in a review matrix for ledger structure, governance type, spatial validation, customary-tenure handling and statutory-revocation capability. Selection and coding rest on the authors' judgement, so the counts reported here describe the coded corpus and should not be read as a census of the field. The limitations of this approach are discussed in Section 5.4.

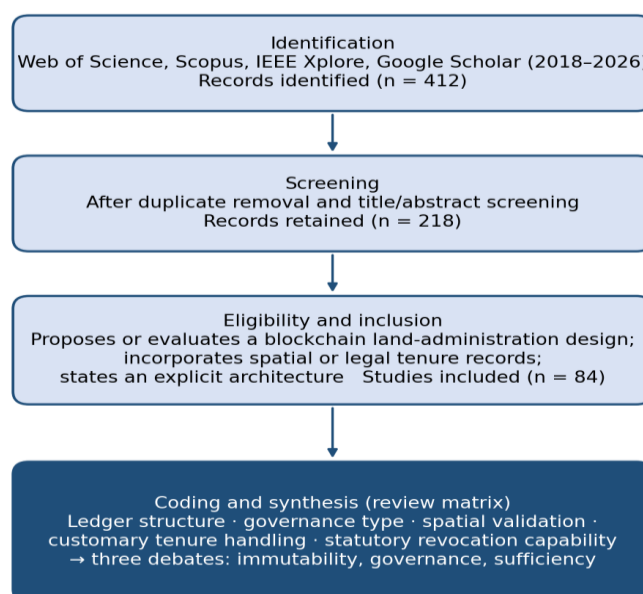


Figure 2: Literature scoping and selection pipeline

Derivation of Design Requirements

The design requirements in Section 4.1 were derived in three steps. First, gaps recorded in the review matrix were consolidated into recurring failure modes of individual technologies (Section 3.4). Second, the procedural elements of statutory revocation (grounds, competent authority, notice to the holder, compensation, and avenues of appeal and dispute resolution) were identified from Section 28 and the related provisions of the Land Use Act, and these were treated as legal requirements to be encoded rather than as optional features. Third, the three SIP principles of Section 2.2 were applied to determine how the components should be coordinated. The five design goals are the outcome of these steps.

Literature Trajectory and Domain Debates

The literature has developed through three broad phases. Early studies framed distributed ledgers as trust-and-provenance mechanisms capable of reducing land fraud (Griggs *et al.*, 2017). Subsequent work moved towards prototypes and smart-contract designs (Thakur *et al.*, 2019; Chandra *et al.*, 2025; Gadagkar & Begum, 2024). Studies in emerging markets then reported that technical properties alone do not secure adoption, which appears to depend on socio-cultural and institutional fit (Ameyaw & de Vries, 2020, 2021, 2023; Ansah *et al.*, 2023). In parallel, recent work has diversified into spatial strands that bind ledger records to GIS coordinates (Bao *et al.*, 2023; Zhao *et al.*, 2022), tokenisation strands that explore NFTs as digital title representations (Hojati *et al.*, 2023), and institutional strands that examine trust, acceptance and legal compatibility (Ajayi *et al.*, 2026; Faku & Amadi-Echendu, 2026). The pattern suggests a shift from technical feasibility towards institutional fit, but the strands are largely developed separately. The three debates below are analytical categories derived by the authors from this corpus and are not controversies named in the literature.

The immutability debate contrasts the view that a registry's value lies in permanence with the view that permanence is a liability wherever rights are legally revocable. Early advocacy emphasised tamper resistance (Griggs *et al.*, 2017),

whereas Nigerian reviews emphasise legal and institutional constraints on adoption (Okoli *et al.*, 2024; Yahya *et al.*, 2026). The governance debate contrasts permissionless public networks with permissioned consortium models. Ameyaw and de Vries (2020) found a permissionless public blockchain to be technically applicable in the Ghanaian context, while authority-based validation schemes such as geographic proof of authority (Mallya *et al.*, 2025) bind validators to institutional roles. The evidence reviewed therefore suggests that the question remains open. The sufficiency debate asks whether blockchain alone can address land-administration problems or is one component in a wider socio-technical system. Institutional and trust-focused reviews point to the latter (Ajayi *et al.*, 2026; Ansah *et al.*, 2023; Faku & Amadi-Echendu, 2026).

Sufficiency Synthesis and Complementary Failure Modes

In the reviewed literature, each technology in the stack appears to have a characteristic blind spot that another component can address (Table 1). A ledger provides tamper-evidence and a single source of truth but cannot verify that a recorded claim corresponds to physical ground reality (Zhao *et al.*, 2022). GIS engines resolve boundary representation and topological accuracy (Maikano *et al.*, 2020; Johnson *et al.*, 2024) but have no native mechanism for multi-institution consensus over transferable rights. NFTs represent unique, transferable titles (Hojati *et al.*, 2023) but presuppose that formal documentation exists before minting, an assumption that may not hold where tenure is customary and undocumented. A hybrid social oracle collects community attestations to fill that gap, but depends on connectivity that can be intermittent in some rural settings, a limitation that MQTT messaging is intended to mitigate. None of the five components, as described in the reviewed studies, addresses what happens when a verified, tokenised and community-attested title must later be lawfully revoked. That sixth gap is the specific problem addressed by the revocation workflow in Section 4. The blind spots in Table 1 are interpretive syntheses by the authors, grounded in the cited sources, and are not findings reported by those sources.

Table 1: Complementary Failure Modes of the Technology Stack and the Components that Address Them

Component	Contribution	Blind spot	Addressed by
Permissioned ledger	Tamper-evidence, shared state, audit trail	Cannot verify physical reality or lawful authority	GIS verification; role-differentiated authorisation
GIS spatial engine	Boundary and topology validation	No native consensus over transferable rights	Ledger and title token
NFT title token	Unique, transferable digital representation	Assumes formal documentation exists; not itself legal title	Hybrid social oracle; statutory register
Hybrid social oracle	Community attestation of undocumented tenure	Depends on reliable connectivity; open to coercion	MQTT messaging; threshold rules
MQTT messaging	Low-bandwidth, asynchronous transport	Carries messages but gives no legal authority	Message signing; workflow manager
Revocation workflow (this paper)	Lawful, auditable change of title state	Not provided by the five components alone	Sections 4.3 and 4.4

Positioning Against Mutable-Ledger Alternatives

Three established responses to the immutability problem exist, and the framework should be read against them. Redactable blockchains allow authorised parties to rewrite ledger content, typically through chameleon-hash constructions (Ateniese *et al.*, 2017). They restore mutability, but by altering history, which weakens the audit trail that a land registry needs in order to show what was recorded and when. Administrator-controlled upgrade or override keys are a second, common engineering response. They are simple, but they concentrate revocation power in a single key, which is the risk the framework seeks to reduce. A third response accepts that code cannot anticipate every legal outcome and relies on legal override outside the system, an approach discussed in the literature on smart contracts and the rule of code (Werbach & Cornell, 2017; De Filippi & Wright, 2018). This preserves legal authority but leaves the registry state to be reconciled manually. Assessments of early property-registry pilots also caution that technical immutability does not by itself secure tenure where the underlying administrative process is unreliable (Graglia & Mellon, 2018).

The framework differs from these alternatives in three respects. It preserves history through appended events instead of rewriting it. It encodes the statutory sequence of proposal, notice, appeal and revocation as role-bound state transitions instead of a generic administrator key. It grounds the state vocabulary in LADM so that revocation is expressed as a change to rights, restrictions and responsibilities. Whether

these differences yield better outcomes than the alternatives remains to be demonstrated.

RESULTS AND DISCUSSION

Proposed Conceptual Framework

The framework described in this section is a proposed architecture. It has not been implemented, tested or approved by any legal or regulatory authority, and the technology names used below are illustrative.

Design Goals and Traceability

To resolve the limitations identified above, the framework adopts five design goals. Requirements traceability requires every component to map to a documented limitation. Tamper-evidence with lawful mutability requires records to resist unauthorised alteration while remaining revocable by authorised statutory actors through an append-only due-process sequence. Statutory alignment requires revocation logic to encode the grounds, authority and preconditions of the governing statute, rather than a generic administrative override key. Verifiability and auditability require every state transition to produce an independent, timestamped and verifiable record that can be audited without exposing personal data. Legitimacy beyond technical correctness requires mechanisms through which community custodians and institutional actors can validate or contest claims. Table 2 links each goal to the responsible component, a representative threat and a validation criterion, so that each design choice can be checked in later work.

Table 2: Traceability Matrix Linking Design Goals to Components, Threats and Validation Criteria

Design goal	Responsible component	Representative threat	Validation criterion
Requirements traceability	All components (Table 1)	Components added without a documented purpose	Each component traced to at least one documented limitation
Tamper-evidence with lawful mutability	Permissioned ledger; revocation state machine	Silent record alteration; unilateral revocation by one actor	Ledger hash chain verifies after a revocation; no revocation completes with fewer than three distinct role signatures
Statutory alignment	Application Layer workflow and authority engine	Revocation without lawful grounds, notice or authority	Every revocation event carries grounds, authority and notice proof; legal review confirms the mapping to the Act
Verifiability and auditability	Ledger events; hash-anchored off-chain documents	Unverifiable or deniable actions; personal-data leakage through audit	Independent auditor reconstructs full status history; no personal data on chain
Legitimacy beyond technical correctness	Hybrid social oracle; MQTT; appeal path	False or coerced attestations; exclusion of remote claimants; message replay	Threshold of independent attestations enforced; conflicts trigger hold; replayed messages rejected; stakeholder acceptance testing

Layered Architecture

The framework organises its components into five layers (Figure 3). Client interfaces cannot write to the ledger directly. Every transaction is validated by the Application Layer and processed through the Integration Layer before reaching the Blockchain Layer. The Presentation Layer hosts administrator web portals and offline-capable mobile collectors for field surveyors. The Application Layer

manages identity, role-based access control, workflow orchestration and the smart-contract authority engine. The Integration Layer houses the GIS spatial engine, the hybrid social oracle and the MQTT broker, which queues field messages for asynchronous synchronisation. The Blockchain Layer runs the permissioned ledger and the on-chain contracts, and the Data Layer holds off-chain documents and encrypted state databases.

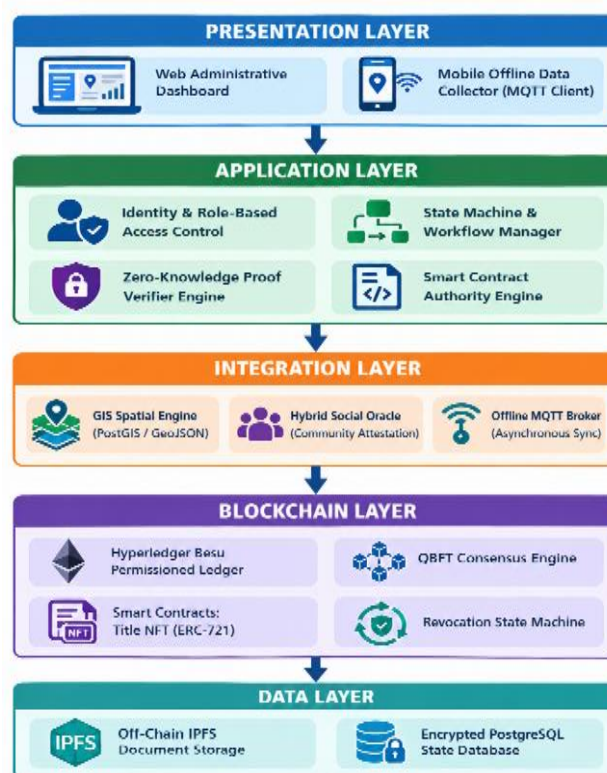


Figure 3: Layered architecture with Application Layer mediation between client interfaces and the permissioned ledger

The platform names shown in Figure 3 (for example Hyperledger Besu with QBFT consensus, an ERC-721 title token and PostGIS) are illustrative implementation choices. The framework itself requires only a permissioned ledger with identity-bound validators, a non-fungible token standard such as ERC-721 (Entriken *et al.*, 2018), a spatial database and a lightweight publish-subscribe protocol such as MQTT (OASIS, 2019). The “smart-contract authority engine” in the Application Layer is an off-chain service that composes, signs and submits transactions and reads contract events. The contracts themselves, including the title token and the revocation state machine, are deployed and executed on the Blockchain Layer. In this paper, a hybrid social oracle denotes a mechanism that combines signed attestations from accredited human custodians with automated consistency checks, such as GIS validation and duplicate detection, and whose output is treated as evidence for the workflow and never as a binding decision.

Title Status and Append-Only Revocation

The framework resolves the tension between tamper-evidence and mutability by treating revocation as a new, authorised ledger event rather than an erasure. Altering

existing blocks would invalidate the hash chain and undermine auditability. A state transition, by contrast, is appended while the original title record and every earlier transition remain preserved. Append-only state transitions are therefore not equivalent to deleting history, and the title’s current status is derived from the sequence of events.

Six title statuses are defined (Figure 4). ACTIVE means the title is in force. DISPUTED means that conflicting community attestations or a boundary claim have placed a hold on the parcel; transfers are blocked but no revocation is under way. REVOCATION_PROPOSED means that an officer has recorded the grounds and legal basis. UNDER_NOTICE means that the proposal has been reviewed and authorised and notice has been issued, with service on the holder and the objection period still to be completed. APPEALED means that the holder has lodged an objection or appeal and the revocation is stayed. REVOKED means that revocation has been finalised, and the status can be exited only by a signed court nullification order. Encumbrances such as mortgages are treated as separate attributes rather than as statuses. Table 3 specifies each transition with its guard, actor and effect.

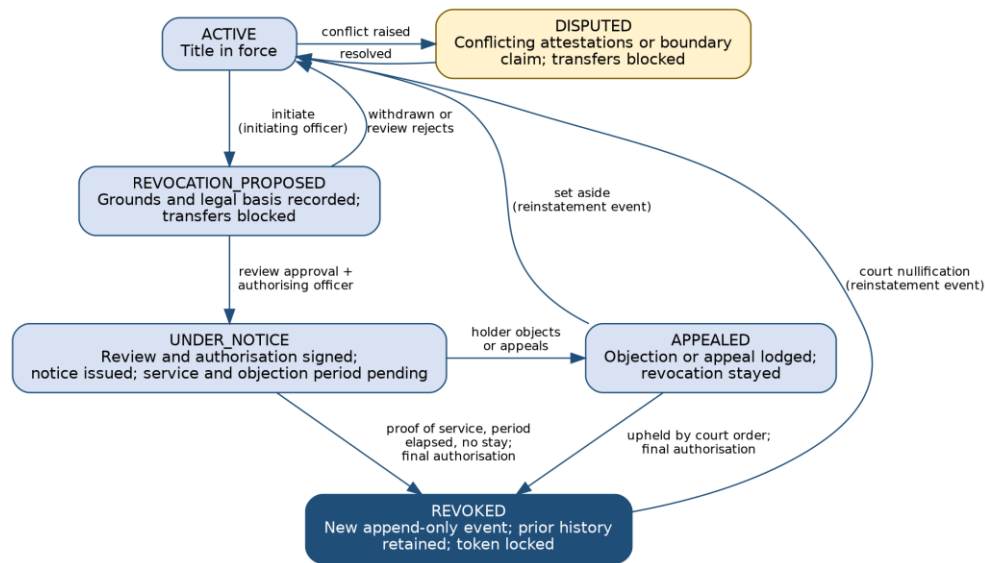


Figure 4: State-transition diagram for title status during statutory revocation

Table 3: Transition Specification for Title Status during Statutory Revocation

Transition	Guard (precondition)	Actor	Effect
Active → Disputed	Conflicting attestation or boundary claim recorded	Oracle or registered party	Transfers blocked
Disputed → Active	Dispute resolved through the designated route	Competent body (signed order)	Hold lifted
Active → Revocation_Proposed	Grounds, legal basis and document hash recorded	Initiating officer	Transfers and new encumbrances blocked; parcel flagged; encumbrances notified
Revocation_Proposed → Active	Proposal withdrawn or review rejected	Initiating or reviewing officer	Case closed; signatures cleared
Revocation_Proposed → Under_Notice	Initiating and reviewing signatures present	Authorising officer	Notice issued
UNDER_NOTICE (Service)	Notice issued	Registry officer or service agent	Proof of service recorded; notice period starts
Under_Notice → Appealed	Objection or appeal lodged	Holder or court	Revocation stayed
Under_Notice → Revoked	Proof of service recorded, notice period elapsed, no stay, and initiating, reviewing and authorising signatures present	Authorising officer (final)	Token locked and marked revoked; versioned GIS status; compensation reference attached
Appealed → Revoked	Signed order upholding the revocation imported	Authorising officer (final)	As above
Appealed → Active	Signed order setting the revocation aside	Court or appeal body	Reinstatement event; period of suspension recorded
Revoked → Active	Signed court nullification order	Court	Reinstatement event; derivative interests reviewed

The legal basis is drawn from Section 28 of the Land Use Act. Revocation is permitted on grounds of overriding public interest or breach of conditions. It must be signified by a public officer authorised by the Governor, and notice must be given to the holder. Compensation is addressed in later provisions of the Act, and compensation disputes are referred to the competent land-use body. Appeals and judicial review remain available through the courts. The framework encodes these elements as workflow stages and does not replace them. The notice period runs only from the recorded proof of service. The duration of the notice period, the identity of the competent bodies and the compensation rules are deliberately left as configurable parameters, because they must be confirmed by legal review (Section 6.3). On finalisation, the token is locked and marked as revoked rather than erased, so that the record of the title and of its revocation remains available to auditors, and administrative control of the parcel reverts to the State in the register. The paper does not specify

whether payment must be verified before revocation takes legal effect, because this depends on the statute as interpreted by legal counsel.

Multi-Actor Authorisation and Revocation Workflow

To reduce the risk of executive abuse, the design does not allow a revocation to be committed on the authority of a single account. Table 4 lists the roles involved. The names are illustrative and must be matched to the institutions designated by law. The role-bound signing rule draws on the reputation-based and proxy-delegate literature reviewed in Section 2.3. Three distinct statutory roles must sign before a revocation can be finalised: the initiating officer, the reviewing officer and the authorising officer. Community attestations, by contrast, are recorded as evidence and can place a title on hold, but they neither approve nor veto a revocation. The court or designated appeal body acts independently of the executive chain.

Table 4: Roles, Authority and On-Chain Acts in the Revocation Workflow

Role	Authority basis (illustrative)	Function	On-chain act
Initiating officer	State land registry or ministry	Proposes revocation with grounds and draft notice	Signed ProposeRevocation
Reviewing officer	Independent legal or committee member	Checks grounds, procedure and compensation provision	Signed review approval or rejection
Authorising officer	Governor or officer authorised by the Governor	Authorises notice and final revocation	Signed authorisation (twice: notice and finalisation)
Holder	Registered right-holder	Receives notice; may object or appeal	Objection event
Hybrid social oracle	Accredited community custodians and neighbours	Supplies attestations and flags disputes (evidence only)	Signed attestations
Court or appeal body	Judicial authority	Stays, upholds, sets aside or nullifies a revocation	Imported signed order
Independent auditor	Oversight institution	Verifies history and process	Read-only validator or observer

The workflow proceeds through six stages (Figure 5). In the proposal stage, the initiating officer submits a signed transaction citing the legal grounds and attaching the public-interest declaration, which is stored off-chain with only its hash recorded. The title becomes REVOCATION_PROPOSED, transfers and new encumbrances are blocked, and the parcel is flagged in the GIS layer. In the review and authorisation stage, the reviewing officer and the authorising officer sign, and the title becomes UNDER_NOTICE. In the service and community notification stage, the notice is served on the holder and proof of service is recorded, because the notice period runs only from that proof. The notice is also routed, through the hybrid social oracle and MQTT, to local custodians and

neighbouring landholders, who may register attestations or flag disputes. Conflicting attestations place the title on hold and escalate the case. In the objection and appeal stage, the holder may object or appeal within the notice period, in which case the title becomes APPEALED and awaits the signed order of the competent body. Where proof of service is recorded, the period has elapsed and no stay exists, or where the revocation is upheld, the authorising officer finalises the revocation and the contract sets the status to REVOKED. In the final stage, a new versioned parcel status is recorded in the GIS layer, a compensation case reference is attached, and the event is emitted to the audit trail. A court may later nullify a revocation, which restores the title through a reinstatement event.

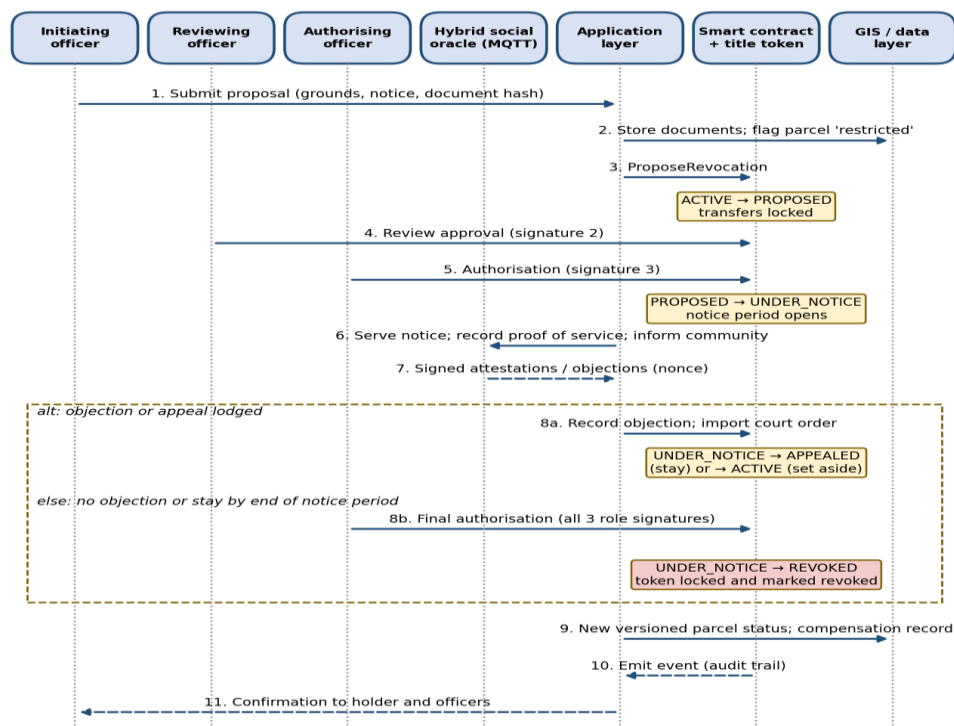


Figure 5: Cross-layer sequence for statutory revocation, showing state changes in the ledger, title token, GIS and data layers

Third-Party Rights and Reinstatement

Revocation of a title affects parties other than the holder, and a registry design must say how. The framework adopts four rules, each of which is a design proposal subject to legal review. First, from the REVOCATION_PROPOSED status onwards, transfers and new encumbrances on the parcel are blocked, so that no purchaser or lender can acquire an interest during the process, and encumbrances already recorded on the

register are notified together with the holder. Second, on revocation, recorded derivative interests such as mortgages, leases and sub-interests are flagged as affected and referred for determination. Whether they are extinguished, converted into a claim to compensation or survive is a question of statute and case law, and the framework records the outcome as an event and does not decide it. Third, a reinstatement following appeal or court nullification restores the previous status

through a new event, records the period of suspension on the ledger and triggers review of any derivative interests flagged during it. Fourth, because history is never rewritten, a later reader can reconstruct who held which rights at any date, which supports the resolution of competing claims.

Safeguards and Legal Interpretation of Components

Legal meaning of the NFT. A token under the ERC-721 standard is not legal title. It functions as a tamper-evident digital certificate that points to the underlying LADM record and shows current administrative status and transaction history. Statutory ownership remains governed by the Land Use Act and the official register, which prevails in the event of divergence. A token transfer has no legal effect unless the statutory consent and registration requirements have been satisfied and recorded as a precondition in the workflow.

Privacy and data minimisation. Personal data, including names, biometric records and national identification numbers, are excluded from on-chain storage in order to support compliance with the Nigeria Data Protection Act (2023). Such data are encrypted and held off-chain, and only salted hashes or commitments are anchored to the ledger. Hashes of personal data can still be personal data, and the immutability of the ledger sits uneasily with erasure rights, so the design keeps the linking data off-chain where it can be deleted. Zero-knowledge proofs, where used, allow holders to prove eligibility without disclosing identity attributes (Nugraha *et al.*, 2026; Majigi *et al.*, 2023), although their use adds complexity and requires independent audit.

Offline message authentication and replay protection. Field messages are recorded locally, timestamped, signed with the surveyor's private key and assigned a monotonically increasing nonce. MQTT is used over an encrypted channel with broker access controls. After reconnection, the Integration Layer verifies signatures, checks nonce sequences and validity windows, and processes each message idempotently, so that replayed or stale messages are rejected.

Offline messages are treated as pending attestations and never write to the ledger directly.

Spatial validation and boundary disputes. Proposed geometries are checked against existing cadastral layers before submission, and those that self-intersect, have zero area or overlap registered parcels are rejected. Boundary claims that remain contested place the parcel in the DISPUTED status. Each geometry is versioned, with a hash of the previous version anchored on the ledger, so that boundary history remains auditable.

Conflicting and false attestations. Attestations are evidence and not conclusive proof. An oracle response is accepted only when a threshold of independent attestations from distinct accredited custodians is met (the threshold being set by context) and when it is consistent with GIS validation. Conflicting attestations put the title on hold and refer it to the designated dispute-resolution route. Reputation mechanisms for custodians (Hasan *et al.*, 2022) could be added as an optional extension to help detect repeated false attestations, although they would have to be designed so as not to entrench existing elites. The framework as specified does not depend on them.

Threat Model and Trust Assumptions

The guarantees described in this section hold under four assumptions. First, validator nodes are operated by independent institutions, and less than the Byzantine fault threshold are compromised. Second, the identity registry that binds keys to roles is accurate, and its own administration is subject to multi-party control. Third, courts register a signing key with the registry and issue orders through it. Fourth, the legal framework on which the workflow stages are based is valid and correctly interpreted. If any assumption fails, the guarantees weaken accordingly. Table 5 summarises the principal threats, the mitigations in the framework and the residual risks.

Table 5: Principal Threats, Mitigations and Residual Risks

Threat	Mitigation in the framework	Residual risk
Collusion among the three signing officers	Separation of roles; independent stay by the court; mandatory proof of service; public audit anchors; non-executive observer nodes	Coordinated action remains possible where holders cannot access courts
Forged or coerced community attestations	Threshold of independent custodians; GIS consistency checks; conflicts trigger a hold; appeal route	Local elite capture, coercion and exclusion of women or minorities
Replay or forgery of offline field messages	Signatures, nonces, validity windows, encrypted MQTT, idempotent processing	Compromised surveyor device keys
Key compromise or loss	Hardware-backed or threshold keys; key rotation and revocation through the identity registry	Delayed detection; recovery procedures need institutional design
Spoofed court order	Court keys registered and governed through the identity registry; orders verified and hash-anchored	Compromise of the court's registered key
Validator capture	Validators drawn from several institutions, including non-executive nodes	Safety is lost if the fault threshold is exceeded
Personal-data exposure	No personal data on chain; salted commitments; encrypted off-chain storage	Linkage attacks on commitments
Connectivity failure	Asynchronous MQTT queue; attestations held as pending; time-bound validity windows	Delays near notice deadlines could disadvantage holders unless deadlines extend for documented outages
Tampering with off-chain documents	Hash anchoring; replicated document store	Loss of document availability

Preliminary Logical Verification

To test the internal consistency of the transition system in Table 3, it was implemented as an explicit-state model in Python (Supplementary File S2) and explored exhaustively. The model abstracts each case as a status together with the set of role signatures, proof of service, notice-period expiry, stay and court-order flags. Four properties were checked: (i) the REVOKED status is never reached without the initiating, reviewing and authorising signatures; (ii) it is entered only when either proof of service has been recorded, the period has

elapsed and no stay exists, or a signed order upholding the revocation has been imported; (iii) no reachable state is a deadlock; and (iv) the ACTIVE status remains reachable from every reachable state.

The model has 17 reachable states and 29 transitions, with a maximum depth of eight events. All four properties held in the baseline model. To test the sensitivity of the check, four faulty variants were created, in which the notice-period guard was removed, a single signer was sufficient, finalisation after appeal required no court order, or the notice stage was

skipped. Each variant produced a violation of property (i) or (ii). These results show that the specified transitions are internally consistent and that the check can detect the faults it targets. They do not show that the legal content is adequate, that an implementation conforms to the specification, or that the design is secure. The model also omits concurrency, timing and multiple simultaneous cases, and a specification in a language such as TLA+ (Lamport, 2002) is proposed as the next step.

Legal and Institutional Boundary Conditions

The framework encodes a procedure and does not create law. The requirement for three distinct role signatures is a design choice intended to reduce the risk of unilateral action. It is not stated as a requirement of the Land Use Act, which, in the provisions summarised above, requires a revocation to be signified by an authorised public officer and notice to be given to the holder. Four boundary conditions should be confirmed through legal review before any implementation. First, the allocation of functions varies between states and the Federal Capital Territory, so role names and competent bodies must be mapped to the institutions that exercise the Governor's functions in each jurisdiction. Second, the Constitution protects property against compulsory acquisition except under a law that provides for prompt compensation and a right of access to court (Constitution of the Federal Republic of Nigeria, 1999), so the workflow must preserve access to court and record compensation. Third, whether a ledger-based record is admissible, and what weight it carries, depends on the rules of evidence for computer-generated records (Evidence Act, 2011), and the register must remain capable of producing certified extracts. Fourth, the workflow should not extend the grounds or powers of revocation, because its purpose is to record lawful revocation in a verifiable way.

Discussion

Theoretical Propositions

Because the paper is conceptual, its outputs are theoretical propositions and an architectural design, not measured results. Each proposition is stated with its scope and with the evidence that would count against it.

Proposition 1 (sufficiency). In land-administration settings where tenure includes undocumented or customary rights and where rights are statutorily revocable, a blockchain ledger alone is unlikely to satisfy the requirements of verification, legitimacy and lawful change, and a multi-component design with an explicit revocation workflow is needed (Table 1). The proposition would be weakened if a ledger-only deployment were shown to meet these requirements in such a setting.

Proposition 2 (immutability). Cryptographic permanence and legal mutability may be reconcilable where revocation is modelled as an authorised, append-only event, in the sense that the history of what was recorded is preserved while the current legal status changes. The proposition would be weakened if legal review showed that Nigerian law requires records of revoked titles to be erased or amended in place, or if an implementation could not satisfy the guards in Table 3 without a privileged override.

Proposition 3 (governance). Where revocation authority must be attributable to accountable institutional roles, binding validator and signer identities to those roles supports accountability better than anonymous validation (Section 2.3). The proposition is limited to settings with a functioning institutional structure, and it would be weakened if a permissionless design were shown to satisfy role-attribution, privacy and revocation requirements, as some studies suggest

may be possible in other contexts (Ameyaw & de Vries, 2020).

Governance Alternatives and Risks

Several governance models are possible. Public permissionless networks offer censorship resistance and open verification, but anonymous validators cannot be bound to institutional roles, transaction fees can be volatile, and publishing personal data on chain raises substantial privacy and legal concerns. A permissioned consortium binds validators to identified institutions and can support role-based authorisation, but it is exposed to institutional capture if the executive controls the validator majority. A hybrid design, in which a permissioned ledger periodically anchors state commitments to a public chain, improves external verifiability at the cost of extra complexity and does not remove the need for role-bound authorisation. A conventional centralised database with an append-only audit log is simplest and most flexible, but its integrity depends largely on the operator, and its protections against insider deletion are weaker unless supplemented by independent logging. The framework adopts the permissioned model because it best fits the accountability and revocation requirements set out here, which is a design judgement and not the result of an empirical comparison.

Permissioned governance carries its own risks. The three signing roles are all drawn from the executive or its agencies, so the separation of duties reduces the risk of single-actor abuse without preventing coordinated action. Proof of service, the independent stay by a court, public audit anchors and non-executive observer nodes are intended to raise the cost of collusion, but they depend on holders having practical access to courts. Hybrid social oracles are vulnerable to bribery, coercion, chieftaincy disputes and the exclusion of women and minorities, which the threshold, hold and appeal mechanisms mitigate but cannot remove. The on-chain recording of personal data would create lasting privacy exposure and is avoided by design.

Tenure Security and Holder Protections

A framework that makes revocation more efficient and more auditable also lowers the administrative cost of exercising state power over land, and this has normative implications. Verifiable process can protect holders against arbitrary action, but efficiency could also make revocation easier to carry out against holders who have limited means to respond, including customary holders and women whose rights are held through family or community. The framework does not expand the grounds or powers of revocation, and it records only what the law permits (Section 4.9). Several protections are built into the design: mandatory proof of service before the notice period runs, an independent stay, blocking of transfers during the process, public auditability of the revocation history and the recording of compensation references. These protections are necessary but not sufficient. Their practical effect would depend on measures outside the system, such as accessible notice in local languages, legal aid for appeals and sequencing rules for compensation, and these should be examined in the stakeholder evaluation (Table 7).

Limitations

The framework has several limitations. It has not been implemented, legally reviewed or empirically evaluated, and the logical verification in Section 4.8 tests only the internal consistency of the specified transitions. The literature synthesis is a scoping review whose selection and coding depend on the authors' judgement, and the three debates are

analytical constructs. The legal provisions are summarised for design purposes and require verification by qualified counsel, and the framework is specific to Nigerian land law, although the revocation-as-event principle may apply elsewhere. Platform choices are illustrative, and the performance, cost and usability of the proposed stack under real rural conditions are unknown. Finally, the model does not address the full range of land-administration processes, such as inheritance and mortgage enforcement.

Recommendations and Future Research

Recommendations

The analysis in Sections 3 to 5 suggests a set of recommendations. They follow from the design argument and the preliminary verification and are not findings of an empirical evaluation, so they should be read as proposals for the actors concerned to test and adapt.

For land administration authorities and policymakers, the first recommendation is to treat lawful mutability as an explicit requirement in the specification of any blockchain-based registry, so that a revocation workflow with notice, appeal and reinstatement paths is required before a pilot is approved. A legal review should fix the role map, the notice period, the compensation sequence and the evidential status of ledger records before the design is frozen (Section 4.9). Oversight should be built into governance by including non-executive observer nodes, such as judicial, civil-society and audit institutions, and by publishing audit anchors, while ensuring that holders have practical access to courts. Any pilot should be bounded, for example to a single local government area or registry, and should run in parallel with the existing register, which should remain authoritative until the framework has been evaluated.

For system designers and implementers, the recommendations follow from the design principles of Section 4. Personal data should be kept off chain, with only salted commitments anchored to the ledger. The non-fungible token should be treated as a certificate that points to the register entry and not as legal title, and it should be locked and marked, not burned, on revocation so that the history remains available. The state machine should be specified formally and verified before implementation, and the guards should be tested by deliberate fault injection, as illustrated in Section 4.8. Community attestations should be treated as evidence and not as decisions, and the system should be designed for offline operation, with deadlines extended for documented outages.

For researchers, funders and organisations supporting customary holders, two recommendations follow. Studies of blockchain land administration should report their search protocol, corpus and coding transparently, and should evaluate socio-technical outcomes such as tenure security, dispute resolution and inclusion, and not only technical throughput. Where customary and vulnerable holders are affected, notice in local languages, legal aid for appeals and accreditation rules for community custodians that include women and minorities should be treated as part of the system and not as optional supports (Section 5.3).

Future Research Directions

Table 6 sets out priority directions for future research. Each is framed as a question that the present paper cannot answer, together with a suggested approach. The directions are ordered broadly from the legal and logical foundations of the framework to its empirical evaluation and generalisation.

Table 6: Priority Future Research Directions

Direction	Research question	Suggested approach
1. Legal analysis	How do the notice, compensation and appeal provisions operate in practice across Nigerian jurisdictions, and can they be expressed as the guards in Table 3 without loss of legal meaning?	Doctrinal and case-law analysis with legal counsel; comparison with other jurisdictions that have revocation or compulsory-acquisition regimes
2. Formal specification	Do the safety and liveness properties of Section 4.8 hold under concurrency, timing, multiple simultaneous cases and derivative interests?	Specification and model checking in TLA+ or an equivalent language; extension of the model to compensation and encumbrances
3. Prototype and field evaluation	Can the proposed stack operate reliably under rural connectivity, and what are its cost, latency and finality in practice?	Design-science prototype; pilot with a registry; measurement of performance and usability
4. Attestation design	How custodian accreditation, thresholds and any reputation or incentive mechanisms should be set so as to resist coercion and elite capture while including women and minorities?	Participatory design; simulation of attack scenarios; field experiments
5. Holder outcomes	Does the framework improve or erode tenure security for customary holders?	Mixed-methods comparative case studies with indicators such as dispute rates, time to resolution and perceived security
6. Governance comparison	Which governance model (permissioned, hybrid anchoring or centralised log) performs best on accountability, cost and resilience?	Comparative evaluation; cost-benefit analysis; Delphi study with experts
7. Privacy and data protection	Can salted commitments and zero-knowledge proofs satisfy minimisation and erasure requirements while preserving auditability?	Legal-technical analysis under the Nigeria Data Protection Act; cryptographic evaluation
8. Generalisability	Does the revocation-as-event principle apply to other registers in which permanent records coexist with lawful alteration, such as civil, company and intellectual-property registries, and to other jurisdictions?	Comparative conceptual analysis; cross-registry case studies

Validation Agenda

Table 7 sets out a four-phase validation agenda that sequences the directions in Table 6 into a practical programme. The

phases are ordered so that legal and logical questions are resolved before implementation effort is committed.

Table 7: Validation Agenda for the Proposed Framework

Phase	Activities	Success criteria
1. Legal and regulatory review	Audit of the workflow against the Land Use Act (grounds, authority, notice period, compensation, appeals), the Constitution and the rules of evidence; review under the Nigeria Data Protection Act; agreement of institutional role names	Written legal opinion mapping each transition in Table 3 to a provision; approved role and parameter map
2. Formal specification and prototype	Specify the transition system in TLA+ or an equivalent language; implement contracts (for example Solidity on an EVM-compatible permissioned ledger), the PostGIS engine and the MQTT broker	Properties of Section 4.8 hold in the specification and in implementation tests; no revocation possible with fewer than three role signatures
3. Security and cryptographic audit	Smart-contract vulnerability analysis; testing against the threats in Table 5; audit of any zero-knowledge components; key-management review	No unresolved critical findings; replayed and stale messages rejected
4. Expert and stakeholder evaluation	Delphi or structured interviews with registry officials, lawyers and customary custodians; usability testing; LADM data-exchange conformance checks; throughput and finality under low bandwidth	Agreed expert consensus thresholds met; acceptance targets met; conformance checks passed

Conclusion

This paper has argued that much of the blockchain land-administration research reviewed appears to rest on an assumption of unqualified permanence that is difficult to reconcile with the statutory revocability of land rights. Its central design principle is that revocation should be recorded as a new, authorised and auditable event, and not as a deletion. The proposed framework applies this principle through an integrated stack of a permissioned ledger, GIS verification, NFT title representation, a hybrid social oracle and MQTT messaging, coordinated by a role-bound workflow that includes proof of service, appeal and reinstatement. A preliminary logical check indicates that the specified transitions are internally consistent. The framework remains conceptual and architectural, and it has not been implemented or empirically tested. The recommendations and research directions in Section 6 are intended to give implementers, legal scholars and registry authorities a defined and checkable basis for the next stage of work.

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