Digital Property Rights and Platform Fairness in Contract-Constrained NFT Exchange Ecosystems

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Abstract

Non-fungible token (NFT) exchange platforms increasingly operate in markets where digital assets are not simple transferable objects. Many NFTs include royalty obligations, revenue creator shares, staking conditions, vesting periods, game utility rights, community access rules, or other smart-contract restrictions that travel with the asset. These restrictions create a platform governance problem that is simultaneously technical, economic, and social: an exchange rule should preserve digital property rights, respect contractual obligations, and avoid unfairly allocating liquidity burdens to users who hold more restricted assets. This paper develops a rights-aware platform fairness framework for contract-constrained NFT exchange ecosystems. Building on market design, matching with contracts, blockchain governance, and algorithmic fairness research, the study reframes NFT exchange as a problem of term-consistent allocation rather than a mere asset-swap problem. The proposed framework distinguishes ownership rights, transfer rights, revenue rights, utility rights, and exit rights, and connects them to platform-level fairness metrics such as term consistency, individual rationality, exposure fairness, waiting-time equity, and creator-rights compliance. A scenario-based data analysis with 12,000 simulated exchange requests compares open swapping, compliance-only filtering, equal-term cycle clearing, and fairness-weighted equal-term clearing. The analysis shows that unrestricted swapping creates high liquidity but also high term-inconsistency risk; compliance-only filtering reduces violations but leaves substantial waiting-time inequality; equal-term cycle clearing sharply reduces property-rights violations; and fairness-weighted clearing further improves fairness with only a moderate liquidity cost. The paper contributes a governance-oriented analytics model for platforms that seek to balance digital property rights, market efficiency, and user fairness in tokenized asset ecosystems.

Keywords: NFT exchange; digital property rights; platform fairness; smart contracts; market design; equal-term matching; digital asset governance; blockchain platforms

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1. Introduction

NFTs have moved from experimental collectibles into programmable digital assets used in art markets, online games, cultural membership systems, virtual land projects, ticketing, intellectual property licensing, and brand communities. The early public narrative treated an NFT mainly as a transferable token that verified scarcity on a blockchain. That view is now incomplete. In many exchange settings, the token is not only a pointer to a digital object; it is also a carrier of contractual terms. A token may include a royalty covenant for the original creator, a lockup period for a launch participant, a staking requirement for in-game rewards, a jurisdiction-specific access condition, or a community rule that limits resale. These features complicate market design because the asset and the obligation cannot always be separated without damaging the rights structure that made the token valuable in the first place. The shift from collectible scarcity to programmable rights has also been recognized in broader NFT technology reviews (Wang et al., 2021). The same shift fits token economic research that treats tokens as institutional objects rather than mere records (Sunyaev et al., 2021).

The platform problem is therefore different from a conventional marketplace problem. In a simple asset exchange, fairness might be discussed mainly in terms of transparent pricing, low transaction costs, and equal access to search. In a contract-constrained NFT ecosystem, fairness also requires term consistency. A user who transfers a locked token should not automatically receive an unrestricted token if this would allow that user to avoid a burden that another user continues to carry. Likewise, a creator who relies on royalty enforcement should not see that revenue right weakened by a swap that technically transfers ownership while bypassing the term under which the asset was issued. These examples show that platform fairness depends on the preservation of digital property rights, not merely on the number of trades cleared. This platform-level perspective is consistent with economic accounts of blockchains as systems for reducing verification and networking costs (Catalini and Gans, 2020). Smart-contract theory emphasizes that blockchain rules can alter how platforms allocate control and residual claims (Cong and He, 2019).

Recent research on NFT exchange markets provides a useful theoretical starting point because it interprets modern NFTs as assets with contractual restrictions such as vesting periods, staking requirements, and royalty obligations. It also shows why equal-term consistency matters when an exchanged asset is encumbered by a term that should travel with the asset. This article extends that direction into a platform-oriented research framework. Rather than focusing only on an impossibility result in abstract mechanism design, the present paper asks how a platform can operationalize rights-aware fairness when large numbers of users, assets, and contract terms interact through a digital exchange interface. Matching-with-contracts research demonstrates that allocation cannot be separated from the terms attached to each feasible assignment (Hatfield and Kojima, 2010). Recent work on large language models and blockchain-based finance also shows that automated rights interpretation is becoming part of digital transaction infrastructure (Yang et al., 2025).

The research question is: how can an NFT exchange platform design allocation and analytics rules that preserve digital property rights while maintaining reasonable liquidity and fair access among heterogeneous users? This question is important for three reasons. First, NFT users are often asymmetrically positioned. Early buyers, creators, gamers, collectors, and liquidity providers may hold bundles of different rights even when they own tokens from the same collection. Second, platform rules are not neutral technical details. A matching rule that prioritizes volume may shift contract burdens to less informed users, while a rigid compliance rule may reduce trading opportunities for users whose assets are legitimate but heavily restricted. Third, NFT platforms

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increasingly mediate social and cultural relationships, so fair failures can damage trust beyond the immediate exchange transaction. Digital-platform studies show that platform governance is a central component of market design rather than a peripheral administrative layer (de Reuver et al., 2018). Platform ecosystem theory further explains why architecture and governance jointly shape who captures value in platform markets (Gawer, 2014).

This paper makes four contributions. First, it develops a conceptual model of digital property rights for contract-constrained NFTs, distinguishing ownership rights, transfer rights, revenue rights, utility rights, and exit rights. Second, it defines platform fairness for NFT exchange as a composite of term consistency, individual rationality, procedural transparency, exposure fairness, and waiting-time equity. Third, it proposes a rights-aware exchange architecture that combines contract metadata, eligibility filtering, equal-term cycle clearing, and fairness-weighted cycle selection. Fourth, it presents a scenario-based data analysis that compares four exchange rules across liquidity, consistency, and fairness outcomes. The analysis is not intended to measure a specific commercial platform; instead, it provides a controlled demonstration of how platform design choices affect different fairness dimensions. Web 3.0 research similarly frames decentralized platforms as environments where participation rights and governance rules co-evolve (Zhang and Lu, 2025).

The remainder of the paper is organized as follows. Section 2 reviews related research on NFTs, smart contracts, matching with contracts, and platform fairness. Section 3 develops the conceptual model of rights and fairness. Section 4 identifies platform fairness requirements. Section 5 presents the rights-aware exchange framework. Section 6 describes the data analysis design and simulation assumptions. Section 7 discusses empirical patterns and platform implications. Section 8 outlines implementation of architecture. Section 9 considers digital society implications. Section 10 presents limitations and future research directions. Section 11 concludes the paper. The FinTech literature further supports the need to connect exchange design with institutional risk and user protection (Kou and Lu, 2025).

2. Related Work

NFT research has documented the rapid emergence of tokenized digital objects, the concentration of trading activity, and the relationship between NFT prices, cryptocurrency market conditions, and social attention. Studies of Ethereum-based NFT markets show that trading networks often have strong inequality in visibility and value capture, with a small number of collections and participants accounting for a large share of activity. Finance-oriented studies further suggest that NFT pricing cannot be understood without considering crypto-asset volatility, scarcity narratives, and platform-specific attention cycles. These findings matter for fairness because market power and visibility are not evenly distributed. A platform rule that appears neutral at the transaction level may amplify unequal exposure at the ecosystem level. NFT pricing research on virtual land shows that token value is strongly shaped by platform-specific scarcity and ecosystem expectations (Dowling, 2022a). Crypto-asset research suggests that NFT prices may respond to cryptocurrency market conditions even when the traded object has distinct cultural meaning (Dowling, 2022b). DeFi-oriented NFT research treats NFTs as asset classes whose value depends on both creation and capture mechanisms (Schwiderowski et al., 2023).

A second stream of work examines NFTs as programmable rights bundles. The most distinctive feature of many NFTs is not merely on-chain uniqueness but the capacity to connect ownership records to usage rights, creator payments, community memberships, and external utilities. Legal and information-systems scholars have emphasized that token ownership does not automatically equal copyright ownership, commercial use permission, or full control over an associated digital file. The rights bundle must be interpreted through code, platform terms, and off-chain legal arrangements. From this perspective, NFT exchange is a rights-transfer problem, not a simple object-transfer problem. Crypto-token research clarifies that tokens work as sociotechnical systems whose meaning depends on the relation between code, holders, and governing infrastructure (Schwiderowski et al.,

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2024). Research on smart-contract templates supports the idea that reusable contractual patterns can reduce ambiguity in automated exchange settings (Clack et al., 2016). Legal scholarship on smart contracts also warns that code execution does not remove the need for contract interpretation (Savelyev, 2017).

Smart contract research shows why this rights-transfer problem cannot be solved only through informal platform policy. Smart contracts lower verification and enforcement costs by embedding conditional execution into code, but code is rarely a complete representation of social intent. Design choices about upgradeability, dispute resolution, oracle dependence, and governance remain crucial. In the NFT setting, a smart contract may record a royalty percentage, but the platform still determines whether a swap is permitted, how the user sees the term, whether an equivalent restriction must be matched, and whether a clearing rule favors liquidity or rights consistency. Technical execution and platform governance are therefore intertwined. Security research on Ethereum smart contracts shows that coded obligations remain vulnerable when assumptions about execution and incentives are incomplete (Atzei et al., 2017). Smart-contract vulnerability research demonstrates that contract automation requires systematic design and verification rather than reliance on deployment alone (Luu et al., 2016). Regulatory-technology research shows that code-based governance can become a form of rulemaking when technical rule's structure market behavior (De Filippi and Hassan, 2016).

Market design provides a formal background for thinking about exchanges of indivisible goods. The classic housing market model studies agents who each own an indivisible object and may exchange objects through rules such as top trading cycles. A central insight is that a clearing rule can produce allocations that are efficient, individually rational, and strategy-proof under certain assumptions. Matching with contracts generalizes this logic by allowing the object and the associated contract terms to be jointly considered. NFT markets are naturally close to this setting because a trade involves both a token and its attached terms. Classic allocation research on existing tenants shows why initial ownership matters when exchange rules are designed around preexisting rights (Abdulkadiroğlu and Sönmez, 1999).

However, NFT platforms add social and computational features that are not fully captured by classical allocation models. They include public transaction histories, creator communities, token-gated memberships, reputation systems, and algorithmic ranking. Platform studies stress that digital platforms act as governance structures that define participation rights, regulate complementors, and shape value capture among ecosystem actors. For NFT platforms, governance is not limited to admission and content moderation. It also includes the design of exchange mechanisms that determine how rights, obligations, liquidity, and exposure circulate through the ecosystem. Platform-evolution research shows that architecture and governance co-evolve as platform ecosystems mature (Tiwana et al., 2010). Research on digital platforms and infrastructures supports this view by showing that platform boundaries shape the responsibilities of users, developers, and operators (Constantinides et al., 2018).

Algorithmic fairness research offers a complementary perspective. It warns that apparently objective computational rules may encode structural bias, create unequal error rates, or reduce fairness to a single metric that does not fit the institutional context. In NFT exchange, fairness is not simply equal treatment of all requests. Treating a locked token and an unrestricted token identically may be unfair because the two assets carry different obligations. At the same time, restricting all locked-token holders too heavily may also be unfair because it traps users in illiquid positions. A rights-aware platform must therefore balance consistency and mobility rather than maximizing either one in isolation. Algorithmic fairness theory stresses that fairness depends on relevant similarity, not merely identical treatment (Dwork et al., 2012). Political-philosophy perspectives on machine-learning fairness show why a single metric rarely captures institutional fairness across heterogeneous users (Binns, 2018). Legal scholarship on data-driven discrimination explains why platform designers must examine downstream effects rather than only stated intent (Barocas and Selbst, 2016).

This paper connects these streams by treating platform fairness as a design problem in contract-constrained exchange. The key argument is that fairness should be evaluated at two levels. At the transaction level, a clear exchange should preserve the terms attached to the assets and leave each participant no worse off than retaining the current asset. At the ecosystem level, the platform should avoid concentrating on waiting time, failed requests, and visibility loss on users who hold restricted assets. This dual-level approach produces a richer design space than a binary choice between unrestricted swapping and strict compliance. Digital innovation research stresses that platform rules organize both technical possibilities and social participation (Nambisan et al., 2017). This sociotechnical interpretation is consistent with information-systems research on the organizing logic of digital innovation (Yoo et al., 2010).

3. Digital Property Rights in Contract-Constrained NFT Exchange

Digital property rights in NFT ecosystems are layered. The most visible layer is taken on ownership, which is the on-chain record that a wallet controls a particular token. A second layer is transferability, which determines whether and how the token may be moved to another wallet. A third layer is revenue participation, including royalties, resale fees, creator splits, or community treasury contributions. A fourth layer is utility access, which may include game items, token-gated events, identity badges, or rights to claim future benefits. A fifth layer is exiting rights, meaning the practical ability of a user to leave a position without being unfairly penalized by opaque restrictions. These layers may align in simple collections, but they often diverge in mature ecosystems. Digital transformation studies provide a broader basis for treating NFT exchange as an organizational change problem rather than a narrow software feature (Vial, 2019). Privacy economics is relevant because disclosure can improve transparency while also creating strategic and informational costs for users (Acquisti et al., 2016).

A contract-constrained NFT exchange occurs when at least one of these rights layers limits the admissible set of trades. For example, an NFT with a ninety-day vesting period may be technically visible in a wallet but not fully transferable. A gaming NFT may be tradeable only if it's associated in-game cooldown period has expired. A membership NFT may retain voting rights only if it is held for a minimum time. A creator pass may require royalty recognition whenever economic value changes hands, including in barter-like swaps. These terms create heterogeneity inside the asset class. Two tokens with similar floor prices may differ substantially in the rights and obligations attached to them.

The most important design implication is that a platform should not collapse all NFTs into a single exchangeable object type. A transaction interface may show two tokens as equivalent in estimated market value, but they may not be equivalent in rights status. If an exchange rule ignores this difference, it may produce unfair outcomes. One user might trade out of a restricted position and obtain an unrestricted asset, while another user accepts a restricted asset without receiving equivalent compensation or disclosure. Such a result undermines property-rights consistency and may also damage creator trust when royalty or utility conditions are diluted. Research on disparate impact shows that formally neutral decision rules may produce unequal consequences across groups (Chouldechova, 2017).

Table 1 summarizes the main restriction categories considered in this paper. The table is deliberately broader than a binary locked-versus-unlocked distinction because NFT platforms increasingly combine multiple forms of encumbrance. A restriction may be temporal, financial, behavioral, identity-based, or utility-related. Each form of restriction creates a different fairness risk and therefore requires a different analytic indicator. The purpose of the table is to translate legal and technical terms into platform design variables that can be monitored by an exchange engine. Opportunity-based fairness research clarifies why access to beneficial outcomes must be evaluated separately from overall accuracy or efficiency (Hardt et al., 2016). Model-reporting research provides a useful analogy for explaining exchange rules through standardized documentation (Mitchell et al., 2019).

Table 1. Contractual Restrictions and Property-Rights Risks in NFT Exchanges

Restriction category	Typical NFT expression	Rights affected	Fairness risk
Temporal lockup	Vesting period, cooldown period, delayed resale	Transfer and exit rights	Users may unknowingly receive assets with lower liquidity.
Royalty obligation	Creator royalty, community treasury fee, resale split	Revenue rights	Swaps may bypass creator compensation.
Utility condition	Staking requirement, game eligibility, token-gated benefit	Utility and access rights	Users may lose expected benefits after exchange.
Identity or membership rule	Allowlist status, verified holder condition, regional access	Participation rights	Some users may be excluded without clear disclosure.
Bundled governance term	Voting lock, delegated voting, DAO participation rule	Governance rights	Voting power may move without compatible responsibility.

Sociotechnical fairness research cautions that abstraction can hide the institutional contexts in which fairness claims operate (Selbst et al., 2019).

4. Platform Fairness Requirements

Platform fairness in contract-constrained NFT exchange is multidimensional. The first requirement is term consistency. The term attached to the received NFT should be compatible with the term under which the user gives up the original NFT. This does not mean that every trade must match identical labels in a narrow sense. In more realistic settings, terms may be equivalent by category or by restriction intensity. A thirty-day lockup may be treated differently from a one-year lockup, but a platform can define equivalence classes that make the rule transparent before users submit requests. Dataset documentation research supports the proposed emphasis on metadata provenance and rights visibility (Gebru et al., 2021).

A second requirement is individual rationality. Users should not be assigned an exchange they did not find acceptable. In a traditional financial market, price can express willingness to trade. In an NFT exchange ecosystem, willingness also depends on identity, utility, rarity, creator reputation, and community meaning. A matching interface should therefore allow users to express acceptable assets, acceptable term types, and unacceptable combinations. Individual rationality protects users against being cleared into a technically compliant but personally undesirable token. Blockchain-governance research demonstrates that governance should be understood as a system-level property rather than a single voting procedure (Laatikainen et al., 2023).

A third requirement is creator-rights compliance. Many NFT ecosystems rely on the expectation that creators will retain some revenue participation or that community treasuries receive fees from secondary activity. Whether royalties should be enforced universally is debated, but a platform that advertises creator-rights preservation must encode that commitment into its exchange design. Otherwise, swaps may become a route for avoiding revenue obligations. Compliance should not be limited to sale transactions; it should also cover barter exchanges, bundled exchanges, and off-chain settlements connected to on-chain transfers. Organizational research on blockchain governance shows that decentralized collaboration requires explicit coordination mechanisms (Lumineau et al., 2021).

A fourth requirement is exposure fairness. NFT platforms shape attention through listing order, recommendation widgets, collection pages, and liquidity pools. If restricted assets are hidden too aggressively, their holders may face a silent liquidity penalty. If restricted assets are shown without clear labels, uninformed users may bear unexpected obligations. A fair platform should expose restrictions clearly while avoiding design choices that stigmatize legitimate restricted assets. The fairness issue is not whether every asset receives identical ranking, but whether ranking differences are justified, disclosed, and auditable. Systematic reviews of blockchain applications suggest that governance, identity, and traceability remain recurring implementation concerns (Casino et al., 2019).

A fifth requirement is waiting-time equity. Contract-constrained matching can reduce the number of immediately available counterparties. If the platform simply prioritizes the easiest unrestricted swaps, users with restricted assets may remain unmatched for long periods even when mutually beneficial trades exist. Waiting-time equity requires the exchange engine to monitor whether particular user groups or term classes face systematically longer delays. A fairness-aware clearing rule can then give moderate priority to under-served term classes without allowing them to bypass property-rights constraints. Research on automated smart-contract generation supports the need for machine-readable representations of institutional rules (Frantz and Nowostawski, 2016).

Table 2 translates these requirements into observable platform metrics. The table is not of a universal standard; it is a design template for platforms that need to make fairness operational. Each metric should be computed at the level of asset classes, user groups, and contract terms. The platform should publish aggregated metrics in a transparency report so users can evaluate whether the exchange rule is consistently preserving rights or merely claiming to do so. Comparative fairness research indicates that fairness interventions must be evaluated against multiple outcome dimensions (Friedler et al., 2019). A broader survey of bias and fairness also supports the use of multidimensional fairness diagnostics rather than a single fairness score (Mehrabi et al., 2021).

Table 2. Platform Fairness Requirements and Observable Metrics

Fairness dimension	**Operational question**	**Example metric**	**Governance use**
Term consistency	Do received and surrendered terms remain compatible?	Inconsistency incidents per 1,000 requests	Detect rights-eroding exchange patterns.
Individual rationality	Did each user receive an acceptable option?	Assignments outside declared acceptable set	Protect users from unwanted clearing.
Creator-rights compliance	Are royalty and revenue terms preserved?	Royalty-compliant transfer share	Maintain creator trust and platform commitments.
Exposure fairness	Are restricted assets visible without being hidden or mislabeled?	Listing exposure by term class	Audit ranking and search design.
Waiting-time equity	Are some term classes delayed systematically?	Waiting-time Gini coefficient	Guide fairness-weighted cycle selection.

5. Rights-Aware Exchange Framework

The proposed framework, named Rights-Aware Fair Exchange (RAFE), has four components: rights metadata, eligibility verification, term-consistent cycle clearing, and fairness-weighted selection. Rights metadata stores the current state of each NFT in a standardized schema. At minimum, the schema records taken identity, collection identity, ownership status, transferability, lockup status, royalty condition, utility condition, and any platform-specific restrictions. Metadata should be machine-readable, but it should also be user readable. A platform fails procedurally if it enforces a hidden term that ordinary users cannot see before submitting preferences. Cryptocurrency exchange-rate research shows that market information and technological features jointly influence token-market behavior (Li and Wang, 2017).

Eligibility verification determines which asset-term combinations may enter the exchange pool. This step screens out transfers that would violate smart-contract restrictions, off-chain licensing commitments, sanctions rules, or explicit collection policies. Eligibility verification differs from matching. It does not decide who should receive which asset; it only defines the feasible set. Separating eligibility from matching improves accountability because a user can see whether a failed exchange request was impossible due to rights restrictions or merely not selected in the current clearing round. Bitcoin market-efficiency research provides a useful caution that decentralized asset markets may remain statistically inefficient for extended periods (Urquhart, 2016).

Term-consistent cycle clearing is the allocation core of the framework. Users submit ranked acceptable exchange options, each option including an asset class and a term class. The platform searches for cycles of mutually acceptable transfers within compatible term categories. When a cycle is cleared, each participant receives an acceptable NFT and gives up the originally committed NFT under a term that is consistent with the received term. The cycle structure fits blockchain implementation because all transfers in a cycle can be packaged into one atomic transaction. If any transfer fails, the entire cycle fails, which prevents partial execution and reduces settlement risk. Cryptocurrency return research shows that digital asset markets have risk structures that differ from conventional asset classes (Liu and Tsyvinski, 2021). Blockchain research has identified open challenges around scalability, market design, and institutional adoption (Lu, 2019).

Fairness-weighted selection is added when multiple term-consistent cycles are feasible. A purely efficiency-oriented rule would clear the cycle with the highest immediate value, the largest number of participants, or the lowest gas cost. Those rules may be attractive, but they can repeatedly favor unrestricted or high-visibility collections. RAFE instead scores feasible cycles using a composite of expected welfare, waiting-time reduction, term-class balance, and creator-rights compliance. The weight assigned to each component should be publicly disclosed. The platform may allow community governance to adjust weights, but it should not change them opportunistically during a clearing round. Research on cryptocurrency arbitrage shows that fragmented platforms can create persistent price and access differences (Makarov and Schoar, 2020).

Figure 1 presents the RAFE ecosystem as a layered platform model. The figure intentionally avoids a linear arrow flow because NFT exchange governance is not a simple one-way process. User preferences, asset metadata, rights restrictions, market analytics, and governance choices interact continuously. The platform governance layer defines the auditability and dispute-resolution environment. The digital property-rights layer records the rights bundle. The matching layer applies term-consistent rules. The analytics layer monitors outcomes. The user and asset layer grounds the system in real participation rather than abstract tokens. Dynamic research on Bitcoin inefficiency reinforces the need to evaluate platform outcomes over time rather than through a single snapshot (Bariviera, 2017). Transaction-fee research shows that protocol-level costs can reshape user behavior and market participation (Easley et al., 2019).

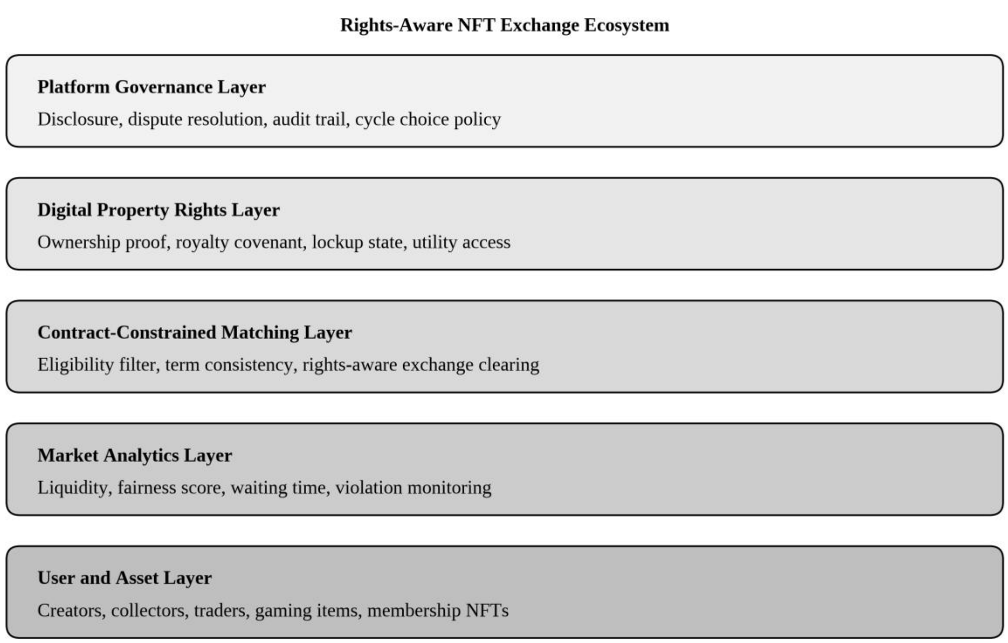

Figure 1. Layered architecture of a rights-aware NFT exchange ecosystem without linear transfer arrows.

6. Data Analysis Design

To evaluate the practical trade-offs of rights-aware platform design, this paper constructs a scenario-based dataset

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of 12,000 simulated exchange requests. The simulation is not a claim about a specific commercial NFT platform. It is a controlled analytic exercise designed to show how different exchange rules behave when the proportion of restricted assets, user preferences, and liquidity conditions vary. Scenario simulation is appropriate here because real NFT platforms rarely disclose complete preference rankings, failed exchange requests, or hidden compliance filters. A transparent simulation makes assumptions visible and allows platform designers to adapt the structure to their own data. Research on stablecoin-related market dynamics shows how hidden dependencies can distort apparently independent crypto-asset markets (Griffin and Shams, 2020).

The simulated ecosystem contains five NFT segments: digital art, gaming items, membership tokens, creator passes, and metaverse land. Each segment contains four term classes: unrestricted transfer, thirty-day lockup, ninety-day lockup, and royalty-bearing transfer. Users differ in their preference for liquidity, utility, creator support, and rarity. The simulation generates ranked acceptable options for each user and then applies four exchange rules. The first rule, open swap, clears value-compatible exchanges without term consistency. The second rule, compliance-only, blocks legally infeasible trades but does not search for fair balanced cycles. The third rule, equal-term cycle, clears only term-consistent cycles. The fourth rule, fairness-weighted equal-term, clears term-consistent cycles while giving moderate priority to under-served term classes and long-waiting users. A systematic analysis of cryptocurrencies as financial assets supports the need to consider volatility and cross-market spillovers in NFT exchange (Corbet et al., 2019).

Table 3 reports the simulation settings. The most important parameter is restriction intensity, defined as the share of listed NFTs carrying a nontrivial transfer, royalty, or utility condition. The analysis varies restriction intensity from 0.10 to 0.85 because platform problems become more severe as restrictions move from rare exceptions to ordinary features of the asset base. The simulation also varies user risk tolerance and segment concentration. These choices allow the analysis to observe whether a clearing rule remains fair when the market becomes less liquid and more contractually heterogeneous. Cryptocurrency governance research shows that technical protocol choices and economic incentives must be analyzed together (Böhme et al., 2015). Security research on cryptocurrencies highlights the limits of purely technical trust in adversarial market environments (Bonneau et al., 2015).

Table 3. Scenario-Based Simulation Settings

Parameter	Value used in analysis	Design rationale
Exchange requests	12,000 generated requests	Large enough to compare rules across repeated clearing windows.
NFT segments	Art, gaming, membership, creator pass, metaverse land	Reflects heterogeneous sources of token utility and rights.
Term classes	R, L30, L90, royalty-bearing	Captures unrestricted, temporal, and revenue restrictions.
Restriction intensity	0.10 to 0.85	Tests markets where restrictions are rare versus common.
Clearing rules	Open swap; compliance-only; equal-term cycle; fairness-weighted equal-term	Represents increasing degrees of rights awareness.
Outcome measures	Completion, inconsistency, IR failure, creator compliance, waiting-time inequality, fairness score	Links liquidity and fairness rather than measuring only volume.

The analysis uses six outcome measures. Completed exchange rate measures the percentage of requests matched in a clearing window. Term inconsistency incidents count cases in which the received and surrendered terms are incompatible. Individual-rationality failure measures cases in which a user receives an assignment outside the declared acceptable set. Creator-rights compliance measures whether royalty and revenue terms are preserved. Waiting-time inequality measures whether some term classes wait much longer than others. The composite fairness score aggregates term consistency, individual rationality, creator compliance, exposure balance, and waiting-time equity into a single index from 0 to 100. The composite score is useful for comparison, but it should never replace the underlying metrics in platform reporting. Recent DeFi research frames decentralized finance as a broader shift in how digital markets coordinate assets and services (Xu et al., 2024).

Figure 2 compares the completed exchange rate and the composite fairness score for the four exchange rules. The open-swap rule produces the highest completion rate because it ignores many contractual differences. Yet it receives the lowest fairness score because it creates frequent term inconsistencies. The compliance-only rule improves fairness but still performs poorly on waiting-time equity because it removes infeasible trade without actively searching for balanced alternatives. The equal-term cycle rule sacrifices some completion rate but sharply improves fairness. The fairness-weight rule produces the best fairness score while recovering part of the liquidity lost under strict equal-term clearing. DeFi market research highlights that smart-contract-based finance requires both technical settlement and economic governance (Schär, 2021). Blockchain-adoption research in supply chains shows that implementation barriers often arise from governance and organizational readiness rather than from code alone (Queiroz and Wamba, 2019).

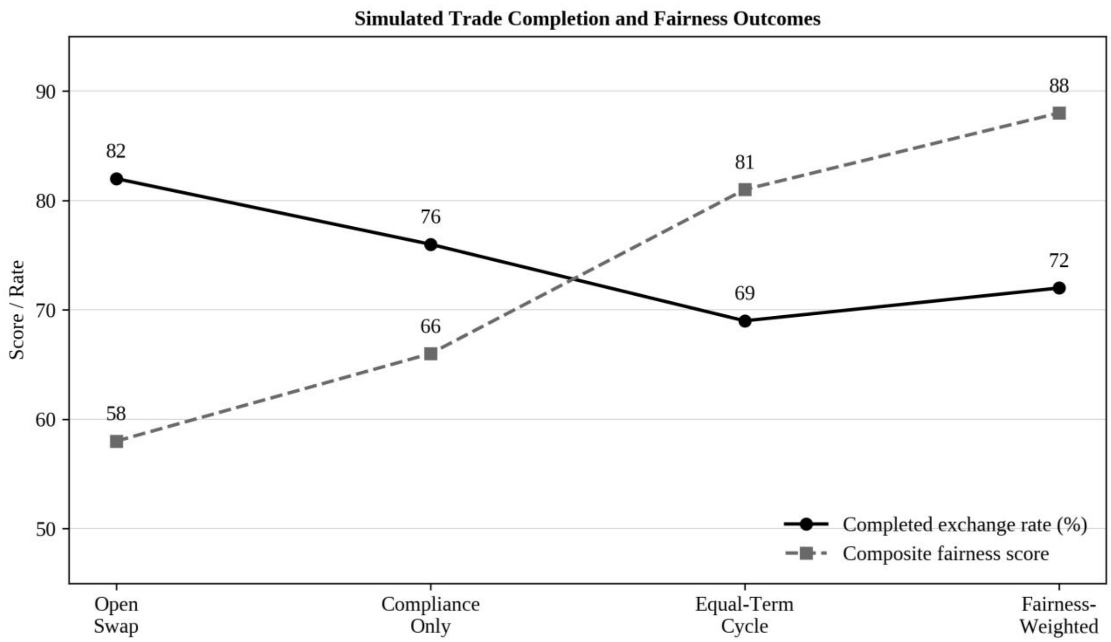

Figure 2. Completed exchange rate and composite fairness score across four exchange rules in the simulated ecosystem.

7. Results and Discussion

The most direct result is that liquidity and fairness do not move together automatically. Open swapping clears 82 percent of simulated requests, but it creates a weak rights environment because restricted obligations can be displaced across users. This result is important because platform growth metrics often reward volume, speed, and apparent liquidity. A high transaction count may hide the fact that the exchange rule weakens creator's rights, transfers obligations without adequate symmetry, or exposes less informed users to unexpected restrictions. In contract-constrained ecosystems, transaction volume is an incomplete performance measure. Sustainable supply-chain research shows that blockchain value depends on trust, traceability, and stakeholder alignment (Saberi et al., 2019).

The compliance-only rule shows the limitation of a narrow legalistic approach. It blocks the most obvious violations and reduces term inconsistency, but it does not solve allocation fairness. Many users with restricted assets remain in the queue because the rule does not actively search for exchange cycles that are both feasible and balanced. Compliance without matching intelligence can therefore create a different fairness problem: users are protected from invalid trade but receive little support in finding valid trades. This may be experienced as platform neglect, especially by creators and early supporters whose assets are more likely to include restrictions. A theory-based blockchain supply-chain framework supports the argument that technology adoption must be tied to clear organizational action (Treiblmaier, 2018).

The equal-term cycle rule performs substantially better on property-rights consistency. It recognizes that a trade is fair only when the received and surrendered terms are compatible. This is consistent with the intuition of matching with contracts, in which an allocation cannot be evaluated by the object alone. The improvement in fairness is achieved with a completion rate of 69 percent, lower than open swapping but still meaningful. For platforms that emphasize community trust, this trade-off may be acceptable. An exchange that clears fewer trades but preserves obligations may be more sustainable than an exchange that maximizes short-term volume at the cost of erosion of rights. Society-in-the-loop research provides a normative basis for involving affected communities in the governance of automated rules (Rahwan, 2018).

The fairness-weight rule offers the best overall balance in the simulation. It completes 72 percent of requests, only three percentage points higher than equal term clearing, but its composite fairness score rises from 81 to 88. The improvement comes from prioritizing cycles that reduce waiting-time inequality and improve term-class balance without violating property-rights consistency. This result suggests that the platform should not stop after defining feasibility. Once feasible cycles are identified, the choice among them remains a governance decision with distributional consequences. Fairness can be improved at this second stage without reopening the door to rights violations. Research on illicit cryptocurrency activity shows why compliance analytics must be integrated into digital-asset platforms (Foley et al., 2019).

Table 4 reports the comparative performance of the four rules. The term-inconsistency rate is particularly revealing. Open swapping produces 31.4 incidents per 1,000 requests, while fairness-weighted equal-term clearing produces 3.2 incidents. The waiting-time Gini coefficient falls from 0.41 under compliance-only filtering to 0.24 under fairness-weighted clearing. At the same time, creator-rights compliance rises to 98.5 percent. These values demonstrate the central argument of this article: fair NFT exchange design requires a rights-aware allocation rule and a fairness-aware cycle selection rule. Ethereum graph analysis demonstrates that transaction networks can reveal behavioral patterns that are not visible from isolated transfers (Chen et al., 2020). Bitcoin payment-network research shows that address-level data can support empirical analysis while also raising privacy and interpretation concerns (Meiklejohn et al., 2013).

Table 4. Comparative Performance of Exchange Rules in the Simulated Ecosystem

Exchange rule	Completed requests (%)	Term inconsistency / 1,000	IR failure / 1,000	Creator compliance (%)	Waiting-time Gini	Fairness score
Open swap	82	31.4	7.8	86.2	0.34	58
Compliance-only	76	17.6	3.1	93.0	0.41	66
Equal-term cycle	69	4.9	1.4	97.6	0.29	81
Fairness-weighted equal-term	72	3.2	1.1	98.5	0.24	88

Information-systems research on blockchain argues that business value depends on the interaction between distributed ledgers and organizational design (Beck et al., 2017).

Figure 3 examines how term-consistency risk changes as the share of restricted NFTs rises. The open-swap rule becomes increasingly fragile as restriction intensity increases. This is expected because the rule treats contractual heterogeneity as a secondary attribute, so each additional restricted asset increases the probability of an inconsistent exchange. Compliance-only filtering improves the outcome but still leaves substantial residual risk when the market is highly restricted. Equal-term and fairness-weighted rules remain comparatively stable, indicating that term consistency becomes more valuable as the ecosystem matures and restrictions become common. Blockchain-economy governance research provides a framework for evaluating rules, actors, and decision rights in decentralized markets (Beck et al., 2018). Research on blockchain contracting and DAOs shows that automated governance can reduce some transaction costs while introducing new coordination risks (Murray et al., 2021).

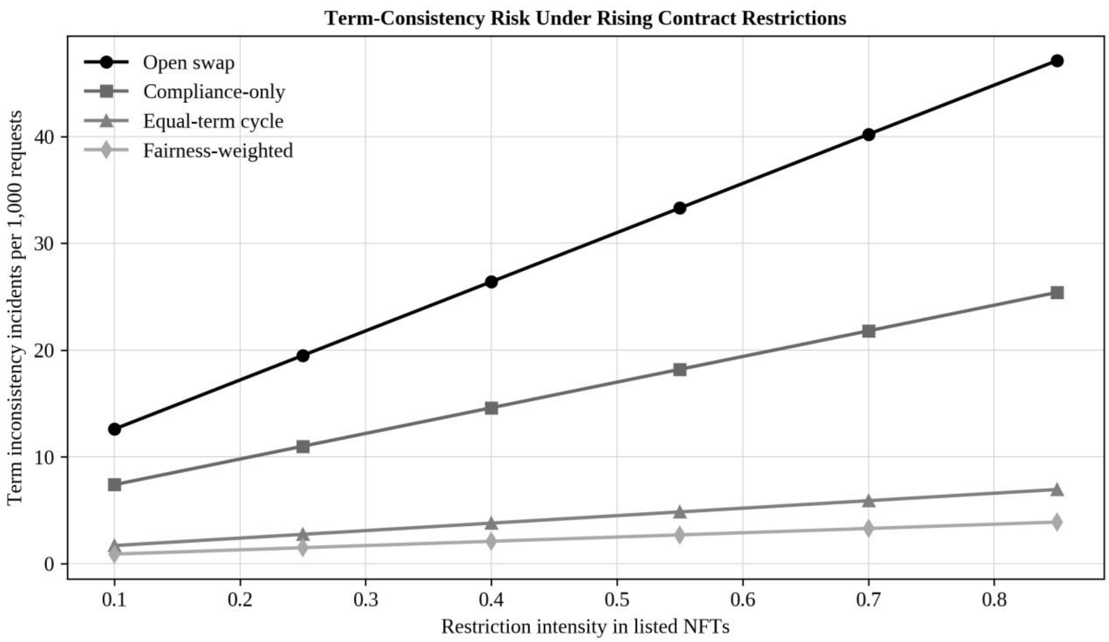

Figure 3. Simulated term-consistency incidents under increasing restriction intensity.

Figure 4 presents a match ability heat map by segment and term class. The simulated results show that unrestricted assets are easier to match in every segment, but the gap varies. Gaming and creator-pass assets have relatively high match ability under lockup and royalty terms because users in these segments often value ongoing utility and creator relationships. Metaverse land has lower match ability across all term classes because values are more heterogeneous and users are more sensitive to liquidity. This pattern underscores the need for segment-specific governance. A uniform exchange rule may be easy to communicate, but platforms should monitor whether its effects differ across communities. Discrimination-measurement research supports the use of empirical diagnostics to identify unfair outcomes even when rules appear formally neutral (Žliobaitė, 2017). Blockchain applications in Industry 4.0 show that distributed ledgers increasingly operate as infrastructure for complex, rights-bearing systems (Chen et al., 2024). Broad surveys of blockchain challenges identify scalability, governance, privacy, and interoperability as persistent constraints (Zheng et al., 2018).

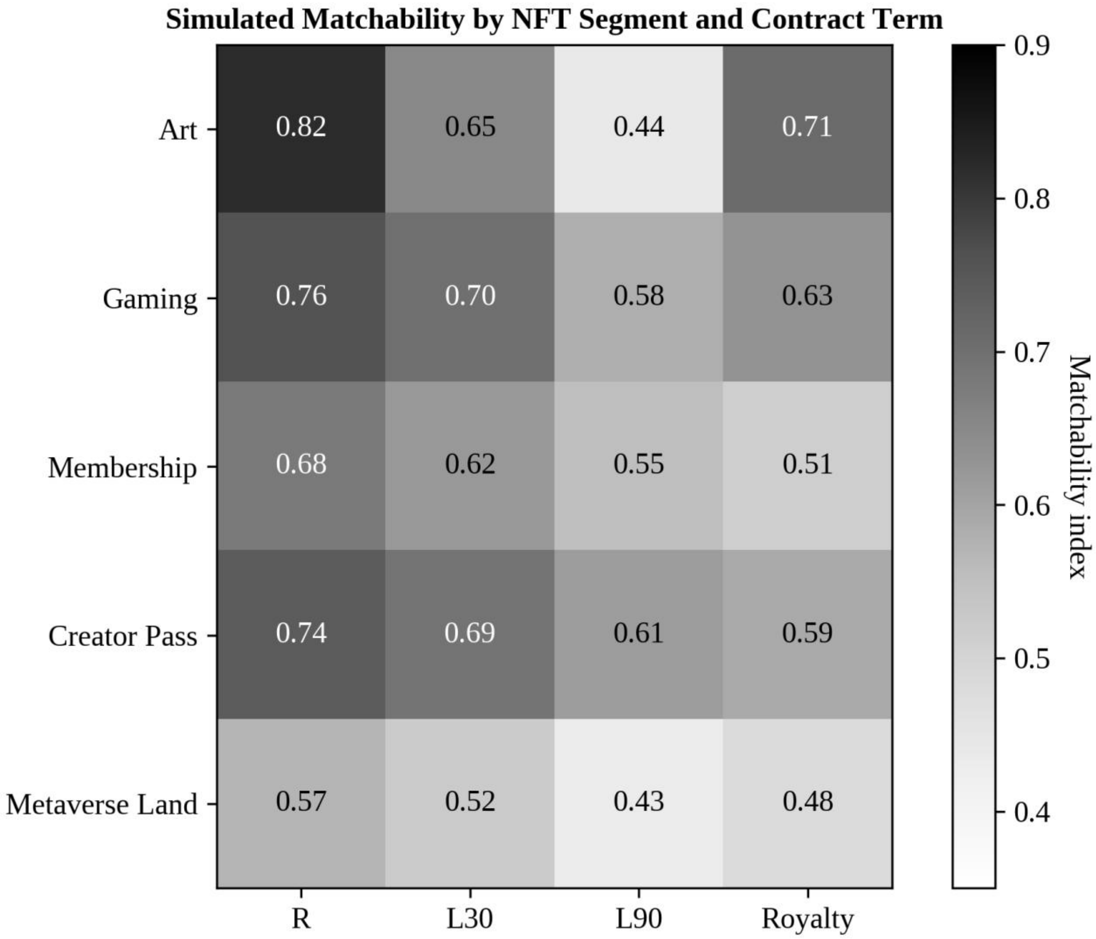

Figure 4. Simulated hatchability index by NFT market segment and contract term class.

The results have several implications for platform designers. First, rights metadata should be treated as infrastructure, not as optional listing information. Without accurate metadata, no matching rule can distinguish a rights-preserving exchange from a rights-eroding exchange. Second, fairness reporting should include failed and delayed requests, not only successful transactions. A platform may look efficient if it reports only completed trades, but fairness problems often appear in the queue. Third, cycle selection should be auditable. Users do not need to see private preference rankings, but they should know which rule selected one feasible cycle over another. Fourth, platforms should offer different disclosure layers: a simple label for ordinary users and a full-term record for advanced users, auditors, and creators. Security research on proof-of-work blockchains illustrates why performance and security cannot be separated in decentralized infrastructure design (Gervais et al., 2016).

The findings also have implications for regulators and standards bodies. Contract-constrained NFT exchange raises questions that sit between consumer protection, securities-like disclosure, intellectual property licensing, and digital platform governance. Regulators should avoid treating every NFT transfer as either a simple sale or a prohibited workaround. The more useful approach is to ask whether the platform has a coherent rights-preservation process, whether restrictions are understandable to users, and whether exchange outcomes are monitored for fairness. Technical standards for rights metadata could make this evaluation easier across platforms. Research on blockchain scaling shows that throughput constraints can directly affect platform fairness when queues become congested (Croman et al., 2016).

There are also risks. Fairness-weighted clearing can be misused if the weights are opaque or if platform operators adjust them to favor insiders. A rule designed to reduce waiting-time inequality might become a tool for discretionary preference. The solution is not to abandon fairness weighting, but to pair it with transparency. The platform should publish the weight categories, change them only through a documented governance process, and store clearing logs for third-party audit. Rights-aware fairness is credible only when the platform can explain its own decisions. Logic-based smart-contract research supports the proposed separation between formal rules and governance interpretation (Idelberger et al., 2016).

8. Practical Implementation Architecture

A practical implementation of RAFE can be divided into six modules. The first module is rights ingestion, which reads smart-contract events, collection metadata, royalty registries, token-gated utility rules, and platform-specific terms. The second module is a rights normalization service that translates heterogeneous metadata into a standardized term taxonomy. The third module is the user preference interface, where users select acceptable assets, term classes, and constraints. The fourth module is an eligibility engine that removes infeasible exchange options before matching. The fifth module is a cycle-clearing engine that identifies feasible term-consistent cycles. The sixth module is an analytics and audit module that records outcomes, failed requests, waiting time, and fairness metrics. Large-scale smart-contract analysis shows that automated markets can contain exploitable contract patterns that require systematic auditing (Nikolić et al., 2018).

Blockchain implementation should minimize unnecessary on-chain computation. Rights ingestion and cycle search may be performed off-chain by a verifiable service because large preference graphs can be expensive to process directly in a smart contract. However, the final clearing instruction should be submitted on-chain as an atomic transaction or a set of linked atomic swaps. The smart contract should verify token ownership, current restriction state, royalty payment logic, and user signatures. If these conditions are not satisfied at execution time, the clearing transaction should revert. This architecture balances computational efficiency with settlement integrity. Blockchain-IoT security research is relevant because NFT utility increasingly interacts with devices and external verification systems (Xu et al., 2021).

The user interface is a critical fairness component. A platform should not ask users to rank assets without showing restriction labels. A clear interface would show an asset card with ownership status, lockup status, royalty condition, utility condition, estimated waiting time, and a plain-language explanation of what the user gives up and receives. The interface should also warn users when a preference ranking creates a low chance of matching because it excludes equivalent term classes. These warnings should be informational rather than coercive; users should remain free to choose stricter preferences. Management-analytics research on blockchain emphasizes that blockchain should be evaluated as a managerial and analytical infrastructure, not merely as a ledger (Lu, 2018).

Table 5 provides an implementation checklist for platform teams. The checklist links technical controls to fairness goals. It can be used in product design reviews, smart-contract audits, or transparency reports. The main lesson is that fairness must be built into the full exchange pipeline. It is not enough to choose a fair matching algorithm if metadata is incomplete, if users cannot understand restrictions, or if outcomes are never audited. Corporate-governance research on blockchains highlights the potential and limits of distributed records for accountability (Yermack, 2017). DeFi research shows that composable financial protocols create new forms of systemic and transactional risk (Werner et al., 2021).

Table 5. Implementation Checklist for Rights-Aware NFT Exchange Platforms

Module	Required control	Fairness contribution
Rights ingestion	Read smart-contract state, royalty registry, utility metadata, and platform terms.	Prevents matching based on incomplete rights information.
Rights normalization	Translate heterogeneous restrictions into a documented term taxonomy.	Makes term equivalence visible and auditable.

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Preference interface	Let users declare acceptable assets and acceptable term classes.	Supports individual rationality and informed consent.
Eligibility engine	Remove infeasible trades before cycle search.	Separates legal feasibility from allocation choice.
Cycle-clearing engine	Clear compatible cycles through atomic settlement.	Preserves property rights and reduces partial-execution risk.
Analytics and audit	Report completion, failed requests, waiting time, and consistency incidents.	Turns fairness from a claim into measurable governance.

9. Governance Implications for Digital Society

The analysis also has implications for digital society beyond the narrow NFT market. Contract-constrained exchange illustrates how platform rules increasingly govern programmable forms of property. When rights are represented in code, users may assume that the platform is merely executing neutral technical instructions. In reality, the platform chooses which rights are visible, which terms are treated as equivalent, which exchanges are feasible, and which feasible cycles are prioritized. These choices shape economic opportunity and social trust. A rights-aware exchange platform is therefore a governance institution, not only a software intermediary. Research on blockchain-enabled internal auditing supports the use of immutable logs and verification trials for accountability (Wu et al., 2025).

For creators, rights-aware fairness offers a way to protect continuing participation without making secondary markets unusable. Many creators' support transferability because it increases community reach and asset value, but they also fear that secondary markets will detach tokens from the commitments that financed the original project. A term-consistent exchange rule helps address this concern by preserving revenue and utility conditions when assets move. At the same time, fairness-weight clearing prevents restricted creator-linked assets from becoming permanently illiquid. This balance is especially relevant for smaller creator communities that cannot rely on large market makers or constant attention from speculative buyers. Information-systems research on blockchain implementation stresses that adoption must address governance, interoperability, and organizational fit (Lu, 2022).

For collectors and ordinary users, the framework emphasizes informed mobility. A user should not need to read smart-contract bytecode or search multiple websites to understand whether a token is locked, royalty-bearing, or utility-limited. The platform should translate these restrictions into clear terms before the user ranks exchange options. Fairness in this context is partly cognitive fairness: users with less technical knowledge should not be systematically disadvantaged. A rights-aware interface can reduce information asymmetry by presenting restrictions in a concise label while preserving access to detailed metadata for users who want verification. Recent blockchain-trend research supports the conclusion that future token markets will require interdisciplinary governance frameworks (Zheng and Lu, 2022).

For platform operators, the framework reframes compliance as a source of competitive advantage. Some marketplaces may believe that reducing restrictions increases liquidity and therefore platform growth. That may be true in the short run, but a platform that repeatedly weakens creator's rights or hides obligations may lose legitimacy. Users may migrate to platforms that offer clearer rights guarantees, especially when the assets represent community membership, game progress, or professional identity. Fairness metrics can therefore become part of platform strategy. They show that the platform is not only processing trades but also maintaining the institutional quality of the ecosystem.

For auditors and researchers, the proposed metrics create a bridge between mechanism design theory and platform accountability. Rather than asking only whether a mechanism is efficient or strategy-proof under ideal assumptions, auditors can ask whether actual platform outcomes show consistent rights preservation, reasonable waiting-time equity, and transparent term treatment. This empirical orientation is important because platform fairness failures are often visible only in aggregate. A single trade may look acceptable, while thousands of trades reveal that a particular term class faces persistent delay or that royalty-bearing tokens receive less exposure than comparable unrestricted tokens.

For policymakers, contract-constrained NFT exchange suggests that disclosure and auditability may be more effective than blanket restrictions. NFT markets are too diverse for a single rule that treats all tokens as either simple collectibles or regulated financial products. A rights-aware approach asks whether the platform maintains accurate rights metadata, whether users understand restrictions before exchange, whether creators' rights are honored when promised, and whether fairness metrics are published. This does not remove the need for legal oversight, but it gives regulators a more precise basis for evaluating platform conduct.

The social value of NFTs remains contested, and many projects have failed to deliver meaningful utility. Nevertheless, the governance problem examined in this article is likely to persist even if the term NFT becomes less fashionable. Tokenized memberships, digital product passports, game assets, intellectual property licenses, and data-access credentials all involve programmable rights that may be exchanged under restrictions. The fairness problem is therefore broader than one asset class. It concerns how digital platforms will manage rights-bearing objects when ownership, access, revenue, and identity are encoded together.

A final implication is that fairness should be designed before the market becomes large. Retrofitting term consistency after users have learned to exploit unrestricted swapping is difficult. Retrofitting metadata standards after collections have issued incompatible contracts is also costly. Platforms that anticipate contract-constrained exchange from the beginning can define term taxonomies, create audit logs, educate users, and align creators' expectations early. Preventive governance is more credible than corrective governance because it reduces the number of users who are harmed before rules are clarified. Research on decentralized-exchange wash trading shows that market-integrity controls are essential when trading behavior is publicly visible but strategically manipulable (Victor and Weintraud, 2021).

Data governance is central to this preventive approach. Rights metadata should have version histories so that users and auditors can determine which terms applied when a preference was submitted, when a cycle was selected, and when the atomic transfer executed. Without versioning, a platform may be unable to explain why a trade that looked feasible in the interface failed at settlement time. Versioning also protects users when collection owners update contract metadata after a token has already entered the exchange pool. A robust platform should freeze the relevant rights snapshot for the clearing window while still checking final execution conditions on-chain. Flash-loan research demonstrates how rapid composability can convert small design weaknesses into platform-level attacks (Qin et al., 2021).

The framework also encourages platforms to separate fairness dashboards from marketing dashboards. Marketing dashboards emphasize floor prices, sales volume, trending collections, and unique holders. Fairness dashboards should emphasize failed requests, blocked reasons, term-class waiting times, royalty-preservation rates, and complaint resolution outcomes. Both dashboards are useful, but they answer different questions. Combining them into a single performance page risks hiding fairness problems behind growth metrics. Publicly separating these dashboards would signal that the platform treats rights preservation and market activity as distinct but equally important dimensions of ecosystem health. Digital economics research further explains why platform rules can alter incentives, search costs, and market power (Goldfarb and Tucker, 2019).

10. Limitations and Future Research

This study has several limitations. First, the data analysis is based on a controlled simulation rather than

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proprietary platform logs. The simulation is useful for isolating design effects, but it cannot capture every behavioral pattern in real NFT communities. Future research should partner with platforms that can provide anonymized data on failed requests, exchange queues, collection-specific restrictions, and user preference revisions. Such data would allow researchers to estimate fairness effects more precisely and to identify whether communities are systematically disadvantaged by existing exchange rules.

Second, the framework focuses on exchange among single NFTs. Many real transactions involve bundles, partial payments, lending, collateralized positions, or cross-chain transfers. Bundled exchange creates additional complexity because a user may receive an unrestricted asset and a restricted asset in the same package. The fairness question then becomes whether the bundle as a whole preserve's rights equivalence. Future work can extend the framework to multi-asset packages and test whether fairness-weighted clearing remains computationally feasible at scale.

Third, the paper treats term equivalence as a platform-defined taxonomy. This is necessary for practical design, but it creates governance questions. Who decides whether a thirty-day lockup is equivalent to a royalty obligation? Should creators, collectors, or taken holders vote on equivalence classes? Can equivalence differ across collections? These questions cannot be answered by technical analysis alone. They require institutional design, community governance, and legal interpretation.

Fourth, the article does not claim that every NFT royalty or restriction is normatively desirable. Some restrictions may protect creators and communities, while others may be confusing, excessive, or anti-competitive. Rights-aware fairness means that whatever restrictions the platform recognizes should be handled transparently and consistently. It does not mean that platforms should enforce every restriction without scrutiny. Future research should examine how to distinguish legitimate rights protection from restrictions that unfairly reduce user autonomy.

Finally, strategy-proofness remains an open challenge. A platform that allows users to submit preferences may be vulnerable to manipulation if sophisticated users can predict the clearing rule. Fairness weighting may reduce some inequalities while creating new incentives to appear disadvantaged. Future studies should evaluate manipulation-resistant variants, randomized cycle selection, commit-reveal preference submission, reputation penalties for repeated strategic withdrawals, and user education tools. The goal is not to eliminate all strategic behavior, which may be impossible, but to design a platform where manipulation does not dominate rights preservation and fair access.

11. Conclusion

NFT exchange platforms increasingly mediate assets that contain contractual restrictions, social meanings, creator rights, and utility claims. In this environment, platform fairness cannot be reduced to fast matching or high trading volume. A fair exchange rule must preserve digital property rights, respect user preferences, maintain creator-rights commitments, and avoid concentrating liquidity burdens on holders of restricted assets. The central argument of this paper is that NFT exchange should be designed as contract-constrained allocation, not as unrestricted token swapping.

The Rights-Aware Fair Exchange framework developed in this article offers a practical way to connect digital property rights and platform fairness. By combining rights metadata, eligibility verification, term-consistent cycle clearing, and fairness-weighted selection, the framework allows platforms to reduce term-inconsistency risk while maintaining meaningful liquidity. The scenario-based data analysis shows that unrestricted swapping produces high completion rates but weak fairness outcomes, whereas fairness-weighted equal-term clearing substantially improves term consistency, creator-rights compliance, and waiting-time equity with only moderate liquidity costs.

The broader contribution is to shift the discussion of NFT platforms from speculation and asset pricing toward governance and rights infrastructure. As tokenized assets become more complex, platforms will need auditable rules that explain not only what trades possible but also why particular trades are fair. This requires interdisciplinary work across information systems, economics, smart-contract engineering, law, and algorithmic fairness. Contract-constrained NFT exchange is therefore not a niche design problem. It is an early example of how digital platforms will govern programmable property rights in increasingly automated markets.

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