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Real Estate Tokenization with Blockchain Solution

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Abstract

Indonesia with large population needs huge property investments to support its economic growth. Real Estate Investment Trusts (REITs) or Indonesian DIRE has become alternative essential investment instruments to finance major property projects and provide job employments. Indonesian Stock Exchange (IDX) and Financial Service Authority (OJK) have encouraged the DIRE products as its strategic growth plan and links them with overseas market frameworks. Although it sounds promising, the DIRE faces market hurdles such as lack of high-quality asset offerings, low market penetration and regulatory inefficiency. DIRE faces multiple regulatory paperworks in several supervisory bodies such as: OJK, IDX, Commodity Futures Trading Regulatory Agency (*bappepti*), National Land Agency (*BPN*), Directorate General of Taxes (*DJP*), and local government (*Pemda*). Studies have examined the use of tokenization REITs with blockchain solutions allow creating direct fractional ownership property in tokenized real estate and 24/7 global trading on digital asset exchanges. It supports reducing operation costs (including acquisition costs), ease of promoting high-quality assets, harmonizing regulations and producing compliance reports. With global coverage capability, the blockchain solution allows lowering regulatory arbitrage risks, restricting transfer to eligible investors only based on jurisdiction-specific roles. To promote further foreign investments, Indonesian authority has promoted ASEAN financial integration frameworks with further constraints on data protection rights and regulatory interoperability amongst members. The article addresses these issues with blockchain-based REIT and supported with cross-disciplinary governance models. The outcome is expected to support DIRE system into financial integration framework.

1. Introduction

The global Real Estate Investment Trusts (REITs) market has demonstrated trend of growths, diversification and increasing integration with broader financial and real estate ecosystems. As of 2023, there were nearly more than 1000 listed REITs across more than 40 countries with a total market capitalization exceeding US $2 trillion, with U.S. remains the largest and most developed market which accounts for nearly 70% of global market, while the others are shared by other major markets include Japan, Australia, U.K. and Singapore (1–3). In U.S., REITs have been supported by a robust legal and tax framework and meet certain distribution requirements. Traditional REITs focuses on commercial real estate assets such as office buildings, shopping centres, and wholesale markets; nevertheless, there is a growing trend toward diversification into newer asset classes, including data centres, industrial warehouses and even cultural and tourism infrastructures. The REITs development has been influenced by evolving policies, market dynamics and regulatory frameworks (4,5). The product architecture of infrastructure REITs has become increasingly more sophisticated and standardized. The maturity of REITs product has enhanced efficiency and transparency transactions and making them attractive to both institutional and retail investors (6).

Indonesia possesses the largest real estate market in Southeast Asia with estimated more than USD 68.55 billion in 2025 (7), unfortunately, with the smallest REITs market penetration. It reflects more on

structural issues rather than demand-side constraints. Indonesia's REITs or known as *Dana Investasi Real Estate* (DIRE) market is considered as underdeveloped with minimal volatility spillover effects compared to neighbouring countries (8). The DIRE market penetration experiences structural constraints that involve tax inefficiency, land title complexity and development restrictions. Indonesian Financial Services Authority (OJK) has mandated DIRE as key financial tools for infrastructure and real estate development. By enabling the securitization of real estate assets, DIRE is expected to provide a mechanism for real estate developers and operators to access capital markets and improve asset management efficiency (6). DIRE can lead investors' participation in real estate market without need for direct property ownership. This integration has led the real estate development become more dynamic and interconnected financial ecosystem, where real estate and capital markets mutually reinforce each other. The future of global REITs market is likely to be shaped by innovation in both product design and asset types of especially digital real estate (9).

Tokenized REIT with blockchain technology emerges to address the liquidity and global access problems (10). Blockchain technology offers improvements to real estate investment in term: fractional ownership, liquidity and transaction efficiency, while smart contracts automate processes such as rental income distribution, compliance checks, asset management and reducing the need for traditional intermediaries (11,12). Tokenization allows a broader range of investors to participate in real estate markets that were previously accessible only to institutional investors. Tokenized real estate market remains nascent with limited liquidity on secondary markets compared to publicly traded REITs. Studies show potential convergence paths of REITs such as (12–15): (1) hybrid models. Traditional REITs may tokenize their shares on blockchain for improved settlement efficiency while maintaining regulatory compliance; (2) regulatory evolution. Securities regulators are working on frameworks specifically for blockchain-based real estate securities that incorporate REITs-like structures; (3) Decentralized Finance (DeFi) integration. Tokenization real estate may integrate with decentralized finance protocols for lending, staking and yield generation that overcome unavailable features of traditional REITs (16–18). Tokenized REITs can exist to complement current REITs rather than replacing it. For investors, tokenized real estate offers higher potential yields and flexibility but comes with greater regulatory uncertainty and less liquidity than established REITs. The article proposes the blockchain solutions to overcome with liquidity and regulatory harmonization issues. Although it remains experimental, but it shows promise for democratizing real estate investment and support OJK initiatives in provide DIRE investment regulatory.

Studies address the persistent gaps between technical interoperability (chains communication) and legal interoperability (transactions recognized across jurisdictions) (11) (17) (19) The persistent gaps involve (2,20–22): (1) smart contract code may execute identically globally, but legal effect varies by jurisdiction; (2) conflict of laws principles remain resolved for self-executing agreements; (3) international private laws still requires identifying asset location and application law challenging for borderless ledger; ASEAN countries have initiated ASEAN financial integration framework that may facilitate harmonizing cross disciplinary governance models and regulations for all members (23–25). The increasing digitization of REITs financial markets presents both opportunities and enhance efficiency and transparency; nevertheless, they also raise concerns about cybersecurity and regulatory

oversight (23,26–28). World bank in 2023 addressed the capacity building initiatives and technical assistance are required by regulatory bodies to develop regulatory infrastructure and foster interoperability. As of January 2025, OJK has taken over the regulation and supervision of digital assets and crypto-related financial innovations (29,30). Within OJK Infinity 2.0 initiative, OJK has emphasized collaboration with industry stakeholders, academia and government to develop blockchain use cases. Currently OJK is running a regulatory sandbox for digital financial assets which includes the testing of tokenization projects like real estate assets in digital form.

The article addresses the emerging challenges that faced by blockchain solution in investment industry such as: (1) compliance with General Data Protection Right (GDPR) (31,32). Blockchain solution supports retail investors to involve in DIRE markets, as contrast to traditional DIRE is dominated by corporate investors. With more retail investors involvement may pose risk of personal data leakages; (2) data minimization. Scholars addressed the use of data minimization mechanism to protect personal data (33–37) It provides strategic approach to managing risks, navigating complex landscape of privacy, regulation compliance, operational efficiency and promoting ethical responsibility; (3) regulatory interoperability (38). Blockchain solution allows attracting foreign investors in REITs markets, however, it needs to deal with regulatory and interoperability issues; (4) cross disciplinary governance depends on a unified data foundation (39). Reliable decision-making requires integrating asset condition assessments, performance metrics (including environmental and social indicators) and financial lifecycle cost analyses (38,40–42). The success depends on (43–48): (1) leadership commitment from regulatory body to foster a risk-aware and stakeholder collaborative culture such as attracting more investors and promoting liquidity markets; (2) structural integration that embeds cross-functional accountability without creating new silos e.g. promoting Know Your Customer (KYC) and AML (Anti Money Laundering) efforts; (3) continuous capability development to keep pace with emerging risks and methodologies. Emerging technologies adoption in investment such as blockchain may deliver significant benefits along with its unidentified risks; (4) transparent processes that enable scrutiny, learning and adaptation. Blockchain allows to identify investment fraudulent and problems that are hardly to be detected in traditional transactions.

2. Theoretical Framework

A. Real Estate Investment Trusts (REITs).

REITs have emerged as essential property investment instruments for major property developers. REITs have enjoyed strong growth in major developed countries such as: United States, Australia, Japan and Singapore. A typical infrastructure REITs product involves four layers: infrastructure assets, project company, asset securitization, and acquiring public fund. This structure enables the separation of ownership and cash flow rights, allowing underlying infrastructure assets to access capital markets while distributing risks and return among investors (49–51). REITs have evolved from foundational performance measurement toward sophisticated analyses of risk management, Environmental Social and Governance (ESG) integration and macroeconomic sensitivity. Scholars address the REITs face

global challenges like sustainability and technological change (5,52–54). It needs to deepen interdisciplinary connections with behavioural economics and digital finance. The common behavioural economics involves diversification portfolio strategies, interoperability REITs investment, and property risk mitigation; while digital finance relates with real estate industry such as providing sandbox frameworks, cybersecurity, distributed ledger architecture, API design, interoperability data governance, and consumer protection. REITs have demonstrated moderate inflation-hedging capacity over long horizons especially during moderate-high inflation regimes. Studies confirm REIT performance correlates with GDP growth, consumer spending and supporting sectors like retail, industrial and lodging during expansionary periods (1,8,9,55–57). Public traded REITs offer high secondary market liquidity on established exchanges; however, with non-traded REITs may suffer from illiquidity.

Indonesian DIRE was introduced in 2007 under Capital Market and Financial Institutions Supervisory Agency (*bapepam-LK*) framework as a collective investment contract (KIK) structure and later amended in 2020 (POJK No.2/2020) to enhance flexibility for fund allocation and cross-border investment provisions. DIRE is supported with robust regulatory infrastructure, however, its market requires coordinated efforts in investor education, asset pipeline development and Shariah standardization. Scholars address several factors such as demographic dividends, urbanization trends, and growing Islamic finance ecosystem provide strong fundamentals for DIRE growth. DIRE framework distinct from corporate trust structure that used in Malaysia or Singapore such as (2,22,58): (1) investment manager, authorises to manage portfolio and make investment decisions; (2) custodian bank, hold assets in safekeeping and ensures compliance with fund objectives; (3) unit holders such as investors receive proportional returns from rental income and capital appreciation; The DIRE structure aims to balance investor protection with operational flexibility with additional layers of governance compared to international REITs models. DIRE serves as Indonesian property investment vehicles that offer portfolio diversification value, however, their underperformance relative to equities highlights structural challenges such as focusing more on development focused business models rather than income-generating rental assets.

The growth of DIRE has several challenges such as (8): (1) low market liquidity that hinders price discovery and inhibit investor options; (2) asset concentration risk. Most listed property companies are developers, not pure-play income assets and it creates volatility and limits REIT-style cash flow stability; (3) investor awareness deficit. OJK addresses the capital market literacy amongst Indonesian are still low, that may constrain retail participation and fund sizing; (4) tax and regulatory complexity. Multiple overlapping regulations e.g. PP No.40/2016, POJK No.19/2016, No.64/2017, create compliance burden. This overlapping regulation may deter smaller investment managers from entering the market. DIRE deals with challenges such as: (1) liquidity problems in both primary and secondary markets such as limited trading volume makes price discovery difficult and limited core value propositions of real estate assets; (2) regulatory rigidity. OJK regulation No.64/POJK.04/2017 imposes structural constraints imposes complex compliance requirements for investment managers and custodian banks to increase operational costs and undergone multiple amendments without achieving critical market adoption; (3) limited diversification options. Investors face constrained asset selection within DIRE universe, with few

listed vehicles offering exposure to different real estate subsectors such as office, retail, industrial and residential. This contrasts sharply with mature REITs market such as Singapore which offer specialised sector-focused trusts (2).

B. Blockchain in Property Investment: Illiquid DIRE market, regulation complexity and institutional fragmentation.

Tokenized REITs has transforming traditional REIT shares with direct property interests into the use of blockchain-based digital tokens (17). Deloitte's Financial Service Centre predicts real estate tokenization market may reach $4 trillion by 2035. The Securities and Futures Commission (SFC) has issued guidelines for tokenized securities and investment products that emphasizing the need for compliance with existing financial regulations (59). The SFC treats tokenized securities similarly to traditional securities and requiring intermediaries to manage new risks such as ownership and cybersecurity risks. Blockchain tokenization represents a different approach in terms (41,59–61): (1) it allows to convert property ownership rights or cash flows into digital tokens on a blockchain. It provides immutable records of ownership and transaction history.; (2) it enables fractional ownership by dividing property into smaller and tradable units; (3) it applies smart contracts to automate transactions, distributions and compliance. It can automate rent distributions, property management fees and compliance. It allows to reduce settlement/transfer costs, although it emerges with blockchain gas fees, smart contract audit expenses, custody solutions for underlying assets and regulatory compliance for digital securities; (4) it operates on distributed ledger technology rather than traditional securities infrastructure, has enabled interoperability investment without traditional intermediaries; Although tokenized REITs are still in early stage, however, it shows significant improvements to overcome major hurdles in terms: regulatory, technical and market structure (16). Most tokenized real estate offerings must comply with securities laws, and it is structured as investment contracts and need to register as securities or qualify for exemptions for REIT-like regulations.

Tokenized REITs operates in 24/7 global trading on digital asset exchanges, and its liquidity depends entirely on platform adoption. Failure to adopt proper platform may cause illiquidity despite on technology capability. Tokenized REITs supports potential for token-weighted governance via Decentralised Autonomous Organisations (DAO), with most implementations retain centralized management due to regulatory/practical constraints. The blockchain architecture is not merely a technology solution, but a governance-enabling framework that addresses fundamental organizational needs for information integrity and coordination innovation (62–64) It allows to address for complex and multi-stakeholder environments where trust and coordination are essential. Studies suggest several promising directions for blockchain implementation (62–64): (1) conditional innovation pathways. Blockchain-enabled information quality allows to create different innovation pathways under varying organizational contexts; (2) cross-organizational coordination. Blockchain can facilitate innovation across organizational boundaries where information asymmetry traditionally limits collaboration; (3) dynamic governance mechanism. Blockchain architecture can adapt governance rules based on changing information quality requirements and innovation priorities; (4) sustainability integration.

Blockchain-enabled information integrity can enhance sustainability reporting and verification, connecting with research showing strong relationships between information quality, innovation and sustainable performance.

Property rights are governed by local real estate laws, which it does not automatically recognize blockchain tokens as legitimate ownership instruments without proper legal wrappers. SEC addresses the tokenized securities must comply with registration requirements or qualify for exemptions (65). SEC distinguishes between issuer-sponsored (direct tokenization by asset owner) and third-party sponsored tokenization (external entity tokenizing existing securities) with heightened scrutiny on latter due to custody and authenticity risks. The emergence of blockchain technology has initiated innovation in real estate investment and creating two distinct models' investment (16,17). The fundamental structural differences of blockchain-based and traditional REITs are illustrated below:

Table 1. Fundamental Structural Differences.

Dimension	Traditional REITs	Blockchain-based/Tokenized REITs.
Legal Form	Corporate entity or trust regulated under securities laws (e.g. U.S. REIT Act, country-specific frameworks).	Digital tokens representing ownership/economic rights in real estate assets, recorded on distributed ledger.
Ownership representation	Shares/units traded on stock exchanges or OTC markets.	Cryptographic tokens (often ERC-20, ERC-721, or similar standards) represent fractional ownership.
Settlement	T+2 standard settlement cycles through central securities depositories.	Near-instantaneous peer-to-peer via blockchain (minutes vs weeks).
Management model	Centralized professional management team with fiduciary duties.	Hybrid models: smart contracts automate distributions/ compliance; human managers often obtained for asset operations.

Note: OTC: over the counter.

C. Data Protection Rights.

In investment industry, data protection rights are primarily governed by national laws. General data protection rights involve a complex interplay of legal frameworks, international agreements and national regulations. The European Union's General Data Protection Regulation (GDPR) and United Nations Convention on Rights and OECD Privacy guidelines ensure the data collected, processed and transferred during investment activities are protected against misuse, unauthorized access and breaches (31,34). In the context of cross-border investments, data protection is a critical concern due to the involvement of multiple jurisdictions with varying data protection standards. The investment industry faces several challenges in ensuring data protection: (1) legal fragmentation. Different countries have different data

protection laws and making it difficult to establish a uniform approach to data protection in international investment; (2) emerging technologies (18,19,60). The use of AI, blockchain and big data analytics in investment activities introduces new risks and challenges in data protection; (3) data localization requirements (30,34). Some countries impose data localization requirements which can hinder the free flow of data and complicate interoperability investment activities; (4) cybersecurity threats (66,67). Investment industry is commonly main target for cyberattacks which can compromise the confidentiality, integrity and availability of data.

The use of tokenization asset with blockchain may incur conflicted issues with GDPR such as (31): (1) right to be forgotten versus immutability., The immutable ledgers challenge traditional data subject rights frameworks. The permanent and tamper proof records conflicts with GDPR requirements that personal data be deleted upon request. Decentralized blockchain architecture complicates GDPR requirement to identify a specific data controller responsible for processing. Some scholars argue that immutability does not necessarily violate GDPR when properly designed with privacy-enhancing technologies (31,34). The use of blockchain in investment is expected to address: (1) ensure legal certainty. By providing a stable and predictable legal framework for data protection through smart contract and immutable property in investment activities; (2) facilitate dispute resolution. Blockchain technology can facilitate easy arbitration mechanisms that offer confidentiality, neutrality and enforceability of awards; (3) promote data protection standards. Hybrid on and off chain can encourage adoption international data protection standards in investment agreements, where sensitive and confidential data is stored in off chain and transaction data is stored on chain; (4). Best practices for data protection in investment industry. Blockchain framework can support regional financial integration framework (24,26,28,68,69).

2. Data Minimization.

Data minimization is a core principle of data protection and privacy and has been emphasized in GDPR regulations (31,70). The data minimization refers to practice of collecting and processing only personal data that is necessary for a specific and legitimate purpose. It allows a strategic approach to managing risk, navigating complex landscapes of privacy, regulation, operational efficiency and ethical responsibility (34,71–73). GDPR requires firms to avoid collecting excessive data about investors such as unnecessary financial details, personal preferences or historical data that is not directly relevant to the service being provided. Studies address the architectural incompatibilities between blockchain's design principles and minimization obligations (74)(75) Blockchain architecture replicates identical data across all validator node globally, vastly exceeding necessity for transaction validation. A single transaction that containing personal data may be stored on thousands of nodes worldwide and violating principal data processing should be limited to minimum number of entities that required for legitimate purposes.

From an operational standpoint, data minimization can reduce the complexity and cost of data management. By limiting the amount of data stored, firms can also improve system performance and

reduce the risk of data misuse or unauthorized access. Moreover, data minimization supports the development of more transparent and ethical data practices (31). In investment industry, trust is a critical asset, where firms need to demonstrate a strong commitment to privacy and responsible data handling can achieve a competitive advantage. Balancing the need of data with need of privacy is not an easy task, since investment firms often rely on extensive data to assess risk, manage portfolios and comply with regulatory requirements. Scholars address the use data anonymization, pseudonymization and data retention policies to align with data minimization principles while still meeting business objectives and regulatory needs (31,70–72). The use of data minimization in investment industry involves (75–78): (1) conducting data mapping and audits, allow identifying what data is collected, where it is stored and how it is used. Selective disclosure protocols allow users to reveal only specific data attributes that is required for a transaction. Data mapping and audits will deliver benefits to regulatory bodies such as OJK, Bank Indonesia, bapepam-LK, etc. to assess investment policy; (2) implementing data retention policies, allows establishing clear timelines for data deletion to avoid unnecessary storage which is required by GDPR laws; (3) training employee, allows to ensure staff to understand the importance of data minimization and how to apply it in their roles; (4) engaging with regulators and industry groups. It allows staying informed about evolving standards and best practices. DIRE regulations may vary with changing external environments.

3. Regulatory Interoperability.

Regulatory interoperability in investment industry refers to ability of regulatory frameworks, standards, and systems across different jurisdictions to work together seamlessly, enabling efficient and harmonized oversight of interoperability investment activities (79–81). Regulatory interoperability faces challenges such as regulatory diversity, data privacy concerns, and technological barriers. The technology barriers persist in international cooperation, regulatory technology adoption and cross-border regulatory sandboxes. OJK has encouraged the DIRE integration with ASEAN financial integration framework and other regional cooperations to attract more foreign investments (24,26,82,83). The challenge in regulatory interoperability involves: (1) diverse regulatory frameworks. Different countries have varying rules, standards and enforcement mechanisms, which can create friction for investors and financial institutions operating interoperability. It involves in reporting requirements, capital adequacy standards and anti-money laundering (AML) regulations (84); (2) data privacy concern. Sharing financial data across borders is often hindered by data privacy laws and concerns over data sovereignty (78); (3) technological and operational barriers. The lack of standardized technological infrastructure and operational practices can impede regulatory interoperability, such as reporting formats, data exchange protocols, and regulatory sandboxes can create inefficiencies; Regulatory fragmentation occurs when jurisdiction adopt incompatible rules for digital assets, data protection, and transaction validation, creating legal uncertainty for interoperability operations (85) .

Blockchain architecture alone cannot solve cross-border regulatory fragmentation, however, it can facilitate interoperability when there is legal harmonization through treaties, mutual recognition agreements, or supranational frameworks like the EU (80,81,85,86). Blockchain technology supports

REITs, a potential solution to regulatory fragmentations, a persistent challenge where divergent national regulations impede seamless international transactions. Blockchain nodes that operate across dozens of countries may exacerbates jurisdictional conflicts particularly in (81,87): (1) legal recognition of smart contracts (enforceable in some jurisdictions while unrecognized in other jurisdictions); (2) conflicting data protection regimes; (3) divergent definitions of digital asset ownership and transfer. The decentralized nature of blockchain technology can complicate legal jurisdiction particularly when interoperability transactions involved. States may retain ultimate authority over (81,88): (1) block node operations within their territory; (2) criminalize certain transaction types; and (3) impose data localisation requirements that conflicting with distributed architectures.

However, selecting appropriate blockchain architecture can address the regulatory interoperability such as: (1) regulatory harmonization. Blockchain can harmonize regulatory across multiple jurisdictions such as investment (OJK, bapepam, Indonesian Exchange or IDX), real estate ownership (National Land Agency or BPN, notary), and crypto asset trading (Commodity Futures Trading Regulatory Agency or bappebti). ASEAN financial integration framework has initiated regional standards that can be adopted or adapted by member jurisdictions and fostering greater interoperability (82). The framework aims to harmonize regulatory standards and facilitate interoperability investment flows within the region; (2) Regulatory Technology (RegTech). The adoption of RegTech solutions such as AI and blockchain, has potential to enhance cross-border regulatory interoperability with AI supports multiple regulatory frameworks compliance simultaneously, while blockchain can facilitate secure and transparent data sharing across multiple regulations (86); (3) interoperability regulatory sandboxes. Regulatory sandboxes provide a testing environment for innovative financial products and services, are increasingly being used to promote interoperability collaboration. For instance, the Monetary Authority of Singapore (MAS) and Hong Kong Monetary Authority (HKMA) have established a cross-border regulatory sandbox to test innovative investment products and services (89,90). As the real estate investment industry continues to evolve, fostering greater interoperability will remain a critical priority for regulators, policy makers and industry stakeholders.

4. Cross-disciplinary governance models.

Cross-disciplinary governance models in investment industry have transformed traditional siloed oversight toward integrated frameworks that unite finance, risk management, technology, compliance, ESG expertise, behaviour science and operational disciplines (91) (39,92) . It involves integrating knowledge and methodologies from multiple fields to enhance decision making, risk management and regulatory compliance. These models are increasingly essential as investment firms to navigate complex regulatory landscapes, emerging risk and stakeholder expectations. In 2025, OJK has pioneered the regulation and fostering the integration of blockchain and digital asset ecosystem within the traditional financial sector to enhance efficiency and security. In strategic roadmap 2024-2028, OJK has focuses on: (1) strengthening governance through establishing clear rules for token offerings, to unlock liquidity and democratize investment; (2) consumer protection through enhancing digital literacy and implementing strict Anti-Money Laundering (AML) protocols for blockchain entities; (3) infrastructure development.

Building necessary digital architecture to support a robust Web3 ecosystem; The OJK regulatory sandbox studies technical solutions in controlled financial environments with direct regulator involvement to establish precedents for legal acceptance. It involves integrating legal scholars, cryptographers and financial regulators in co-designing architectures where immutability serves regulatory goals (e.g. audit trails), while personal data remains erasable (93,94).

Investment industry has lack of clear national or industry standards for blockchain platforms. It leads to inconsistencies in platform quality, neutrality and verification capabilities, which hinders the widespread adoption of blockchain in investment services. The use of blockchain in investment services may face legal and operational risks, which could slow down its development and application (79,88). Effective governance in investment industry requires robust data governance frameworks that address lack of standardization and deep integration with existing investment systems. It involves creating a multi-level architecture that ensures secure and efficient data sharing across different sectors is crucial for investment decisions and regulatory oversight. Blockchain governance encompasses technical and social means to make decisions across multiple levels (80,88): individual, community, organizational, and regulatory that involve actors, roles, rights, incentives, responsibilities, and business. Cross-disciplinary governance models in blockchain architecture development represents a paradigm shift from traditional centralized oversight toward integrated frameworks that unite computer science, cryptography, economics, law, sociology and organizational design (81,87,95,96). Blockchain system is not merely technical protocols but socio-technical ecosystems where code, incentives, legal frameworks, and human coordination must align to achieve sustainable, trustworthy, and adaptable decentralized systems. Current blockchain platforms are mostly enterprise-oriented with limited accessibility for individual investors. This restricts the potential blockchain to serve a broader investment clients and limits its scalability in the investment industry. Cross-disciplinary governance addresses four integrated dimensions such as (86,93,97,98):

(1) technical dimension: code as governance infrastructure. It includes systems, mechanisms, and processes that automate governance decisions:

- Consensus algorithm (PoW, PoS, BFT variants) encodes trust assumptions.
- Smart contracts enforce rules without intermediaries.
- On-chain voting mechanism.
- Protocol upgrade pathways such as forkless upgrades, runtime modification.
- Privacy-preserving primitives (zero-knowledge proofs, proxy re-encryption) for compliant data handling.

(2) economic dimension: incentive alignment and tokenomics. It ensures behavioral alignment through carefully engineered incentive structures:

- Stake-weight voting ties decision power to economic commitment. It provides best investment scenarios for investors.

- Slashing mechanisms penalize malicious validator behaviour.
- Treasury governance enables investment community-controlled funding of ecosystem development.
- Game-theoretic modeling informs optimal incentive design.

(3) legal and regulatory dimension: compliance by design. It addresses the tension between decentralization and enforceability:

- Hybrid cooperative (HC) models introduce jurisdictional modules for local legal compliance alongside decentralized execution layers, achieving selective decentralization where only legally necessary functions are centralized.
- Code-deferent legal foundations allow smart contracts to reference external legal agreements when enforceability is required.
- Decentralized Autonomous Organization (DAO) legal recognition is expanding. By 2025, more jurisdictions recognize DAOs as legal entities, raising questions about participant liability and prompting governance proposals to include legal review stages.
- Regulatory primitives embed consent management, purpose limitation, and auditable metadata directly into protocol logic to support GDPR compliance.

(4) social dimension: community coordination and legitimacy. It encompasses non-technical governance processes essential for legitimacy and adaptability:

- Off-chain deliberation via forums, social media, and working groups enables discussion before formal voting.
- Multirole delegation allows token holders to assign voting power to domain experts per proposal category, addressing investment knowledge asymmetries.
- Reputation systems and transparent documentation build trust among pseudonymous participants.
- Media and public discourse serve as informal oversight mechanisms influencing investment key actors through reputation effects.

3. Research Method

A. Design Science Research (DSR) Method.

The article applies Design Science Research (DSR) method, that focuses on examining innovative artifacts to develop DIRE architecture with blockchain solution (see Fig.1). The use of DSR is expected to deliver advantages in (adapted from (99)): (1) direct relevance to Indonesian DIRE digital architecture. It provides a dual-sidechain architecture anchored to established blockchains for cost-effective, secure and private transaction management; (2) create actionable knowledge for practitioners in regulated securities trading with enhanced auditability and privacy; (3) accommodates complexity process through iterative refinement to ensure best practise can be achieved; (4) allows bridging decentralized platform

meeting with regulatory requirements and practical gap. Peffers et.al. (100) formalised a six-step iterative process in DSR that is comprises of:

(1) identify problem and motivate. The step identifies challenges in Indonesia's DIRE tokenization architecture by identifying current problems and analysing relevant paper works. The research gaps to address such as: illiquid DIRE market, regulation complexity and institutional fragmentation, GDPR privacy-enhancing technologies, data minimization, interoperability regulatory and cross-disciplinary governance models.

(2) define objectives of a solution. The step defines objectives of solution that involve: (a) functionality. What financial services does the DIRE intermediary can provide? (b) architecture. How is the platform technically structured (e.g. degree of decentralization); (c) security. What mechanisms are in place to protect assets and data?

(3) design and development, the step creates artifacts by using blockchain design principles. It involves developing conceptual model that model the stakeholders' interactions in a role-based approval framework.

(4) demonstration. The step demonstrates DIRE blockchain based investment architecture environment such as programmable authorization, verification flows, and restricted transaction logic.

(5) evaluation. The step uses expert-based evaluations to examine the correctness of approval flows, compliance traceability and role segregation. This stage ensures the architecture design aligns with regulatory constraints.

(6) communication. The step disseminates the architecture design lesson learned. The design prototype is presented and discussed with domain experts to review and for further development.

B. Data Gathering Methods.

The article applies data gathering methods comprises of:

(1) primary data, were obtained with ten experts interviews that between July and November 2025, with key professionals are reviewing conceptual model and examined the problems that related to property development, investment management, legal practice, financial oversight and blockchain technology. They are real estate developers and DIRE fund managers, legal consultants and notaries, blockchain developers and Fintech association members, as well as investors and representatives from digital asset platforms;

(2) secondary data, were collected from various sources: (a) official regulatory documents and guidelines that is issued by OJK, bapppebti, and Bank Indonesia; (b) literature reviews related on blockchain and asset tokenization;

C. Research Questions.

We developed research questions based on literature study and preliminary study with key professionals, with following topics (see Table 2):

Table 2. Research Gap and Requirements.

No	Research Gap	Requirements
1	Illiquid DIRE market, regulation complexity and institutional fragmentation.	It requires creating DIRE in DAO-like structures. Corporations can tailor their real estate products digitally in DAO offerings where investors and regulators can monitor DIRE performance in real time.
		The DAO structure supports harmonization regulation to avoid regulation complexity. With harmonization regulations, it can enhance DIRE performance, introduce high-quality assets (DIRE), and trade globally in 24/7 (increase liquidity).
		It needs robust frameworks that embed REIT-specific regulatory requirements into blockchain architecture.
2	Immutable Vs GDPR's Rights to delete data. scholars argue that immutability does not necessarily violate GDPR when properly designed with privacy-enhancing technologies.	It needs Off-chain storage architecture: Storing only reference/hashes on-chain while keeping personal data off-chain to enable deletion.
		Pseudonymization techniques: Using cryptographic methods to separate identifying information from transaction data.
		Permissioned/private blockchains: Designing controlled blockchain environments that can implement GDPR-compliant governance structures.
3	Data Minimization: GDPR's requirement that personal data be adequate, relevant and limit to in relation to the purpose for which they are processed. Studies address the architectural incompatibilities between blockchain’s design principles and minimization obligations.	Functional minimization: Hybrid architecture achieves functional minimization: cryptographic references and meta data still constitute personal data processing under GDPR Requirements.
		Zero-knowledge proof (ZKP): enables verification without revealing underlying data, processing only proof of compliance rather than raw data.
		Selective disclosure protocols allow users to reveal only specific data attributes required for a transaction (e.g. age verification without revealing birthdate).
		Personal data should be kept off chain whenever is possible as a baseline minimization requirement. On-chain storage is permissible only when strictly necessary for specific use case after documented necessity assessment.

3	Regulatory Interoperability: Nodes may operate across dozens of countries may exacerbates jurisdictional conflicts.	Bridges allowing value/data transfer across chains.
		Interoperability frameworks with standardized messing layers for payments.
		Multi-chain architectures where jurisdiction-specific chains connect via trusted intermediaries.
		Layered governance model: combining technical protocols with multi-stakeholder governance bodies that include regulators.
		Hybrid-architectures: Off-chain regulatory processing with on-chain audit trails, storing e.g. storing only hashes on public chains while keeping person data in jurisdiction-compliant repositories.
4	Cross-disciplinary governance models.	Regulatory sandbox studies testing technical solutions in controlled financial environments with direct regulator involvement to establish precedents for legal acceptance.
		Integrating legal scholars, cryptographers and financial regulators in co-designing architectures where immutability serves regulatory goals (e.g. audit trails) while personal data remains erasable.
		Immutable transaction integrity layers and mutable personal data layers, can be validated for financial audit requirements.

4. Design and Findings

A. Identify Problem and Motivate.

We summarised the findings below:

Table 3. Current Challenges and Blockchain-enabled Improvement mechanism.

Current Challenges	Expected Improvement Mechanism
The conceptual model allows creating DIRE in DAO-like structures. Corporations can tailor their real estate products digitally in DAO offerings where investors and regulators can monitor DIRE performance in real time. Problems related to product valuation and pricing mechanism can be monitored transparently and through taxation mechanism.	(1). Integrated workflow synchronization: Corporations can tailor and offer DIRE product offerings where their performance can be monitored in real time: Smart contracts coordinate sequencing (e.g., appraisal → SPA → DoSP and ensure each step is completed before proceeding to next step. It addresses fragmentated regulations verification across PPAT, BPN, banks, appraisals. (2) document integrity through hashing algorithm: SPA/DoSP drafts, appraisal reports, and tax proofs stored off-chain but hashed on-chain to ensure tamper detection. Document integrity supports harmonization regulations and creates liquid DIRE, trade globally in 24/7. (3) immutable auditability. Every approval, signature event, and workflow action recorded on chain, enabling full traceability. It creates robust frameworks REIT-specific regulatory requirements. It solves unclear audit trails and missing approval history. (4). Automated rule enforcement (compliance-by-design) supports harmonization regulations, avoids complexity and addresses vulnerable for forgery or manipulation. (5). Programmable escrow and conditional release allow payment is executed only when predefined on-chain conditions are met.
The DAO structure supports harmonization regulation to avoid regulation complexity. Current fragmentation regulation verification across PPAT, BPN, banks, appraisals can be avoided. With harmonization regulations, it can enhance DIRE performance, introduce high-quality assets (DIRE), and trade globally in 24/7 (increase liquidity).	
The conceptual model provides robust frameworks that embed REIT-specific regulatory requirements into blockchain architecture. Avoid paper-based documents are vulnerable to forgery or manipulation.	
Off-chain storage architecture: Storing only reference/hashes on-chain while keeping personal data off-chain to enable deletion.	(1). Programmable personal data, escrow and conditional release: Personal data is stored off-chain to enable deletion, while only references/hashes in on-chain. Payment is made only when predefined on-chain conditions are met (e.g., verified SPA).
Pseudonymization techniques: Using cryptographic methods to separate identifying information from transaction data.	(2). Automated rule enforcement (compliance-by) supports pseudonymization techniques: separating specific information from transaction data.
Permissioned/private blockchains: Designing controlled blockchain environments that can	(3). We use Polygon Hybrid system that supports permissioned/private blockchains and has compliant governance structures. (4). Reusable decentralized identity (DID): KYC stored once and referenced by smart contract. reduce duplication and onboarding time. (5). Digitally verified and time stamped workflow: automatic tracked milestones, improve coordination and reduce turnaround time. (5). Reduce intermediary overhead:

implement GDPR-compliant governance structures.	automation removes redundant verification, reduces manual paperwork and lowers operational burden.
Functional minimization: Hybrid architecture achieves functional minimization: cryptographic references and meta data still constitute personal data processing under GDPR requirements. Zero-knowledge proof (ZKP). Enables verification without revealing underlying data, processing only proof of compliance rather than raw data. Selective disclosure protocols allow users to reveal only specific data attributes required for a transaction. Personal data should be kept off chain whenever it is possible as a baseline minimization requirement. On-chain storage is permissible only when strictly necessary for specific use case after documented necessity assessment.	(1). Programmable personal data supports functional minimization and complies with GDPR requirements. It provides reversible transforms personal data before on chain recording. (2). Smart contract (blockchain) supports ZKP mechanism and document integrity through hashing: SPA/DoSP drafts, appraisal reports, and tax proofs are stored off-chain but hashed on-chain to ensure tamper detection. Selective disclosure protocols allow users to reveal only specific data attributes for transaction. (3). The use of Polygon allows on-chain storage is permissioned when necessary specific use case is required especially for auditing process. (4). Digitally verified and time stamped workflow allows to address slow mortgage processing (appraisal, underwriting, approval).
Bridges allowing value/data transfer across chains. Interoperability frameworks with standardized messaging layers for payments. Multi-chain architectures where jurisdiction-specific chains connect via trusted intermediaries. Layered governance model: combining technical protocols with multi-stakeholder governance bodies that include regulators.	(1). Integrated workflow synchronization supports bridging value/data across chains and interoperability frameworks with standardized messaging layers for payments. (2). Polygon Hybrid supports multi-chain architecture via trusted intermediaries and tokenized debt instruments: SPV-issued tokens allow fractional investment with transparent yield structures is reported. (3). Automated rule enforcement (compliance-by design) supports layered governance models. It allows manual compliance checks that cause delays in verification. (4). Reusable decentralized identity (DID) and digital verified and time stamped workflow, support jurisdiction-compliant repositories and regulatory sandbox that is required by OJK. DID allows repetitive KYC admin across banks, notaries, developers.

Hybrid architecture: Off-chain regulatory processing with on-chain audit trails, storing e.g. storing only hashes on public chains while keeping person data in jurisdiction-compliant repositories.	
Regulatory sandbox studies testing technical solutions in controlled financial environments with direct regulatory involvement to establish precedents for legal acceptance.	(1). Document integrity through hashing supports regulatory sandbox studies to address fragmentation regulation verification. (2). Increase potential secondary market liquidity while serving regulatory goals: tokenized debt can be listed on regulated digital marketplaces. (3). Bank Indonesia and OJK are pioneering tokenized products in digital markets. The article proposes tokenized DIRE that supports immutable transaction integrity layers and mutable personal data layers. (4). Tokenized debt instruments allow global retail access to property-backed investment products.
Integrating legal scholars, cryptographers and financial regulators into co-designing architectures where immutability serves regulatory goals (e.g. audit trails) while personal data remains erasable.	
Immutable transaction integrity layers and mutable personal data layers can be validated for financial audit requirements.	

Note:

1. Land Deed Official: PPAT (Indonesian).
2. National Land Agency: BPN (Indonesia).
3. Sale and Purchase Agreement (SPA) or PPJB (Indonesian).
4. Deed of Sale and Purchase (DoSP) or AJB (Indonesian).
5. Know Your Customer (KYC).

We confirmed the findings with expert interviews (see Table 4)

Table 4. Expert Interviews (Triangulation).

Affiliation / Role	Discussion Focus	Key Findings
Real Estate developer, Chair of REI North Sumatera.	Real estate investment and financing opportunity.	Emphasize the need for alternative and transparent financing strategies to make liquid DIRE products, comply with regulatory and address institutional fragmentation issues. May accommodate to introduce digital organization (DAO) that can embed high quality assets into DIRE products to create more investment and financing opportunity.
Co-Founder and senior Director, Leads Property.	Market transparency and valuation	Highlighted valuation inefficiencies; supported blockchain for improved disclosure timeliness. Corporation can introduce tokenized DIRE that allows easy monitoring performance in real time.
Director and CFA, Asset Management.	Fund structure and regulatory integration.	It is confirmed that debt tokens could complement DIRE structures under OJK's digital financial innovation framework. It confirms with the urgency creating robust conceptual DIRE frameworks that embed specific regulatory requirements, especially GDPR related to data minimization, privacy-enhancing technology, and rights to delete data.
Marketing and BBD Director, property Developer.	Developer adoption readiness.	Recognized tokenization’s pre-sale potential, dependent on taxation and legal clarity. System can verify proof of compliance procedure instead of manual data.
Founder, GORO.id (Property tech platform).	Retail investment and crowdfunding.	Minimum crowdfunding cap, sandbox testing for higher-value property projects, and compliance reports. Need digital DAO based on blockchain architecture to create property investment platform while personal data is kept off chain whenever is possible. On-chain storage should be designed as permissioned network only when needed. Bridging facility allows value/data across multiple chains and supports standard messaging layers for interoperability payments.
Founder, stablecoin Ramp platform.	Fiat-to-crypto ramp infrastructure.	Explained corporate use of stablecoin ramps for interoperability transactions. Agree with hybrid-architecture (off-chain for audit trails and on-chain for storing hashes on public chains).
Lawyer specializing in crypto Exchange.	Exchange integration and subaccount control.	Address layered governance model that supports integration with multi-stakeholder governance bodies including regulators. State that exchanges can manage subaccounts via APIs for IDR on/off-ramp operations. Regulatory sandbox studies is needed to establish precedents for legal acceptance.
Notary/PPAT.	Contract legality and notarization.	Clarified that transactions must comply with regulation to remain enforceable. Immutability serves regulatory goals (e.g.audit trail) while personal data

		remains erasable and validated for financial audit requirements.
Architect and property Investor	Property investment and taxation.	Emphasized high tax and transaction costs limiting liquidity. Harmonization regulation is required to address double taxation.
Lawyer and cryptocurrency, and regulation advisor.	Legal structuring and collateralization.	Recommended debt-token models allowing secured obligations. GDPR compliance is necessary with personal data protection (deletion rights, data minimization) and interoperability regulatory.

Note: Decentralised Autonomous Organization: DAO.

B. Define Objectives of Solution.

We consolidate the findings into prototype requirements as shown in Table 5:

Table 5. Consolidation Insights, Research Gaps and Prototype Requirements.

Key Insights	Problem Identification	Proposed Solution
1. Limited institutional understanding; need for gradual implementation to address institutional fragmentation.	(1). Lack of digital automation for KYC and onboarding absence of unified review workflow. (2). Corporations can tailor their real estate products into DIRE products through DAO offerings.	(1). Digital identity and KYC pipeline with wallet authentication and whitelist. (2). Investors and regulators can monitor DIRE performance in real time.

Table 5. Consolidation Insights, Research Gaps and Prototype Requirements (continued).

Key Insights	Problem Identification	Proposed Solution
1. Limited institutional understanding; need for gradual implementation to address institutional fragmentation.	(1). Lack of digital automation for KYC and onboarding absence of unified review workflow. (2). Corporations can tailor their real estate products into DIRE products through DAO offerings.	(1). Digital identity and KYC pipeline with wallet authentication and whitelist. (2). Investors and regulators can monitor DIRE performance in real time.
2. Structural property- market constraints to address privacy-enhancing technologies and data protection (GDPR compliance).	(1). Tokenization cannot fix asset scarcity and paper works to address. (2). Maintain hybrid architecture: off-chain for managing sensitive personal data and on-chain for transaction data.	(1). Systems should focus on compliance and transparency, not property selection. (2). The conceptual model provides robust frameworks REIT-specific regulatory requirements in blockchain architecture. (3). Hybrid architecture (KYC/Docs off-chain → IPFs hash on-chain.
3. DIRE weaknesses and misaligned incentives: illiquid DIRE and regulation complexity. Address product valuation and pricing mechanism.	(1). Ownership-based tokenization is legally risky and commercially weak. (2). Need transparency pricing and market acceptance.	(1). DAO addresses the issues with debt-based SPV token model with predictable returns. (2). REIT-specific requirements framework can address risky tokenization and commercial weakness. (3). Investors and regulators can monitor market anomaly and potential fraud.
4. Legal ambiguity and enforcement risks especially for interoperability regulatory: Address regulation harmonization and embed REIT-specific regulatory requirements into blockchain architecture.	No integrated approval mechanism and weak enforceability.	Improvement approval mechanism through on-chain RBAc and dual approval with immutable audit trail.
	(1). Fragmentation between off- chain and on-chain processes. (2). Multi-chain architectures where jurisdiction-specific chains connect via trusted intermediaries (SPV).	(1). Hybrid architecture (KYC/Docs off-chain → IPFs hash on-chain. (2). DAO provides off-chain storage architecture: storing only reference/hashes on-chain while keeping personal data off-chain to enable deletion (GDPR compliance). (3). DAO accommodate multi-chain architecture via intermediaries (SPV).

5. Mature tokenization and exchange infrastructure, however, need to address architectural incompatibility between blockchain's design principles and data minimization obligations.	(1). Lack of deterministic workflow anchors. (2). Promote pseudonymization techniques that are embedded in blockchain's design principle and minimization mechanism.	(1). Improve workflow and automation thru smart-contract state machine: Requested → Approved →Mintable → Minted (pseudonymization techniques). (2). Cryptographic methods are used to separate identifying information from transaction data (minimization mechanism).
	(1). Limited automation for issuance lifecycle. (2). Supports ZKP mechanism.	(1). Event-based audit logs for all compliance actions (ZKP mechanism). (2). Support verification without need to reveal underlying data and processing (only proof of compliance).
6. Low public awareness and institutional hesitation: need to address cross-disciplinary governance models.	(1). Minimal transparency in approval and issuance lifecycle (Minimization). (2). Bridging allowing value/data transfer across chains. (3). Regulatory sandbox studies, (4). Immutable transaction integrity layers that can be validated for financial audit requirements.	(1). Address transparent issuance dashboard with real time status and events and support piloting DIRE regulatory sandbox study for regulatory body (OJK, Bank Indonesia). (2). Blockchain solution as alternative financial integration framework to OJK and ASEAN frameworks.

Note:

1. RBAc: Role-based Access control.
2. IPF: Inter-Planetary File.
3. ZKP: Zero-knowledge Proof.

Table 6. Stakeholders and Responsibilities.

Stakeholder	Role and Responsibilities
Propose Operator Platform.	(1). Administers KYC verification, maintains whitelist registry, assigns roles (Notary, Fund Manager, property owner), and coordinates the approval workflow. Investors and regulators can monitor the compliance in real time. (2). Possibility to offer multi-chain architecture that tailors specific jurisdiction chains via trusted intermediaries (SPV).
User Platform (system operator).	(1). Performs operational tasks such as validating submitted documents and updating whitelist and role records. (2). Automatic regulation harmonization (OJK, Bank Indonesia, bappepti, etc.) and avoid regulation complexity. (3). Create liquid DIRE (24/7) and embed high quality assets in DAO. (4). Propose robust REIT-specific regulatory framework into blockchain architecture. (5). Run hybrid architecture: off-chain storage to comply with GDPR requirements (data deletion) and on-chain architecture to store DIRE transaction references/hashes to achieve minimization functionality. (6). Support layered-governance model by combining technical protocols with multi-stakeholders' governance bodies that include regulators.
Property owners/developers.	(1). Complete KYC onboarding, register as issuers, and submit legal and asset documentation for token issuance. (2). Promote DAO-like structures that allow collaboration amongst property owners/developers. They can tailor real estate products digitally in DAO offerings.
Notaries (PPAT).	(1). Undergo KYC and act as legal validators, providing the first mandatory authorization in the issuance process. (2). DAO integrates with Notary (PPAT) in DIRE offerings and regulatory compliance resolution.

Table 6. Stakeholders and Responsibilities (continued).

Stakeholder	Role and Responsibilities
Propose Operator Platform.	(1). Administers KYC verification, maintains whitelist registry, assigns roles (Notary, Fund Manager, property owner), and coordinates the approval workflow. Investors and regulators can monitor the compliance in real time. (2). Possibility to offer multi-chain architecture that tailors specific jurisdiction chains via trusted intermediaries (SPV).
User Platform (system operator).	(1). Performs operational tasks such as validating submitted documents and updating whitelist and role records. (2). Automatic regulation harmonization (OJK, Bank Indonesia, bappepti, etc.) and avoid regulation complexity. (3). Create liquid DIRE (24/7) and embed high quality assets in DAO. (4). Propose robust REIT-specific regulatory framework into blockchain architecture. (5). Run hybrid architecture: off-chain storage to comply with GDPR requirements (data deletion) and on-chain architecture to store DIRE transaction references/hashes to achieve minimization functionality. (6). Support layered-governance model by combining technical protocols with multi-stakeholders' governance bodies that include regulators.
Property owners/developers.	(1). Complete KYC onboarding, register as issuers, and submit legal and asset documentation for token issuance. (2). Promote DAO-like structures that allow collaboration amongst property owners/developers. They can tailor real estate products digitally in DAO offerings.
Notaries (PPAT).	(1). Undergo KYC and act as legal validators, providing the first mandatory authorization in the issuance process. (2). DAO integrates with Notary (PPAT) in DIRE offerings and regulatory compliance resolution.
Fund Managers.	(1). Complete KYC and perform financial and investment validation, providing the second authorization required for issuance. (2). Supports interoperability regulatory with standardized messaging layers for payments. (3). Blockchain creates legal foundation for blockchain-based asset trading, mandates transaction transparency requirements: Compliance with OJK Regulation No.23/2025 (Digital Financial Asset Trading and Property Tokenization that establish licensing framework for crypto/token exchanges, custodians, and clearing institutions), with built-in compliance hooks (e.g. ownership restriction for foreigners).
Smart contract.	(1). Validates role permissions, enforces sequential dual authorization, generates immutable audit logs, and mints tokens only after full approval. (2). Support pseudonymization and data minimization: using cryptographic methods to separate information data from transaction data.

	(3). Permissioned/private blockchain (Polygon): support GDPR-compliant governance structures (hybrid architecture). Personal data is kept off-line. (4). Verification through ZKP mechanism without revealing important data or raw data, only proof of compliance. (5). Allow users to reveal required data attributes for transaction. (6). Bridges value/data transfer across chains. (7). Interoperability framework with standardized messaging layers for payments.
Regulators (conceptual).	(1). Representing oversight requirements from OJK, BPN, and DJP, shaping system-level compliance constraints without interacting directly. (2). As alternative OJK regulatory testing sandbox related to DIRE framework with direct regulator involvement to establish precedents for legal acceptance. (3). Integrating legal scholars, cryptographers and financial regulators in co-design architecture to promote immutability personal data layers (audit trails). (4). Immutable transaction integrity layers and mutable personal data layers can be validated for financial audit requirements. (5). Invite more interdisciplinary research that includes computer science, law, finance and regulatory policy, in regulated financial services while maintaining systemic stability and consumer protection. (6). Blockchain solution promotes regulatory gatekeeping for token issuance and prevents fraudulent offerings: source of funding, pricing transparency and market transparency, while protecting sensitive personal information.

Note: Directorate General of Taxation: DJP (Indonesia).

C. Design and Development.

We use a four-layer architecture model to ensure modularity separation of concerns and clarity in how compliance requirements are enforced across the platform (see Table 7):

Table 7. Architecture layer design matrix.

System Design Layer	KYC and Role Management	Issuance (Dual Authorization)
1. Application Layer	(1). Wallet login and authentication.	(1). Corporation can issue DIRE token (issuance request submission) and needs notary and fund manager (investor) approval through dashboard; Status tracking is issued: regulator body can monitor the progress and further compliance report can produced whenever is necessary.
	(2). KYC submission and verification User Interface (UI). (3). Role assignment interface.	(2). Further REIT-specific regulatory requirements can be embedded within KYC mechanism and role assignment. (3). GDPR-compliant governance structures are defined and maintained. (4). Cross-disciplinary governance models can be added here: ASEAN Integration financial regulatory framework.

Table 7. Architecture layer design matrix (continued).

System Design Layer	KYC and Role Management	Issuance (Dual Authorization)
1. Application Layer	(1). Wallet login and authentication. (2). KYC submission and verification User Interface (UI). (3). Role assignment interface.	(1). Corporation can issue DIRE token (issuance request submission) and needs notary and fund manager (investor) approval through dashboard; Status tracking is issued: regulator body can monitor the progress and further compliance report can produced whenever is necessary. (2). Further REIT-specific regulatory requirements can be embedded within KYC mechanism and role assignment. (3). GDPR-compliant governance structures are defined and maintained. (4). Cross-disciplinary governance models can be added here: ASEAN Integration financial regulatory framework.
2. Integration Layer	(1). Synchronize KYC results to whitelist; (2). Manage identity records; (3). REST API for role updates.	(1). Document routing between stakeholders. It stores only references/hashes on-chain while personal data is kept off-chain for necessary data deletion (as required by GDPR): data minimization and pseudonymization techniques. (2). Event listener for approval/minting. (3). Logging issuance audit trail. (4). REST API supports data exchange for external markets.
3. Smart contract layer.	(1). Validate whitelisted addresses. (2). Immutable transaction integrity layers and mutable personal data layers are maintained.	(1). Enforce sequential approval (Notary → Fund Manager). Mint only after dual authorization. Emit immutable events. (2). Dual authorization allows functional minimization is maintained and ZKP mechanism, only selected attributed data can be revealed. (3). Cryptographic methods to separate identifying essential information from transaction data. (4). Immutable data serves regulatory goals (audit trails) while

		personal data is erasable. (5). Regulation harmonization and interoperability payment are supported.
4. Infrastructure Layer	KYC data storage. whitelist registry. DID/identity management.	(1). Document storage and reference hashing. secure orchestration of approval workflow, system integrity and failure handling. (2). Hybrid architecture is maintained: Off-chain regulatory for audit trails and on-chain for transactions. (3) Regulatory sandbox testing is provided in controlled financial environment for legal acceptance.

The design comprises of four core components aligned with the architecture model: (see Table 8)

Table 8. System Architecture Model.

Components	Implementation details	Purpose
Application Layer (React/Next.js or equivalent).	Wallet login (MetaMask), KYC form, role assignment UI, issuance request form, approval dashboard.	Enables user interaction and coordinates workflow steps: creating liquid DIRE product, globally traded and regulatory compliance.
Integration Layer (Node.js backend).	REST APIs for KYC verification, JsON-based document storage, event listeners for smart-contract events.	Synchronizes off-chain verification with on-chain approval logic: regulation harmonization, separate essential information from transaction data (GDPR compliance, data minimization, regulatory interoperability, cross-disciplinary governance models).
Smart contract Layer (Direction1155c on polygon Amoy).	Role-based modifiers, whitelist validation, sequential approval functions, controlled mint function, state machine.	Enforces compliance-by- design, dual authorization, and audit logging: privacy-enhancing technology.
Infrastructure Layer.	Whitelist registry, KYC JsON repository, document hash storage, static non-executable document URLS.	Maintains data integrity and secures identity/document references: Regulatory sandbox testing solutions that integrate with legal scholars, cryptographers and financial regulators in co-designing architecture.

Note:

1. JsON: Java script Object Notation.
2. URLs: Unified Resource Locators.

We apply Smart Contract (Direction 1155C) extends standard ERC-1155 behaviour with a comprehensive suite of compliance-embedded functions that govern identity verification, issuance and platform administration. Table below summarizes all major functions in the system and highlights regulatory logic encoded into each operation, demonstrating how legal and financial aligned control logic can be systematically expressed and constrained at smart contract level:

Table 9. Key Smart Contract Functions.

Function	Description	Embedded Authorization and Control Logic
KYC & Identity Layer		
approveKyc(address user)	Marks a wallet address as KYC-approved.	Ensures that only verified identities can participate in issuance and trading; aligns with commonly accepted KYC/AML control practices as referenced in Indonesian financial regulations. Data minimization and pseudonymization techniques are supported. Regulation interoperability is supported.
revokeKyc(address user)	Removes KYC eligibility form an address.	Immediately blocks participation when red flags or non-compliance risks are detected: potential fraudulent.
kyc[address] (mapping)	Stores the on-chain KYC status.	Serves as the single source of truth for transfer/mint validation. Regulation interoperability verification.
onlyKyc modifier	Restricts access to KYC-approved addresses.	Enforces mandatory identity verification at smart-contract layer to prevent unauthorized token transfers.
	Assign roles (Notary, Manager, Controller).	Provides transparent on-chain role assignment with auditability supports internal governance and segregation of duties.
grantRole(bytes32 role, address account)	Assign roles (Notary, Manager, Controller).	Provides transparent on-chain role assignment with auditability supports internal governance and segregation of duties.
revokeRole(bytes32 role, address account)	Removes roles from an address.	Prevents unauthorized or outdated role holders from performing restricted actions.
Issuance Workflow (Dual Authorization)		
approveByNotary(uint256 id, address to, uint256 amount)	Notary validates legal documents for the issuance ID.	Only NOTARY_ROLE can execute and ensure legal due diligence before issuance: regulation harmonization is ensured.
approveByManager(uint256 id)	Fund Manager approves the financial structure.	Only MANAGER_ROLE can execute; it requires Notary approval first, implementing sequential dual- authorization like DIRE governance. Interoperability governance model is supported.

mintApproved(uint256 id,address to, uint256 amount)	Final Mint transaction after both approvals is complete.	Prevents unauthorized token creation; issuance cannot occur without both legal and financial validation. Compliance reports are created.
approvedByNotary[id]	Boolean flag: legal approval.	Used for compliance auditing of the legal validation step.
approvedByManager[id]	Boolean flag: financial approval.	Ensures issuance follows the correct regulatory and governance sequence.

Note: Know Your Customer: KYC.

Anti Money Laundering: AMC.

Table 10. Off-chain KYC, documents and Whitelist management.

Off-Chain Process	Description	Output / Interaction With On-
1. KYC Verification	Verification of investor/issuer identity: KTP/passport check, selfie match, sanctions/PEP screening, email/phone verification. Verification can extend to regulatory harmonization.	Backend updates structured JSON → triggers approveKyc(address) dan revokeKyc(address) on- chain.
2. Legal document validation (Notary).	Review and validation of property-related documents (e.g. certificates, deeds, PPAT records, SHM/HGB status), including authenticity checks and dispute screening, performed by a licensed notary. Compliance reports are created.	Hash of validated documents uploaded to IPFS. Notary performs on-chain approveNotary(Id).
3. Financial and Investment Review (Fund Manager)	Assessment of financial structure, risk profile, yield model, and investment soundness, conducted by a licensed fund manager in reference to prevailing regulatory guidelines: product valuation and market transparency is supported.	Approval decision triggers on-chain approveFundManager(id) to allow minting.
4. Off-Chain document storage.	Storage of legal PDFs, appraisal reports, agreements, and metadata. Usually stored in IPFS, S3, or secure backend. Data minimization and pseudonymization techniques are supported.	Only IPFS hash stored on-chain; ensures tamper-proof linkage.
5. Role Assignment and Administrative Controls.	Manual role management: assigning Notary, Fund Manager, Operator, and updating user permissions. Regulation interoperability is supported.	Calls on-chain functions (grantRole (ROLE, account); revokeRole (ROLE, account)).
6. Operational Logging and Audit Management	Off-chain logs for admin actions, KYC timestamps, approval decisions, and document history. Hybrid architecture is maintained to comply with GDPR and data protection policy.	Provides supporting records for internal audit, expert review, or potential regulatory inspection; complements immutable on-chain event logs.
7. Compliance Panel and UI Operations.	Admin dashboard for identity checks, document uploads, whitelist sync, and freeze/unfreeze management.	Backend syncs status updates →triggers appropriate on-chain. Functions.

Compliance reports is created and ready to be assessed.

The DIRE property layout can be seen below (see Fig.2).

Role Assignment Dashboard (Notary, Fund Manager, Operator, Owner) is shown in Fig.3.

Approval Console for Notary and Fund Manager are shown in Fig.4.

On-Chain Issuance Status Tracker is shown in Fig.5.

The system requirements validation is shown in Table 11.

Table 11. System Requirements validation.

Requirement	Validated?	Evidence
Digital KYC + whitelist	Yes	KYC JSON + on-chain whitelist used successfully.
Role-based access control	Yes	Only Notary/FM could approve; contract checks enforced
Dual-authorization workflow	Yes	FM approval blocked until Notary approval
Immutable audit logs	Yes	On-chain events captured (request, approvals, mint)
Hybrid off-/on-chain integration	Yes	JSON documents + IPFS hash references validated
Debt-based SPV model	Yes	Contract uses non-ownership token class (economic rights only)
Deterministic state transitions	Yes	Requested → Approved → Mintable → Minted sequence confirmed
Transparent issuance tracking	Yes	PolygonScan provides public visibility of on-chain state, role-based approvals, and event logs.

The prototype was developed and tested using (see Table 12):

Table 12. Deployment Environment.

Environment Component	Specification
Blockchain Network	Hardhat and Polygon Amoy Testnet (PoS/zkEVM).
Smart Contract Framework	Hardhat + Chai.
Front-end	React/Next.js.
Back-end	Node.js + Express.
Storage	JSON-based local repository.

We apply Polygon hybrid framework with standard ERC 1155C (https://github.com/ljcom/erc1155c) and design can be found in: https://amoy.polygonscan.com/address/0x7c80E676758cc6f1748ddF0c02dB0abE8Ec42631.

D. Evaluation and Communication.

While smart contract enforces on-chain compliance rules, a significant regulatory workflow must be shown in off-chain. The off-chain processes comprise identity verification, legal document assessment, financial analysis, payment confirmation and operation monitoring (compliance with regulatory requirements). The design evaluation is shown below (see Table 13 and 14)

Table 13. Off-chain Compliance Verification Process.

Off-chain Compliance Process	Description	Output / Interaction with on-chain system
1. KYC verification.	Verification of investor/issuer identity: ID/passport check, selfie match, sanctions/PEP screening, email/phone verification. (data minimization and pseudonymization techniques).	Backend updates structured JsON → triggers approveKyc(address) and RevokeKyc(address) on chain.
2. Legal Document validation (notary).	Validation of property certificates, deeds, PPAT records, SHM certificates, SHM/HGB status, dispute checks, authenticity confirmation. (regulation harmonization and compliance reports).	Hash of validated documents uploaded to IPFS; Notary performs on chain approveNotary(id).
3. Financial and Investment Review (Fund Manager)	Assessment of financial structure, risk evaluation, yield model, investor protection, OJK compliance review: (promote liquid product, transparent valuation and market access and global access).	Approval decision triggers on chain approveFundManager(id)to allow minting.
4. Off-chain document storage.	Storage of legal PDFs, appraisal reports, agreements, and metadata. usually stored in IPFS, S3, or secure backend. (regulation harmonization, interoperability regulation, cross-disciplinary governance models).	Only IPFS hash stored on chain; ensures tamper-proof linkage.
5. Role Assignment & Administrative controls.	Manual role management: assigning Notary, Fund Manager, operator, and updating user permissions.	calls on-chain functions (grantRole(ROLE, account); revokeRole(ROLE, account).
6. Operational logging and audit management.	Off-chain logs for admin actions, KYC timestamps, approval decisions, and document history.	Provides proof for regulators; complements immutable on-chain event logs.
7. Compliance panel and User Interface (UI) operation.	Admin dashboard for identity checks, document uploads, whitelist sync, and freeze/unfreeze management.	Backend syncs status updates → triggers appropriate on-chain function.

Note:

1. Certificate of Ownership: SHM (Indonesia).
2. Right to Build Title: HGB (Indonesia).

Table 14. Evaluation Dimension.

Evaluation dimension	Purpose
Functional Testing	Verify core functions: login, KYC registration, role assignment, issuance request and Notary/Fund Manager approvals
Workflow consistency testing.	Ensure sequential authorization (Notary → Fund Manager) and correct state transitions across issuance stages.
Usability of compliance flow.	Evaluate system behaviour under valid, invalid, incomplete, and rejected issuance scenarios.
Institutional Coherence.	Assess regulatory plausibility and institutional alignment with Indonesian practices. A separate regulatory review is not conducted, as regulatory insights were already obtained through expert interviews.

5. Discussion and Conclusion

The article addresses the stagnation of DIRE growth with regulation complexity and infrastructure improvement with blockchain solution. Since 2025, OJK has supported tokenized assets as investment instruments and encouraged foreign investments in local market. The tokenized property emerges to provide secure foreign investments through immutable property; while the distributable property allows corporations to offer high quality assets in token forms. The Securities and Futures Commission (SFC) has issued guidelines for tokenized securities and investment products that complies with existing financial regulations. Tokenized property allows to convert property ownership rights or cash flows into digital tokens on a blockchain and trades in 24/7 global digital asset exchanges. Although it sounds promising, the liquidity of tokenized property depends on platform adoption. Failure to adopt proper platform may cause illiquidity despite technology capability. The article examines the research gaps relate to proper platform adoption such as: (1) illiquid DIRE market, regulation complexity and institutional fragmentation. The blockchain based REITs addresses key challenges such as: regulatory and compliance complexity, liquidity paradox and valuation and pricing mechanism; (2) data protection compliance with GDPR requirements with properly designed privacy-enhancing technology. Traditional REITs markets are dominated by institutional investors, while blockchain allows retail investors to participate more in REITs markets; (3) data minimization that allows only relevant data can be shared while protecting essential personal data. Data minimization mechanism is required to address the immutable property that may expose privacy data and violate GDPR requirements; (4). interoperability regulatory. The immutable and shareable property allows REITs to be traded globally, however, the different regulatory in each country may halt the transaction. ASEAN countries have initiated developing financial integration frameworks for member countries including investment markets. The blockchain solution can be used as alternative OJK's sandbox to pioneer REITs transaction in ASEAN regional; and (5) cross-disciplinary governance models. Pioneering REITs with blockchain requires integration of multi-disciplinary governance models that involve financial risk management, digital technology, compliance regulation, ESG expertises, behaviour science and operational disciplines.

Declarations

Author Contributions

Surjo Sastro Harjono: Writing – original draft, data curation, editing, formal analysis, conceptualization; **Gunawan Wang (Corresponding Author)**: Writing –original draft, review and editing, funding acquisition; **Deshinta Arrova Dewi**: Validation, final supervision. **Mochammad Isro Alfajri**: supervision, editing.

Data Availability

The article is based on publicly available literature, official regulatory documents, and expert interviews. All sources cited are properly referenced within the manuscript. Further data source for the article can be accessed: https://zenodo.org/records/18829723.

Ethical Approval and Accordance Statement to Participants: Not Applicable

This study did not involve experiments on humans or animals and therefore did not require formal ethical approval. All procedures performed were in accordance with academic ethical standards and research integrity guidelines.

Consent to Publish declaration: Applicable.

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Competing Interests

The authors declare that they have no competing interests.

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Figures

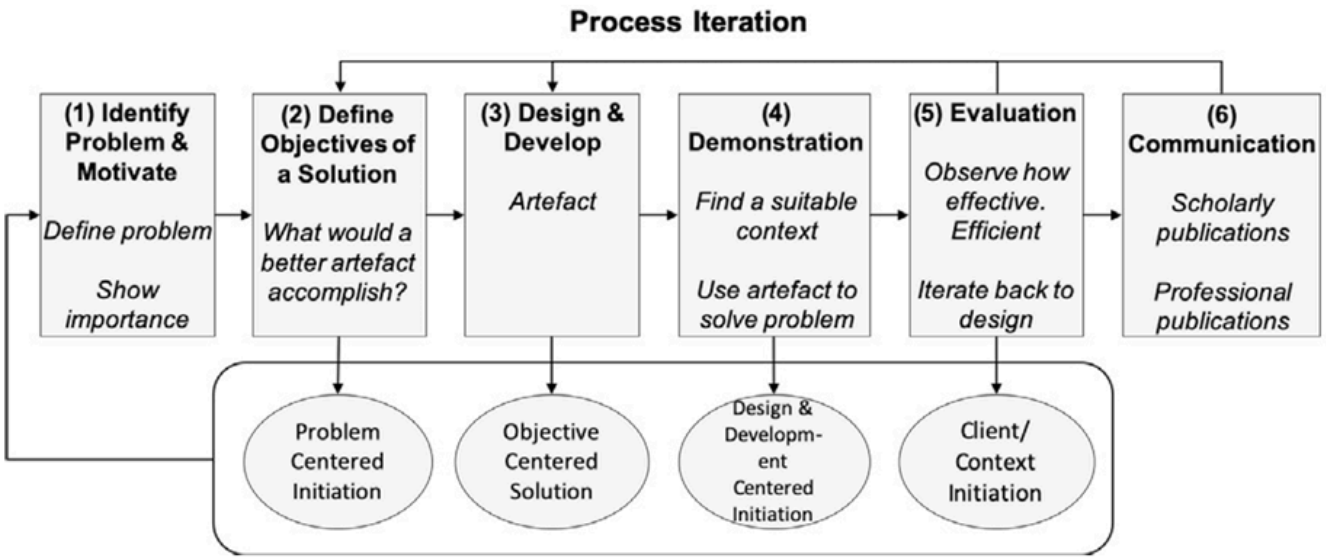


Figure 1

Design Science Research (DSR) Method.

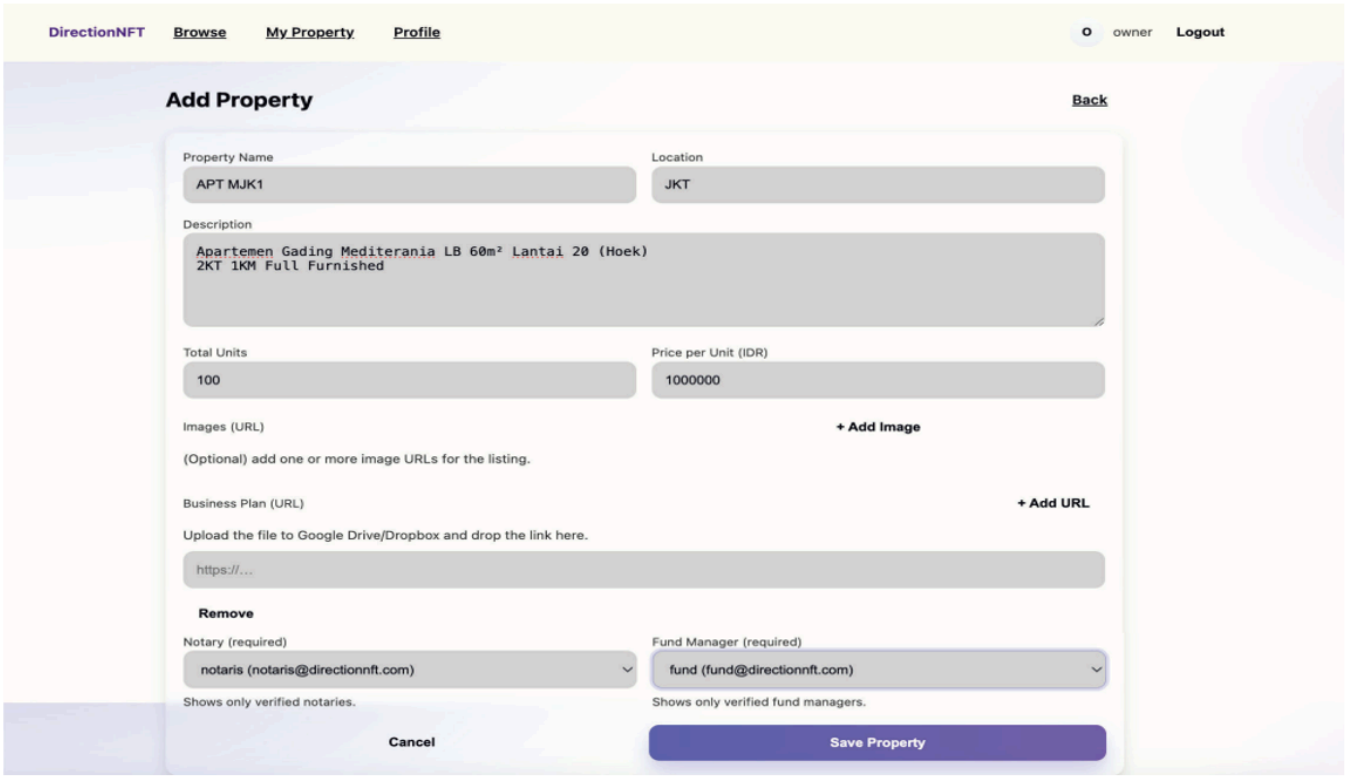


Figure 2

DIRE property layout.

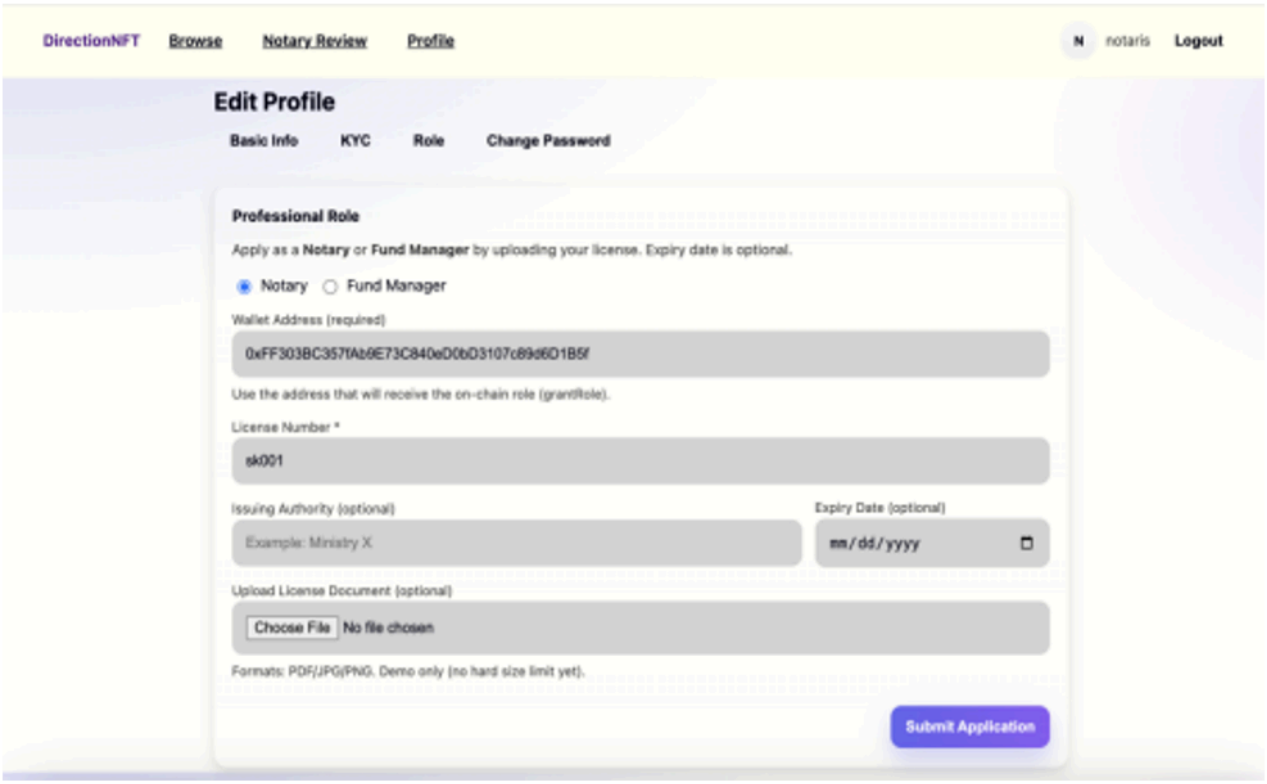


Figure 3

Role Assignment Dashboard.

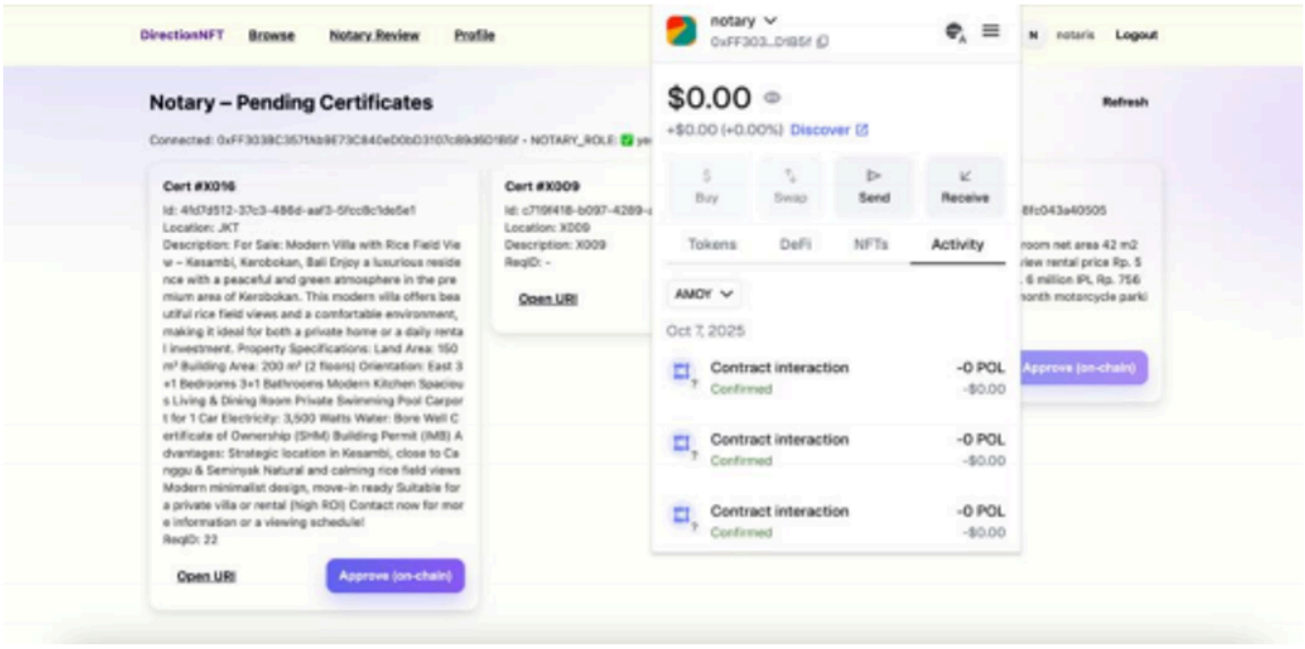


Figure 4

Approval console.

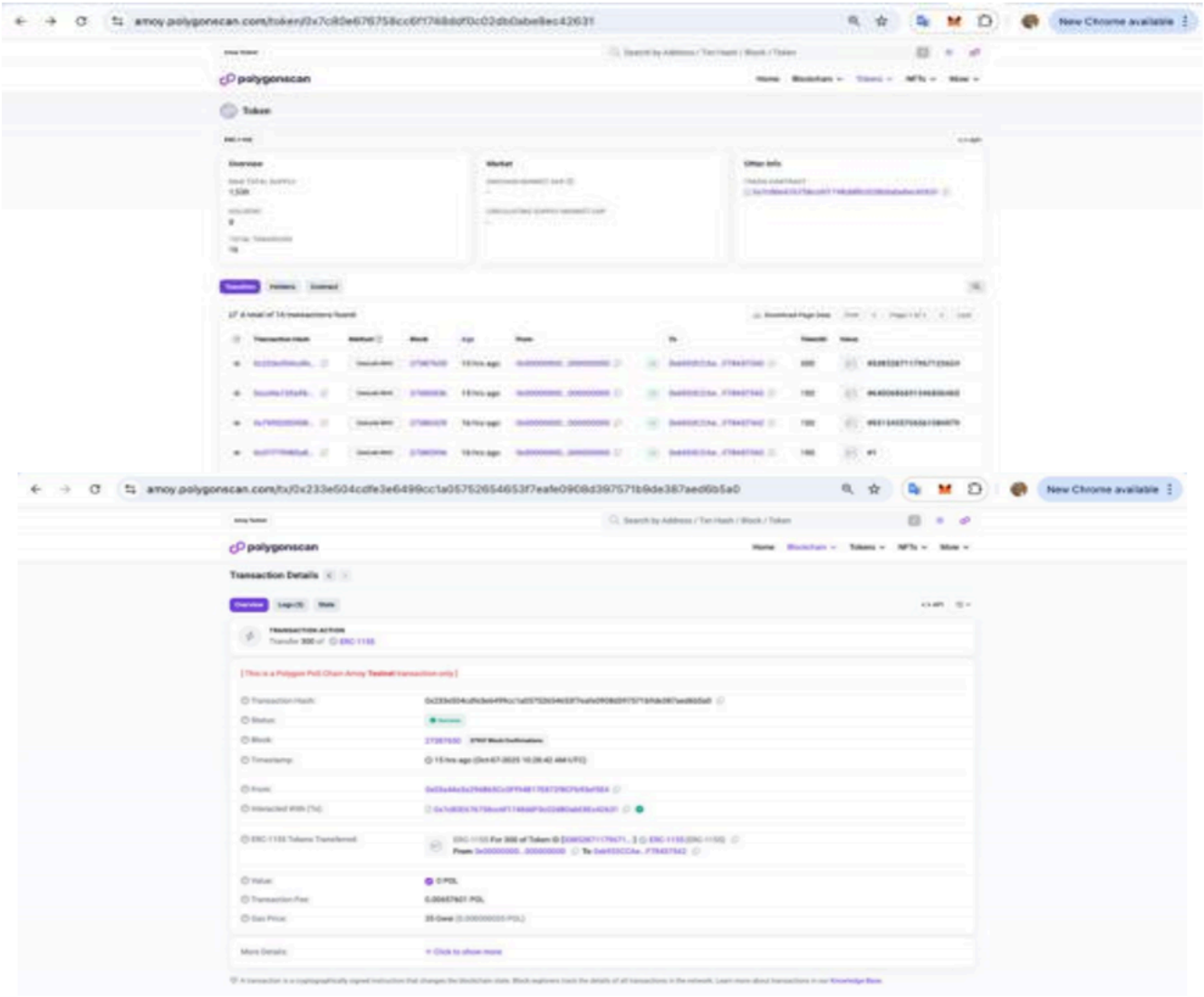


Figure 5

On-Chain Issuance Status Tracker.

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