Cross-Chain Equal-Term Exchange for Programmable Digital Assets: Future Architectures for NFTs, RWAs, and Smart Contract Rights Markets

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Abstract

Programmable digital assets increasingly combine economic ownership with contractual restrictions that do not disappear when the asset moves across chains or trading venues. Non-fungible tokens may carry royalties, vesting periods, staking obligations, or access rights; real-world asset tokens may carry transfer-agent rules, compliance limits, redemption windows, or collateral covenants; and smart contract rights markets may represent claims whose value depends on the persistence of duties attached to them. Existing cross-chain exchange designs usually solve the technical problem of asset movement but treat contractual terms as metadata, leaving platforms exposed to unequal transfers in which one party sheds a burden while another absorbs an equivalent asset without an equivalent term. Building on the equal-term exchange logic in NFT mechanism design, this article develops a future-oriented architecture for cross-chain equal-term exchange across NFTs, real-world assets, and smart contract rights markets. The proposed architecture separates asset identity, term semantics, matching logic, settlement verification, and governance oversight into auditable layers. A stylized simulation compares bridge-only routing, equal-term batch matching, and equal-term matching with term-netting across heterogeneous market conditions. The analysis shows that equal-term architectures reduce term-dispute exposure and manual audit burden, although they introduce settlement latency and require stronger registries for term classification. The paper contributes a conceptual framework, an implementation roadmap, and a research agenda for programmable asset markets that must coordinate liquidity, property-rights consistency, interoperability, and platform fairness.

Keywords: cross-chain exchange; equal-term matching; NFTs; real-world assets; smart contracts; programmable digital assets; platform fairness; interoperability; tokenization

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I. INTRODUCTION

Programmable digital assets are moving from collectible markets toward multi-chain infrastructures for ownership, financing, licensing, and automated service delivery. The first generation of public blockchain markets treated transferability as the central feature of a token: a wallet signed a transaction, a ledger updated balances, and a marketplace recorded the new owner. That view is no longer sufficient. Many digital assets now embody a bundle of terms that are just as important as the token identifier. A gaming NFT may include a staking period, usage restrictions, and a royalty split. A tokenized invoice or real-estate share may include redemption rules, investor eligibility checks, and jurisdictional constraints. A smart contract right may represent an option, a coupon, a licensing entitlement, or a claim on a future protocol revenue stream. These assets are transferable, but their transferability is not unconditional [Ante, 2022; Nadini et al., 2021]. FinTech research similarly treats new digital markets as bundles of payment, data, risk, and governance capabilities (Kou and Lu, 2025). Authenticated data-feed research provides an early model for connecting external facts with smart-contract execution (Zhang et al., 2016).

The motivating mechanism-design problem is simple but consequential. If an owner transfers away an asset encumbered by a lockup, royalty obligation, or compliance restriction, an exchange mechanism should not allow that owner to receive an unencumbered asset unless the difference is priced, disclosed, and accepted. The uploaded source manuscript frames this problem as an equal-term exchange problem in NFT markets. It

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argues that contractual restrictions such as vesting periods, staking requirements, and royalties create a market structure like housing markets with contracts, where the term under which an agent receives an asset should be consistent with the term under which the agent's own asset is used [Shapley & Scarf, 1974; Jeong, 2026]. That insight is powerful because it moves the discussion from isolated NFT trading toward a more general theory of programmable property rights. Interoperability surveys also show that cross-chain communication must integrate technical messaging with governance and verification layers (Belchior et al., 2022). Governance research cautions that blockchains can shift trust from institutions to technical and social arrangements without eliminating trust altogether (De Filippi et al., 2020).

This paper extends the equal-term logic to cross-chain markets. The extension is necessary because programmable assets are increasingly fragmented across layer-1 chains, layer-2 rollups, application-specific chains, custodial tokenization platforms, and off-chain registries. Cross-chain bridges and messaging protocols can move tokens or synchronize token representations, but they cannot by themselves guarantee that a term attached to one asset has an economically and legally comparable term on another chain. A bridge may verify that a token was locked on Chain A and minted on Chain B, yet it may not verify that royalties, vesting status, redemption rights, or transfer-agent constraints remain equivalent. The result is a fairness gap between technical interoperability and contractual interoperability [Belchior et al., 2021; Xu et al., 2019]. Information-systems research has emphasized that blockchain implementation requires organizational governance rather than simple software deployment (Lu, 2022). Discrete-resource exchange theory helps explain why incentive compatibility and allocation efficiency can conflict under realistic market constraints (Pycia and Unver, 2017).

The central research question is therefore: how can cross-chain exchange systems match programmable assets while preserving equal-term consistency across heterogeneous asset classes and smart contract environments? This question is not only technical. It is also institutional and economic. An architecture that verifies contractual terms too loosely may produce adverse selection, disguised obligation transfer, and post-trade disputes. An architecture that verifies terms too rigidly may destroy liquidity by making every asset incomparable with every other asset. A workable system must classify terms, route liquidity, provide credible evidence, and retain enough flexibility for market participants to express preferences over assets and conditions [Cong & He, 2019; Schär, 2021]. NFT evidence also shows that non-fungibility is shaped by market design and metadata conventions, not only by uniqueness at the token level (Bao and Roubaud, 2022). Industry 4.0 research reinforces the need to treat digital assets, automated systems, and data governance as interdependent infrastructure (Lu, 2025).

This article makes three contributions. First, it generalizes equal-term exchange from single-market NFT trading to cross-chain programmable asset markets that include NFTs, real-world assets (RWAs), and smart contract rights. Second, it proposes a layered architecture in which semantics, matching, settlement, and governance are separated but interoperable. Third, it presents a stylized data analysis that compares bridge-only routing with equal-term batch matching and equal-term matching with term-netting. The results are not intended as claims about a particular live platform; they show how design choices affect match rates, dispute exposure, latency, and audit burden under controlled assumptions. The remainder of the paper proceeds as follows. Section II reviews conceptual foundations. Section III defines architecture. Section IV develops mechanism-design requirements. Section V presents the analytical scenario. Section VI discusses governance, compliance, and platform fairness. Section VII concludes with a research agenda. This point is consistent with research on smart contracts as mechanisms that alter coordination and market structure (Cong and He, 2019). Systematic reviews of blockchain in sustainable supply chains also emphasize classification frameworks and evidence standards (Paliwal et al., 2020).

II. CONCEPTUAL FOUNDATION

A. From Equal-Term NFTs to Programmable Asset Rights

The source manuscript begins with the observation that contemporary NFTs are not merely images or collectibles. They often contain conditional access rights, revenue-sharing obligations, lockups, staking

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claims, and royalty rules. These conditions create a contractual environment in which a token's tradable object cannot be separated from the term under which the object is transferred. Classical top trading cycles in a housing market can deliver efficient and strategy-proof outcomes when each agent owns one indivisible asset, but the introduction of contractual terms changes the logic because the asset and its transfer condition become a combined contract [Roth, 1982; Ma, 1994]. Matching-with-contracts theory provides a useful vocabulary for treating asset allocation and contractual obligations as a single design object (Hatfield and Milgrom, 2005). Trust research shows that supposedly trust-free systems still depend on social, institutional, and interface-level trust (Hawlitschek et al., 2018).

Equal-term consistency can be stated in practical language. A party that contributes an asset under a restrictive term should receive an asset under an equivalent restrictive term, unless the exchange explicitly prices the difference. This does not mean that every restriction must be identical word for word. It means that a platform must have a rule for deciding whether terms are comparable within a clearing class. For instance, a 30-day vesting remainder may be comparable with another 30-day vesting remainder, but not with an unrestricted token. A royalty obligation of two percent may belong to a different class than a royalty obligation of ten percent. A tokenized receivable subject to know-your-customer transfer checks cannot be treated as equal to a freely transferable collectible. The term is part of the object of exchange [Valeonti et al., 2021]. DeFi research likewise shows that programmable finance depends on the interaction of protocol logic, collateral rules, and market governance (Xu et al., 2024). Corporate-governance scholarship is relevant because tokenized rights can change control, disclosure, and accountability relationships (Yermack, 2017).

The equal-term lens is especially useful because it separates three goals that are often conflated in platform design: efficiency, incentive compatibility, and fairness. Efficiency asks whether the exchange reaches mutually beneficial allocations. Incentive compatibility asks whether agents have incentives to reveal their preferences truthfully. Fairness asks whether property rights and obligations are transferred consistently. In a frictionless setting these goals may align, but programmable assets often create tensions. The source manuscript shows that an equal-term core can be empty and that no mechanism can simultaneously guarantee Pareto efficiency, equal-term consistency, and strategy-proofness in the general NFT exchange environment. Cross-chain markets inherit the same tension and add additional frictions from asset wrapping, oracle evidence, network fees, and regulatory constraints. Oracle research warns that off-chain facts must be authenticated before they can safely affect on-chain settlement (Al-Breiki et al., 2020). Tokenomics research helps explain why some programmable claims function as governance instruments, access instruments, and investment instruments simultaneously (Malinova and Park, 2023).

B. NFTs, RWAs, and Smart Contract Rights Markets

NFTs, RWAs, and smart contract rights differ in their economic substance, but they share a common design challenge: the token is a bearer of programmable claims. NFTs usually represent unique digital or hybrid objects. Their terms often concern royalties, access, gaming utility, or membership status. RWAs represent claims on off-chain assets such as real estate, invoices, commodities, carbon credits, or private credit instruments. Their terms usually concern eligibility, redemption, custody, reporting, and legal enforceability. Smart contract rights markets represent claims generated inside protocols, including governance rights, revenue shares, time-locked yields, liquidity-provider positions, and options embedded in decentralized finance. Their terms usually concern maturity, collateral, liquidation, protocol risk, and governance change [Chen & Bellavitis, 2020; Howell et al., 2020]. Metaverse land markets illustrate how unique digital assets can acquire value from scarcity, location, and platform expectations (Dowling, 2022a). Traceability studies identify business requirements and success factors that are directly relevant to term registries and evidence workflows (Hastig and Sodhi, 2020).

TABLE I. PROGRAMMABLE ASSET FAMILIES AND EQUAL-TERM EXCHANGE CONCERNS

Asset Family	Typical Programmable Rights	Equal-Term Concern	Evidence Source
NFTs	Royalty, access, staking,	A restricted collectible should not	Token metadata,

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	vesting, membership utility	clear against an unrestricted collectible without pricing the difference.	marketplace rules, issuer attestations
RWAs	Redemption, custody, investor eligibility, jurisdiction, reporting	A token with transfer-agent limits should clear only with comparable compliance status.	Issuer registry, custody attestation, compliance oracle
Smart contract rights	Maturity, collateral, liquidation exposure, protocol revenue claim	A right with high protocol or collateral risk should not be treated as a clean claim.	On-chain state proof, protocol oracle, risk monitor
Hybrid assets	Physical ownership plus digital utility or financing rights	The digital wrapper and off-chain claim must remain consistent across chains.	Registry link, legal document hash, audit certificate

Table I highlights why equal-term exchange is broader than NFT trading. The same principle applies whenever the economic object being exchanged is a rights bundle rather than a bare token. The table also shows that equal-term verification is evidence-dependent. A metadata-only NFT and a custody-attested RWA can both be programmable assets, but they require different evidence sources before a platform can classify their terms with confidence. Applications of blockchain in Industry 4.0 further demonstrate the importance of connecting digital ledgers with operational controls (Chen et al., 2024). DeFi crisis research demonstrates that composability can amplify risk when protocols depend on shared collateral and price feeds (Gudgeon et al., 2020).

These asset classes are converging. An NFT can represent a license to a real-world object; an RWA token can be issued as a unique claim; and a DeFi position can become a transferable NFT that embodies collateral, debt, and liquidation rules. As a result, exchange platforms cannot rely on asset class labels alone. The relevant unit for exchange is a rights bundle, and the rights bundle contains attributes that are both technical and legal. Term equivalence therefore requires semantic classification, not merely token standard recognition. ERC-721 and ERC-1155 identify token interfaces, but they do not guarantee that the rights associated with two tokens are economically equivalent [Entriken et al., 2018; Radomski et al., 2018]. Token-sale evidence shows that digital claims often combine access rights, governance expectations, and financing functions (Adhami et al., 2018). Entrepreneurial-finance research shows that tokenized fundraising should be compared with older financing mechanisms rather than treated as isolated innovation (Block et al., 2021).

III. CROSS-CHAIN EQUAL-TERM EXCHANGE ARCHITECTURE

A. Design Principles

A cross-chain equal-term exchange architecture should be modular because no single layer can solve all aspects of term consistency. Asset identity asks whether the system knows what asset is being transferred. Term semantics asks what contractual restrictions attach to that asset. Matching asks whether a counterparty's asset belongs to a compatible term class. Settlement asks whether the exchange can be completed atomically or with acceptable fail-safe guarantees. Governance asks how term taxonomies, oracle evidence, and disputes are maintained over time. Treating all these functions as a single smart contract would make the system brittle, expensive, and difficult to audit. A layered architecture makes it possible to evolve standards without rebuilding the entire platform [Wüst & Gervais, 2018]. DeFi market analysis confirms that settlement automation can reconfigure intermediation without removing the need for risk controls (Schar, 2021). Consensus-security research shows that even apparently robust decentralized systems can face strategic vulnerabilities (Eyal and Sirer, 2014).

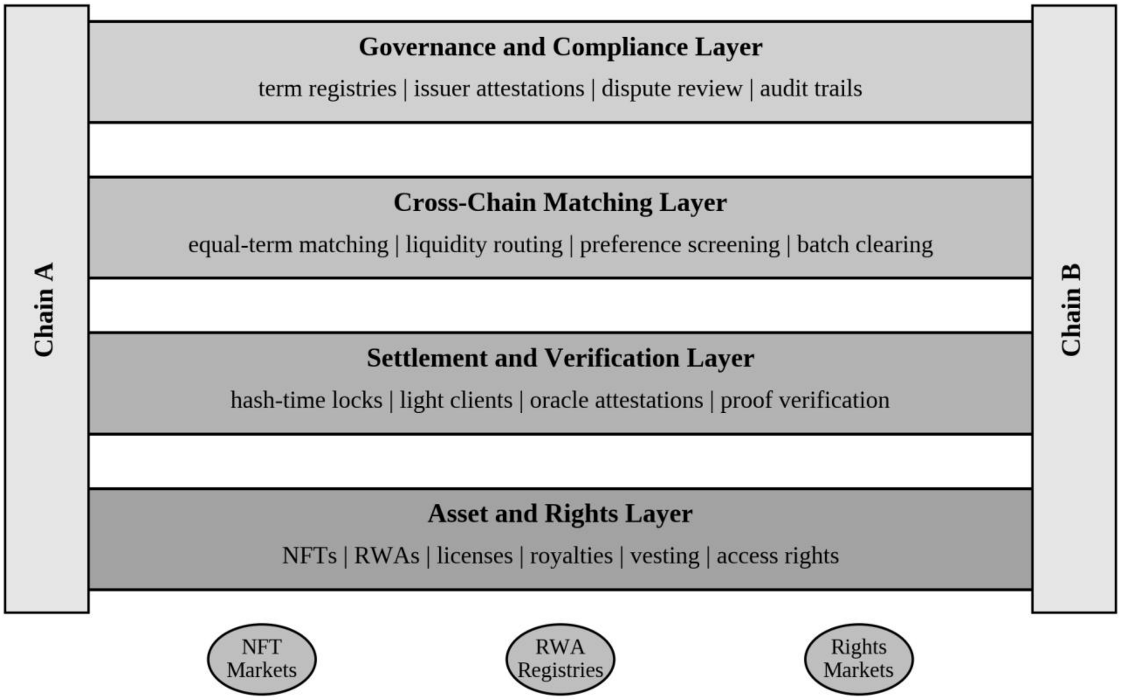

Figure 1. Layered architecture for cross-chain equal-term exchange

Figure 1 intentionally avoids representing the system as a simple pipeline. Cross-chain equal-term exchange is not a one-directional bridge; it is a coordination stack. The side columns represent chain environments, while the horizontal layers represent the functions that must be present in each environment or verified across environments. This design makes it possible to add new chains, asset classes, and term registries without changing the core fairness principle. Security studies of Ethereum contracts show that code-level failures can convert contractual ambiguity into irreversible loss (Atzei et al., 2017). Application surveys of later-generation blockchain systems indicate that domain-specific architecture is often more important than generic token transfer (Di Francesco Maesa and Mori, 2020).

TABLE II. ARCHITECTURAL LAYERS, CONTROLS, AND FAILURE MODES

Layer	Primary Function	Key Controls	Failure Mode Addressed
Asset and rights layer	Defines token identity and rights bundle	Issuer IDs, token standards, legal links, metadata hashes	Ambiguous asset identity
Term semantic layer	Classify contractual restrictions	Term registry, equivalence rules, version control	Hidden obligation transfer
Matching layer	Clears compatible offers across chains	Equal-term constraints, batch windows, term-netting	Fairness-liquidity imbalance
Settlement layer	Executives or aborts exchange	Escrow, state proofs, timeout rules, rollback logic	Partial execution and bridge failure
Governance layer	Maintains rule legitimacy	Audits, dispute review, registry updates, compliance evidence	Taxonomy capture and opaque enforcement

The failure modes in Table II are intentionally practical. Programmable asset markets fail not only through hacks or bridge outages but also through semantic confusion. A token may move successfully while the market misunderstands what moved. Equal-term architecture treats semantic failure as a first-order design risk. Security-token research is particularly relevant because regulated programmable assets embed investor rights and transfer constraints in the tradable instrument (Lambert et al., 2022). Artificial-intelligence research is relevant for automated term extraction, anomaly detection, and user-facing explanation (Zhang and Lu, 2021).

The architecture proposed in Figure 1 has four layers. The asset and rights layer records token identifiers, issuer attestations, chain identifiers, off-chain registry links, and term-relevant metadata. The settlement and verification layer provides cross-chain message validation, state proofs, escrow logic, and oracle attestations. The cross-chain matching groups offer equal-term classes and clears compatible cycles or batches. The governance and compliance layer maintains term registries, evidence standards, audit logs, and dispute workflows. The key architectural premise is that equal-term consistency should be verified before settlement, not reconstructed after a dispute has occurred. Blockchain-IoT research also supports the need to connect asset identifiers with secure devices, sensors, and event data (Xu et al., 2021). Energy-policy research reminds platforms that chain selection can create environmental and public-policy consequences (Truby, 2018).

B. Identity Reconciliation Across Chains

The economics of blockchain clarifies why verification costs, settlement finality, and network effects are central to platform design (Catalini and Gans, 2020).

Identity reconciliation is the first operational challenge. A token can be native, wrapped, mirrored, or represented through a custodial receipt. These forms are not interchangeable. A native NFT on one chain may be wrapped in another; an RWA token may be represented by a custodian-controlled smart contract on a public chain; a smart contract right may exist only as a position inside a protocol but be represented externally through a transferable receipt. Equal-term exchange therefore requires a canonical asset reference that is separate from the chain-specific token address. Without such a reference, a platform may compare two wrappers rather than the underlying rights bundle. The canonical reference should include issuer identity, asset family, chain representation, registry links, and evidence of whether the representation is redeemable or only synthetic. Network analysis of crypto-art markets suggests that NFT value formation is shaped by relationships among creators, collectors, and platforms (Vasan et al., 2022). Collaborative business-process research is important for multi-party settlement workflows that cross organizational and chain boundaries (Di Ciccio et al., 2019).

The architecture also needs a lifecycle model. An offer should move through discovery, classification, matching, settlement preparation, execution, and post-trade audit. During discovery, the system reads token metadata and issuer attestations. During classification, it maps the rights bundle to a term class. During matching, it searches for compatible counterparties. During settlement preparation, it freezes or snapshots relevant states so that a term cannot change silently while the transaction is pending. During execution, it moves assets or updates balances through the selected cross-chain method. During post-trade audit, it stores evidence that the terms cleared as represented. This lifecycle is more demanding than a conventional swap, but it is necessary when rights are conditional, and chain environments are heterogeneous. Smart-contract security research therefore supports a cautious design that separates matching logic from irreversible settlement execution (Luu et al., 2016).

A second design issue is the relation between public and private information. Some term information should be public, such as a royalty rate or vesting timestamp. Some information may be private or permissioned, such as the legal identity of an RWA investor or the full text of a financing agreement. Equal-term architecture should not force sensitive information onto a public ledger. Instead, it can publish commitments, hashes, attestations, and class labels while keeping raw documents with the issuer, custodian, or regulated verifier. The market needs enough evidence to determine term equivalence, not necessarily full disclosure of every legal file. This distinction is important for privacy, commercial confidentiality, and compliance with data protection rules. The auditability of blockchain systems is also relevant for post-trade review, because programmable rights markets require evidence that can be inspected after settlement (Wu et al., 2025).

IV. MECHANISM DESIGN FOR EQUAL-TERM INTEROPERABILITY

A. Preferences, Terms, and Clearing Classes

The mechanism-design problem begins with a set of offers. Each offer includes an asset, a chain location, a term vector, and a preference profile over possible incoming assets. A term vector is not a mathematical abstraction for its own sake; it is a practical encoding of restrictions that matter to exchange. Typical dimensions include liquidity status, lockup maturity, royalty burden, redemption rights, jurisdiction, compliance eligibility, collateral exposure, governance dependence, and oracle dependency. A clearing class is a platform-defined group of term vectors that are considered equivalent for a specific market context. Two assets can be equal-term compatible within one market but not within another. For example, a 2 percent royalty NFT and a 3 percent royalty NFT may be compatible in a gaming marketplace, while a tokenized bond with different redemption law may require a stricter class. Operations-management research further indicates that distributed ledgers reshape coordination problems rather than simply digitizing existing records (Babich and Hilary, 2020). Sustainability assessments of blockchains suggest that efficiency metrics should include energy and infrastructure costs (Vranken, 2017).

A direct cross-chain swap design asks whether two parties can exchange assets atomically. Equal-term exchange asks a richer question: can a set of parties exchange assets such that every party’s outgoing term class is matched by the incoming term class that the party accepts? This may be implemented through bilateral swaps, cycles, or batch auctions. The uploaded source manuscript emphasizes the value of a dual top trading cycles approach when strict strategy-proofness is secondary to efficiency and term consistency. In cross-chain settings, the same logic suggests a batch-clearing engine that separately tracks preference over assets and compatibility over term classes. The platform should not clear an attractive asset match when the term class is inconsistent. The security and performance limits of public blockchains also make settlement timing a substantive design parameter (Gervais et al., 2016).

B. Cross-Chain Settlement Logic

Settlement is where equal-term design becomes operational. A chain can verify its own state, but a cross-chain exchange must either trust a bridge operator, verify light-client evidence, use a threshold attestation network, or rely on optimistic dispute periods. Each method has different implications for latency, security, and cost. Equal-term exchange adds another verification burden: the system must confirm not only that the asset exists and is locked but also that the relevant term class remains valid at the time of settlement. An RWA token may change compliance status if an investor whitelist changes. A staked NFT may become withdrawable after a block timestamp. A DeFi position may cross a collateral threshold. Therefore, term snapshots should be time-stamped and tied to the settlement window [Yaga et al., 2019; Al-Breiki et al., 2020]. Legal scholarship on decentralized finance shows that programmable markets still interact with regulatory duties and institutional boundaries (Zetzsche et al., 2020). Information-systems scholarship positions blockchain as both a technical artifact and a new institutional coordination mechanism (Beck et al., 2017).

C. Term-Netting and Liquidity Preservation

A strict equal-term rule can fragment liquidity if it creates too many classes. Term-netting is a design principle that reduces fragmentation by allowing compatible obligations to offset within a batch. For example, if three participants exchange assets that all carry a comparable 30-day lockup, the platform does not need to treat each lockup as unique. If multiple RWA tokens share the same investor eligibility class and redemption window, they can clear together even if their underlying assets differ. The challenge is to define netting rules transparently. A platform that expands classes too aggressively risks unfair transfers; a platform that narrows them too aggressively suppresses exchange. The governance layer must therefore publish classification criteria and audit changes over time. The same logic appears in supply-chain research, where blockchain records are valuable only when they improve traceability, trust, and process accountability (Kshetri, 2018).

D. Incentives and Manipulation Risks

Equal-term matching changes the strategic environment. In a bridge-only market, the main strategic behavior is price discovery and routing. In an equal-term market, participants may try to influence classification. A seller may prefer that an encumbered asset be placed in a more liquid class; a buyer may prefer that a rival asset be placed in a more restrictive class. The platform must therefore separate self-reported term data from verified term data. User declarations can be useful during order creation, but clearing should rely on evidence from token state, issuer records, and approved attestations. When evidence is uncertain, the platform should either route the offer to manual review or clear it under a conservative class rather than letting the participant choose the most favorable interpretation. Early blockchain reviews emphasized that decentralization, consensus, privacy, and scalability must be analyzed together (Lu, 2018).

The impossibility results in the source manuscript warning against expecting one mechanism to achieve every ideal property. In cross-chain markets, the platform may deliberately prioritize equal-term consistency and ex-post auditability over full strategy-proofness. This is a defensible choice when the harm from term-inconsistent exchange is concentrated and difficult to reverse. A participant who receives an asset with an unexpected lockup or compliance limit may face immediate financial loss, legal exposure, or inability to exit. By contrast, small manipulation opportunities in preference ranking may be mitigated through batching, random tie-breaking, reputation penalties, and clear disclosure of matching rules. The platform’s design objective should be realistic incentive containment rather than perfect incentive elimination. Contract-law analysis reinforces the point that code can automate performance while still leaving interpretation, remedies, and legal validity unresolved (Savelyev, 2017). Bibliometric work on logistics and blockchain reinforces the importance of linking technical traceability with managerial adoption and governance (Rejeb et al., 2021).

Pricing also matters. Equal-term consistency does not imply that all matched assets have equal market value. A rare NFT with the same royalty burden as another NFT may still be more valuable. A tokenized invoice with the same compliance class may have different credit risks. Therefore, an equal-term exchange system needs a price or value-adjustment layer when assets are not intended to trade one-for-one. This layer can take the form of side payments, stable coin balancing, auction-cleared exchange rates, or protocol-defined compensation bands. The equal-term rule specifies which rights bundles are comparable; the pricing layer specifies whether participants accept the value difference. Keeping these two functions separate prevents the platform from hiding value disagreements inside term classifications. A systems perspective on DeFi also stresses composability, liquidation risk, oracle dependence, and governance vulnerabilities (Werner et al., 2022).

Batch design is another mechanism choice. Short clearing windows provide immediacy but reduce the chance of finding compatible term cycles. Long windows improve compatibility but increase state-change risk and user impatience. A practical system may use adaptive windows: common low-risk terms clear frequently, while complex RWA or rights classes clear in scheduled sessions with stronger review. The clearing engine can also support cancellation rules when a term state changes before execution. For example, if a lockup expires between submission and settlement, the offer should be reclassified rather than forced into the old class. This logic avoids stale-term execution, one of the most likely sources of disputes in cross-chain rights markets. Architectural research on smart contracts supports separating application logic, contract execution, and governance functions (Wang et al., 2019).

V. DATA AND ANALYTICAL SCENARIO

A. Scenario Design

The empirical component of this article is a stylized simulation rather than a live blockchain measurement. This choice is deliberate. Real platforms differ sharply in bridge design, token standards, custody arrangements, market depth, and disclosure quality. A controlled simulation makes the design tradeoffs visible without presenting platform-specific claims. The simulation considers a clearing window with 100 to 5,000 active offers distributed across three asset families: NFTs, RWAs, and smart contract rights. Each offer is assigned to a term vector with one of four liquidity states, one of three obligation states, and one of three verification states. Agents submit ranked preferences over incoming asset families and acceptable term classes. The model then compares three clearing approaches: bridge-only routing, equal-term batch matching, and equal-term matching with term-netting. Real-estate tokenization research illustrates why RWAs require custody, valuation, and legal-rights evidence beyond a token identifier (Joshi and Choudhury, 2022). Economic analysis of Bitcoin shows that technical protocols and governance incentives must be studied together (Bohme et al., 2015).

TABLE III. STYLIZED SIMULATION PARAMETERS

Parameter	Value / Range	Purpose
Active offers per window	100, 250, 500, 1,000, 2,000, 5,000	Tests market thickness
Asset families	NFT, RWA, smart contract right	Captures programmable-asset diversity
Liquidity states	Unrestricted, soft lock, hard lock, redemption window	Defines transferability differences
Obligation states	None, royalty/revenue share, compliance duty	Defines burden differences
Verification states	Metadata only, issuer attested, proof verified	Defines evidence quality
Clearing approaches	Bridge-only, equal-term batch, equal-term + term-netting	Compares architecture choices
Outcome metrics	Match rate, dispute exposure, latency, audit burden	Captures liquidity and fairness tradeoffs

Table III shows the controlled assumptions behind the analysis. The parameters emphasize design comparison rather than platform prediction. A live implementation would need chain-specific gas data, bridge-specific failure rates, real order books, and verified asset-term annotations. The stylized scenario is nevertheless useful because it isolates the consequences of including or excluding equal-term constraints. IoT-oriented smart-contract research is useful for thinking about rights that depend on external events and machine-generated evidence (Christidis and Devetsikiotis, 2016).

Bridge-only routing represents a conventional design in which cross-chain technical availability is the main constraint. It can match assets across chains but does not enforce equal-term compatibility before settlement. Equal-term batch matching rejects any match that violates the outgoing and incoming term class equivalence rule. Equal-term with term-netting allows compatible subclasses to clear together when obligations are standardized and auditable. The analysis tracks accepted match rate, term-dispute exposure, settlement latency, and manual audit burden. These are not exhaustive metrics, but they capture the core exchange between liquidity and fairness. Recent blockchain research also frames interoperability, privacy, and governance as persistent future-trend issues (Zheng and Lu, 2022).

VI. RESULTS AND DISCUSSION

A. Match Rates and Effects

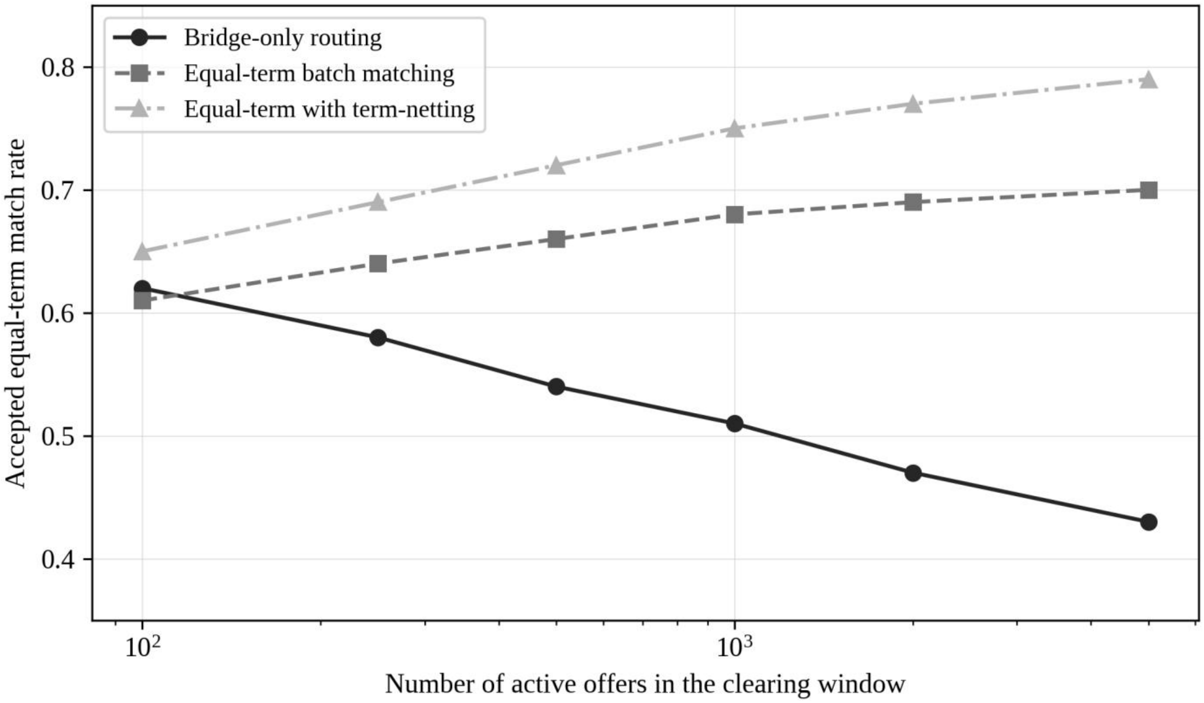

Figure 2. Stylized accepted equal-term match rate under different clearing designs

Figure 2 reports the accepted equal-term match rate across clearing windows of different sizes. Bridge-only routing appears attractive in small markets because it accepts technically feasible swaps without waiting for term-compatible counterparties. However, its accepted equal-term match rate declines as the market grows because more technically feasible matches violate term consistency. Equal-term batch matching improves with scale because larger clearing windows contain more compatible term cycles. The term-netting variant performs best in the simulation because it allows standardized obligations to be matched without treating every minor contractual attribute as unique. ICO evidence helps explain why token markets frequently attach financing expectations to technical transferability (Fisch, 2019). Token-financing research documents how disclosure, issuer quality, and contractual design affect digital-asset markets (Howell et al., 2020).

The result has an important platform design implication. Equal-term exchange is not necessarily a liquidity killer. In very small markets it may reduce immediate match availability, but in thicker markets the loss is mitigated by batch clearing and term-netting. This means that platforms should not evaluate equal-term rules only through the lens of bilateral swaps. The economic value of equal-term design is clearest when it is combined with a market microstructure that collects orders, groups term classes, and clears in scheduled windows. The analogy is not a traditional order book; it is closer to a rights-aware clearinghouse that treats term comparability as a first-class market attribute [Budish, 2011]. Technical overviews of blockchain further clarify why consensus, immutability, and distributed validation must be specified before relying on a chain as evidence (Yaga et al., 2019).

B. Dispute Exposure and Audit Burden

Regulatory-technology scholarship shows that code-based enforcement may also become a tool for legal and institutional ordering (De Filippi and Hassan, 2016).

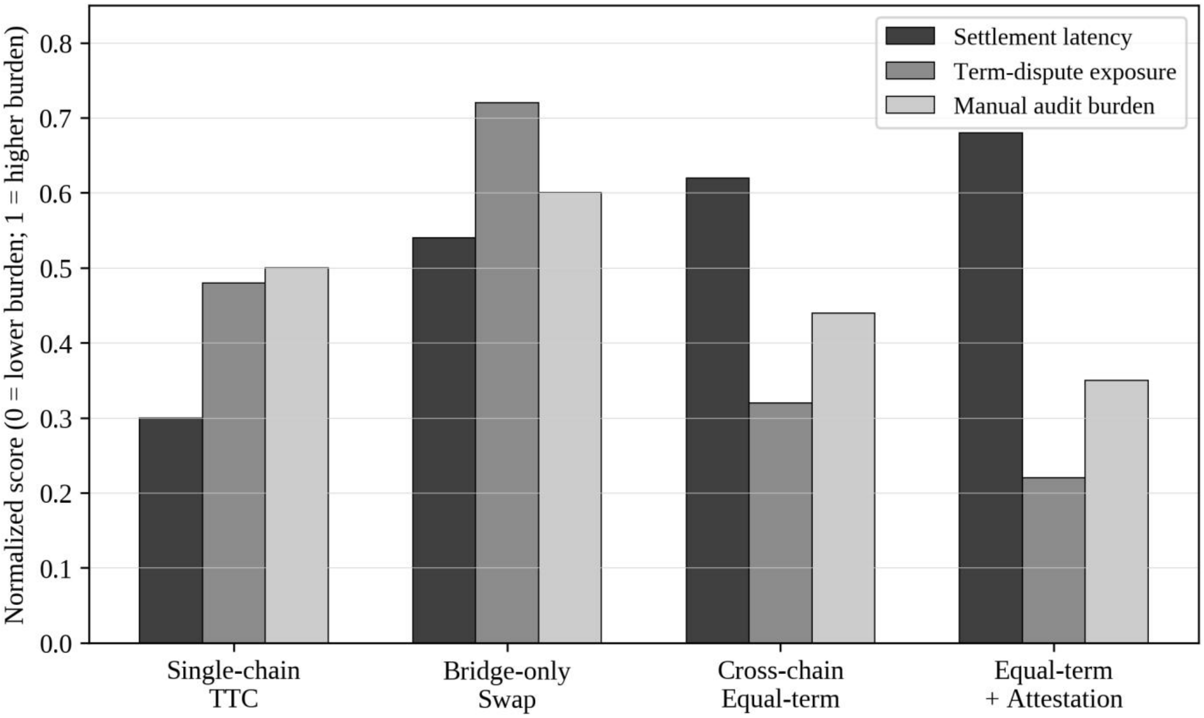

Figure 3. Normalized operational burden across programmable asset exchange designs

TABLE IV. COMPARATIVE DESIGN IMPLICATIONS

Design Option	Liquidity Effect	Fairness Effect	Operational Cost	Best-Fit Context
Bridge-only routing	High short-run acceptance but declining clean matches as heterogeneity rises	Weak; term differences are checked after settlement	Low technical cost; high dispute cost	Simple fungible assets or low-value transfers
Strict equal-term batch	Moderate; improves with market thickness	Strong; incompatible term bundles are blocked	Moderate verification and batching cost	NFT collections and standardized rights classes
Equal-term with term-netting	High when obligations are standardized	Strong if registry governance is credible	Higher registry and attestation cost	RWA pools, gaming assets, DeFi rights positions
Manual legal review	Low throughput	Potentially strong for bespoke assets	Very high professional cost	High-value non-standard RWA transfers

Table IV converts the simulation logic into design guidance. Bridge-only routing is not wrong; it is appropriate for simple assets whose rights are either absent or standardized outside the platform. Equal-term matching becomes necessary when rights and obligations are material to value. Manual legal review remains essential for bespoke high-value claims, but it cannot serve as the default infrastructure for scalable cross-chain markets. NFT pricing research further suggests that programmable asset prices may be correlated with broader crypto-market conditions (Dowling, 2022b).

The simulation also shows that bridge-only routing carries higher term-dispute exposure because it externalizes term comparison to post-trade review. This is the familiar problem of incomplete contracting in a new technological form. When a transaction clears quickly but fails to carry comparable rights, the platform may later face claims that a party received a different bundle than expected. Equal-term matching reduces this exposure by rejecting inconsistent trades before settlement. The attestation-enhanced version lowers manual audit burden further by making term evidence machinereadable and time-stamped. IoT cybersecurity research is relevant because many RWA attestations depend on devices, sensors, and data pipelines that must be protected (Lu and Xu, 2019).

Figure 3 summarizes the normalized burden scores for settlement latency, term-dispute exposure, and manual audit. The cross-chain equal-term design has a higher latency score than single-chain TTC because it must verify cross-chain evidence. Yet it has lower dispute and audit scores than bridge-only swaps. The attestation-enhanced design performs best on dispute and audit dimensions because it shifts term verification from ad hoc human review to standardized evidence. The tradeoff is that the platform must maintain reliable registries and evidence providers. In other words, equal-term exchange moves the market from opaque speed toward accountable interoperability. Foundational cryptocurrency research shows that security assumptions and incentive assumptions are inseparable in decentralized systems (Bonneau et al., 2015).

Platform Fairness Empirical research on NFTs and DeFi tokens also indicates that programmable asset classes can transmit shocks across markets

The fair value of equal-term architecture lies in preventing hidden obligation transfer. In a bridge-only market, a sophisticated participant may exploit metadata gaps by transferring an asset with unfavorable restrictions while receiving a cleaner asset from a less informed counterparty. This is not simply a disclosure failure. It is a structural market design failure because the platform permits non-equivalent term bundles to clear as if they were equivalent. Equal-term exchange reduces that failure by making the term class part of the matching constraint. Participants are still free to prefer more liquid assets, but they cannot silently exchange away burdens without a comparable incoming burden or explicit compensation. Legal-informatics research distinguishes imperative smart-contract execution from declarative legal commitments, a distinction central to term registries (Governatori et al., 2018).

The analysis also suggests that fairness does not require identical treatment of all asset classes. NFTs, RWAs, and smart contract rights require different verification evidence. A royalty-bearing NFT may be verified through token metadata and marketplace royalty enforcement. A tokenized receivable may require issuer attestations and legal registry links. A DeFi rights token may require collateral state and protocol-risk indicators. Fairness requires consistent treatment within a disclosed term taxonomy, not a one-size-fits-all rule across every asset. The governance layer is therefore central to market legitimacy. Supply-chain blockchain research shows that traceability depends on governance incentives as much as ledger architecture (Saberi et al., 2019).

VII. GOVERNANCE, COMPLIANCE, AND IMPLEMENTATION ROADMAP

A. Term Registries and Evidence Standards

The proposed architecture depends on term registries. A term registry is a structured vocabulary that maps market-relevant restrictions into verifiable classes. It should identify the asset family, term dimension, evidence source, update frequency, expiry rule, and responsible issuer or verifier. The registry is not merely a database. It is a governance artifact that determines which rights are comparable and which trades are blocked. For that reason, changes to the registry should be versioned, auditable, and subject to review. If a platform changes the class boundary between limited and unrestricted assets, it changes the economic meaning of exchange. Asymmetric-information evidence from token offerings helps explain why platforms need transparent classifications of obligations and rights (Momtaz, 2021). Research on ICO contracts illustrates how Ethereum-based instruments can combine fundraising, governance, and programmable execution (Fenu et al., 2018).

Evidence standards should be risk sensitive. Low-value collectible NFTs may require only on-chain metadata and marketplace policy checks. High-value RWA tokens may require custody attestations, transfer-agent records, and jurisdictional compliance proofs. Smart contract rights may require real-time state proof and protocol-governance monitoring. A useful roadmap is to begin with low-complexity equal-term classes, such as lockup status and royalty range, then expand toward more complex RWA and rights classes as evidence infrastructure matures. This staged approach avoids the common mistake of designing a universal interoperability protocol before the market has agreed on the meaning of the rights being transferred. Blockchain architecture research provides the basic vocabulary of consensus, decentralization, and data structures used by the proposed design (Zheng et al., 2017).

B. Compliance Without Centralized Lock-In

RWA markets raise compliance challenges that cannot be solved by decentralized code alone. Investor eligibility, sanctions screening, transfer restrictions, and redemption rights often depend on legal institutions. However, acknowledging legal constraints does not imply that cross-chain exchange must become fully centralized. The architecture can separate compliance evidence from market clearing. A regulated issuer or transfer agent can attest that a token belongs to a class of eligible transfers, while the matching engine remains open to multiple issuers, chains, and liquidity providers. This division preserves interoperability while respecting the fact that some rights are enforceable only through off-chain institutions [Yermack, 2017]. The platform should also ask when a blockchain is necessary, because some evidence functions may be better handled by permissioned registries (Wust and Gervais, 2018).

C. Implementation Phases

A practical implementation roadmap has four phases. Phase one is term discovery: platforms collect metadata, issuer rules, and market disputes to identify recurring restrictions. Phase two is term registry publication: the platform publishes a controlled vocabulary and asks issuers or collection owners to map assets into classes. Phase three is equal-term pilot clearing: the platform runs batch matching for a limited set of compatible terms, such as lockups or royalty ranges, while keeping manual review available. Phase four is cross-chain expansion: term registries are connected to bridge attestations, light-client proofs, and dispute workflows. Each phase should include user-facing disclosure so that participants understand why a trade was accepted, rejected, or routed to review. Legal critiques of smart contracts reinforce the need for dispute procedures when coded outcomes and legal expectations diverge (Giancaspro, 2017).

D. Dispute Resolution and Accountability

Dispute resolution should be designed before the market goes live. In many blockchain applications, disputes are treated as exceptional events handled through social media, informal governance, or emergency multigeniture actions. That approach is inadequate for programmable rights markets. A term dispute may involve legal claims, investor eligibility, collateral valuation, or a physical asset record. The platform should define evidence hierarchy, review timelines, appeal rights, and remedies. Remedies may include trade reversal when technically possible, compensation when reversal is impossible, suspension of an issuer, or reclassification of a term class. The important point is that users should know the dispute path before they trade. Business-model research shows that blockchain adoption changes value creation, value capture, and partner relationships simultaneously (Morkunas et al., 2019).

Accountability must also be assigned across roles. Issuers are accountable for the accuracy of asset-level rights claims. Oracles and verifiers are accountable for evidence availability and correctness within their service scope. The exchange platform is accountable for using the published matching and classification rules. Bridge providers are accountable for the integrity of cross-chain messages. Users are accountable for preference declarations and compliance declarations. A clear allocation of responsibility reduces the ambiguity that often follows smart contract failures, where every actor claims to be only a neutral infrastructure provider. Equal-term exchange makes responsibility more visible because each cleared trade has a record of the term class, evidence source, and settlement path. Decentralized business-model research is consistent with the view that programmable rights markets create new forms of intermediation rather than eliminating intermediation entirely (Chen and Bellavitis, 2020).

The governance layer should publish transparency reports. These reports need not reveal user identities or confidential asset documents. They should report the number of offers by term class, rejection reasons, dispute categories, average settlement time, registry changes, and verifier performance. Such reports would allow researchers, regulators, issuers, and users to evaluate whether the platform is preserving fairness or merely advertising it. They would also create feedback loops for improving term definitions. If one class generates repeated disputes, the class may be too broad, the evidence source may be weak, or the user interface may be misleading. The broader blockchain research agenda also identifies scalability, privacy, interoperability, and governance as open problems (Lu, 2019).

VIII. FUTURE RESEARCH AGENDA

Future research should develop formal models that capture equal-term exchange under cross-chain uncertainty. The source manuscript provides a foundation by analyzing the tension among efficiency, equal-term consistency, and strategy-proofness in NFT markets. Cross-chain environments add probabilistic settlement failure, time-varying term status, and heterogeneous evidence quality. A useful next step would be to model equal-term matching when terms can change between order submission and settlement. Another step would be to study whether partial strategy-proofness can be recovered for asset families whose terms are monotonic, such as lockups that only decrease over time. Assignment-market research shows that allocation design can combine fairness constraints with efficiency goals when the design object is carefully specified (Budish, 2011). Supply-chain use cases in pharmaceuticals demonstrate why high-stakes assets require verifiable provenance and exception handling (Bocek et al., 2017).

Empirical research is also needed. Public blockchain data can reveal token transfers, but term semantics often live in metadata, off-chain contracts, legal documents, marketplace policies, and issuer dashboards. Researchers will need hybrid datasets that combine on-chain events with term-class annotations. Such datasets could support measurement of hidden obligation transfer, post-trade dispute frequency, and liquidity fragmentation caused by term heterogeneity. Without these measurements, platform designers will continue to rely on anecdote and ideology rather than evidence. Business-process research suggests that blockchain is most valuable when it coordinates shared state across organizational boundaries (Mendling et al., 2018).

A third agenda concerns human-computer interaction and explainability. If a platform rejects a cross-chain trade because of term incompatibility, users need a clear explanation. Technical proof is not enough. The interface should show which term dimension failed, what evidence was used, and whether the user can revise the offer. For RWAs, explainability is also a compliance requirement because investors and issuers need auditable reasons for transfer restrictions. Future work should therefore connect mechanism design with user-interface design and legal informatics. Technical surveys of digital currencies also show why settlement finality, transaction propagation, and consensus delay matter for cross-chain exchanges (Tschorsch and Scheuermann, 2016).

Finally, governance research should examine who controls term registries. A registry maintained by a single marketplace may produce lock-in. A registry maintained by a decentralized autonomous organization may face capture, slow updates, or weak legal accountability. A registry maintained by regulated issuers may preserve legal precision but reduce openness. Hybrid governance models, in which independent verifiers, issuers, marketplaces, and user representatives jointly maintain term classes, may be necessary. The design of such models will determine whether programmable asset markets become fair and interoperable or merely fragmented versions of existing financial silos. Recent evidence on token governance confirms that retention and resale restrictions shape market outcomes (Fuchs and Momtaz, 2025).

A measurement agenda should also examine the cost of not implementing equal-term controls. Most market discussions focus on the cost of compliance, verification, or slower settlement. The hidden cost of unfair exchange is harder to measure because it appears as disputes, reputational loss, adverse selection, and market exit by cautious participants. Researchers can model this cost by comparing user retention and dispute rates across markets with different term-disclosure practices. They can also analyze whether assets with poorly standardized rights trade at persistent discounts because buyers fear hidden restrictions. Such evidence would help platforms decide when the additional complexity of equal-term design is economically justified. Empirical evidence from operations and supply-chain settings shows that adoption depends on organizational readiness and ecosystem coordination (Queiroz et al., 2021).

Another promising direction is automated term extraction. Many rights are described in natural-language documents, issuer notices, or marketplace policies rather than in clean smart contract fields. Large language models and information extraction systems could assist by identifying lockups, royalties, redemption windows, transfer restrictions, and termination clauses. However, these tools should support human and institutional verification rather than replace it. A model-generated term label may be useful for triage, but clearing a high-value RWA exchange requires accountable evidence. Future work should investigate hybrid pipelines in which AI extracts candidate terms, verifiers approve classifications, and smart contracts consume only approved term attestations. DeFi scholarship also places programmable settlement within a broader transition toward open financial infrastructure (Harvey et al., 2021).

Finally, cross-chain equal-term exchange has implications for market competition. If every marketplace builds its own incompatible term taxonomy, liquidity will fragment, and users will face high switching costs. If a single taxonomy becomes dominant without accountability, it may become a private regulatory layer for programmable property. Open standards, interoperable registries, and portable attestations could reduce this risk. Research should therefore connect technical interoperability with institutional interoperability: the ability of users, issuers, verifiers, and marketplaces to move not just tokens but also trusted term evidence across platforms. Research on blockchain data quality shows that poor input data can undermine even technically valid distributed ledgers (Choi and Luo, 2019).

IX. CONCLUSION

Cross-chain exchange is usually discussed as a problem of moving tokens across ledgers. That framing is incomplete for programmable digital assets. NFTs, RWAs, and smart contract rights carry terms that shape their economic value and legal meaning. If those terms are ignored, cross-chain markets may produce technically valid but substantively unfair exchanges. Equal-term exchange addresses this gap by requiring consistency between outgoing and incoming rights bundles unless differences are explicitly priced and accepted. Market-efficiency research on NFTs and cryptocurrencies highlights the need to assess liquidity and movement when evaluating exchange designs (Pereira et al., 2022). FinTech research frames digital-asset platforms as part of a wider transformation of financial-service infrastructures and business models (Gomber et al., 2018).

This article has proposed a layered architecture for cross-chain equal-term exchange. Architecture separates asset identity, term semantics, matching, settlement verification, and governance. It extends the equal-term logic of NFT mechanism design to broader rights markets and shows through stylized analysis that equal-term systems can reduce dispute exposure and audit burden while preserving liquidity through batch clearing and term-netting. The approach does introduce latency and governance complexity, but those costs are the price of accountable interoperability. Future programmable asset markets will not be judged only by how quickly they move tokens. They will be judged by whether they preserve the rights and obligations that make those tokens meaningful. Cryptocurrency market analysis also indicates that regulatory uncertainty and market microstructure influence adoption (Giudici et al., 2020). Institutional economics views blockchains as governance technologies that reshape contracting, coordination, and exchange institutions (Davidson et al., 2018).

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