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DEVELOPMENT OF A BLOCKCHAIN-BASED DECENTRALISED APPLICATION WITH NFT FOR LAND REGISTRATION

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Abstract: Land registration in Indonesia often encounters challenges in transparency, data integrity, and centralized bureaucracy. Manual and semi-digital systems remain vulnerable to manipulation and delays. The National Land Agency has initiated digitalization, but several challenges remain, particularly in ensuring transparency, efficiency, and security of land ownership data. Blockchain technology offers a potential solution through its decentralized and immutable characteristics. This study adopted a design and development method consisting of system analysis, requirements identification, architecture design, implementation, and black-box testing. The developed decentralized application (DApp) integrates smart contracts, NFTs, and IPFS to manage land certificates. Core functions such as minting, transfer, splitting, and self-custody were implemented and successfully tested, with all scenarios producing expected results. The findings demonstrate that blockchain integration can enhance security, reduce duplication, and streamline land administration. The study contributes a functional prototype with practical implications for modernizing land registration in Indonesia while identifying scalability and regulatory adaptation as areas for further research.

Keywords: blockchain; decentralized application; land registration; NFT; smart contract.

Abstrak: Sertifikat tanah di Indonesia kerap menghadapi tantangan dalam hal transparansi, integritas data, dan birokrasi yang tersentralisasi. Sistem manual dan semi-digital masih rentan terhadap manipulasi dan keterlambatan. Badan Pertanahan Nasional telah memulai proses digitalisasi, namun berbagai kendala masih dihadapi, terutama dalam menjamin transparansi, efisiensi, dan keamanan data kepemilikan tanah. Teknologi blockchain menawarkan solusi potensial melalui karakteristiknya yang terdesentralisasi dan tidak dapat diubah. Penelitian ini menggunakan metode perancangan dan pengembangan yang terdiri atas analisis sistem, identifikasi kebutuhan, perancangan arsitektur, implementasi, dan pengujian kotak hitam (black-box testing). Aplikasi terdesentralisasi (DApp) yang dikembangkan mengintegrasikan smart contract, NFT, dan IPFS untuk mengelola sertifikat tanah, di mana fungsi inti seperti minting, transfer, pemecahan (splitting), dan pengelolaan mandiri (self-custody) telah diimplementasikan dan diuji dengan sukses, dengan seluruh skenario menghasilkan hasil sesuai harapan. Temuan penelitian ini menunjukkan bahwa integrasi blockchain dapat meningkatkan keamanan, mengurangi duplikasi, dan memperlancar administrasi pertanahan, serta memberikan kontribusi berupa prototipe fungsional dengan implikasi praktis bagi modernisasi pendaftaran tanah di Indonesia, sekaligus mengidentifikasi skalabilitas dan adaptasi regulasi sebagai area untuk penelitian lebih lanjut.

Kata kunci: aplikasi terdesentralisasi; blockchain; NFT; sertifikat tanah; smart contract.

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INTRODUCTION

Land registration is a critical process in securing property rights and supporting economic development. In Indonesia, the National Land Agency (BPN) manages this process, but challenges remain. By 2023, only 67% of land parcels had been certified, leaving a significant gap in coverage [1]. Cases of duplicate land certificates in Nabire and Nganjuk illustrate the persistence of disputes and inefficiencies [2][3]. The introduction of electronic certificates (e-sertifikat) represents progress in digitalization, but the system still relies on centralized databases and paper-based documents, creating vulnerabilities in transparency and efficiency [4].

Previous studies have examined blockchain's potential to strengthen land administration. Research shows that blockchain can enhance security and transparency by providing immutable and verifiable records [5][6]. Other works emphasize its role in reducing duplicate certificates and improving land services in Indonesia [7], while highlighting the urgency of stronger digital certificate security to prevent forgery [8]. These studies confirm blockchain's transformative potential for modernizing land management.

Further research has explored complementary technologies. Non-Fungible Tokens (NFTs) can uniquely represent assets with transparent ownership histories [9], and have been proposed for secure land certification [10]. Smart contracts enable automation of land-related transactions, though legal and infrastructural challenges remain [11][12]. DApps, as decentralized platforms, eliminate single points of failure and ensure transparent execution of processes [13][14]. Together, these studies provide valuable insights but largely remain conceptual or lack prototypes tailored to Indonesia's context.

This research addresses that gap by developing and evaluating a blockchain-based decentralized application integrating NFTs for land registration. The system implements key functions such as certificate issuance, transfer, subdivision, and self-custody. The objective is to demonstrate how blockchain integration can improve transparency, prevent duplication, and strengthen security in Indonesia's land registration practices.

METHOD

This study employed a design and development approach through system analysis, requirements identification, architecture design, implementation, and testing to address challenges in conventional land registration and demonstrate the feasibility of blockchain and NFT integration.

The first stage involved analyzing the current land registration system. The land registration process in Indonesia is managed by the National Land Agency (BPN) to ensure legal ownership recognition. The conventional process involves application submission, document verification, field surveying, and certificate issuance. Despite the introduction of electronic services such as e-sertifikat, the system remains dependent on centralized databases and paper-based documentation. This reliance results in administrative inefficiency, certificate duplication, and limited transparency, particularly in regions with high land transaction activities.

The second stage focused on designing a proposed innovation. To address these weaknesses, this study pro-

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poses a blockchain-based decentralized application (DApp) that integrates Non-Fungible Tokens (NFTs) for land registration management. The system utilizes smart contracts to automate certificate issuance, ownership transfer, and subdivision processes. Each land certificate is represented as a unique NFT linked to metadata stored in the InterPlanetary File System (IPFS). The DApp serves as the main platform for interaction, providing secure, transparent, and tamper-proof land ownership records.

The third stage was devoted to requirements analysis. Functional requirements were defined to ensure the system met the needs of stakeholders. Three primary user roles were identified: (1) contract owner, who deploys and maintains the smart contract, (2) institution, authorized to mint and split certificates, and (3) landowner, who can hold and transfer land certificates. The use case diagram reflects interactions among these roles, focusing on the main processes of certificate minting, transfer, splitting, and secure self-custody by landowners. The system development scope is limited to the digital management of land certificates and does not include physical surveying, legal reforms, or integration with existing BPN databases.

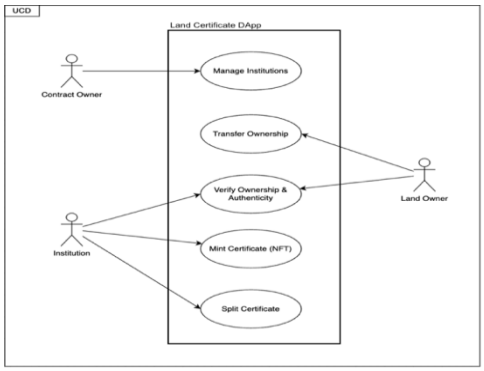

Figure 1. Use Case Diagram

The fourth stage concerned the design of the system architecture. The system was developed with a fully decentralized architecture. Smart contract on the Ethereum blockchain form the core of the business logic, including certificate minting, transfer, and splitting. IPFS is used for decentralized storage of metadata, ensuring tamper-proof records. The frontend was built with React.js and Ethers.js, allowing direct interaction with the blockchain via MetaMask as the digital wallet. This architecture removes the reliance on centralized servers and enhances security, transparency, and accessibility.

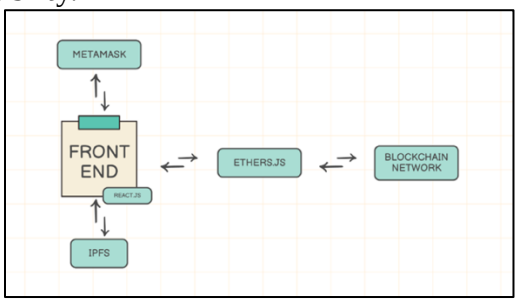

Figure 2. DApp Architecture

To support traceability, the smart contracts extend the ERC-721 standard with additional features for land management. These include linking parent and child certificates during subdivision, managing token activation status, and assigning roles for institutions authorized to issue certificates. This modular design ensures that every certificate can be traced across its lifecycle, from initial issuance to transfer and subdivision, while maintaining transparency and eliminating reliance on centralized databases.

The fifth stage addressed the use of data sources and development materials. System development relied on simulated land certificate data to validate functionality without compromising sensitive or real records. The simulation included attributes such as land area, location identifiers, legal status, and ownership details, which were uploaded to

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IPFS as metadata linked to NFTs. This approach provided realistic scenarios for testing while ensuring privacy and data integrity.

The development environment incorporated widely used blockchain and web technologies. Smart contracts were built and tested using Node.js, Hardhat, and OpenZeppelin libraries. Ganache was employed as a local blockchain for simulations, while Pinata was used as a gateway for IPFS storage. The frontend was implemented in React.js, integrated with Ethers.js for blockchain connectivity, and MetaMask for wallet-based authorization. These tools collectively provided a robust environment to design, deploy, and evaluate the DApp effectively.

The final stage involved system testing. System validation applied black-box testing to confirm that outputs matched expected results. The main scenarios included certificate minting, transfer, splitting, and self-custody. Each case was executed in a Ganache test environment and confirmed to perform as intended.

RESULT AND DISCUSSION

This section presents the implementation results and analysis of the developed blockchain-based decentralized application for land registration. The outcomes are described through the main system functions, including certificate minting, transfer, splitting, and self-custody using MetaMask. Each function was tested in a simulated environment to verify its correctness and reliability, with results supported by user interface screenshots and black-box testing. The discussion further analyzes how these results address the challenges of conventional land registration systems and the implications for potential adoption in practice.

System Setup and Implementation

The system was deployed and tested on a local Ethereum network using Ganache as the blockchain simulator. Several accounts were generated to represent contract owners, institutions, and landowners. MetaMask served as the wallet interface, enabling transaction authorization and interaction with the smart contracts. The frontend was developed using React.js, while IPFS with Pinata was used for metadata and document storage. This setup allowed the simulation of land registration workflows under controlled conditions, closely replicating real-world scenarios.

Figure 3 shows the homepage of the DApp, which serves as the entry point for users. The interface provides direct access to the main modules, including Home, My Properties, Verify, and Create, while the Connect Wallet option integrates MetaMask for secure authentication. The homepage also displays a sample digital land certificate, giving users an overview of how ownership data such as token ID, area, and wallet address are presented. This design improves usability by providing a clear starting point before navigating to specific features such as minting, transfer, or splitting.

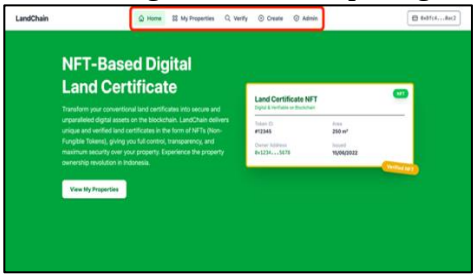

Figure 3. System Implementation Overview

Land Certificate Issuance Process (Minting NFT)

The minting process enabled institutions to issue digital land certificates.

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As shown in Figure 4, the institution completed a form that included legal status, land area, survey number, boundary information, and location details. Supporting documents were uploaded to IPFS, generating a Content Identifier (CID) linked to the certificate NFT. Once confirmed through MetaMask, the certificate was minted as a unique token with a tokenId.

Figure 4. Mint Digital Land Certificate Form

The test demonstrated that each certificate was uniquely recorded on the blockchain, permanently associated with its metadata. This process addressed one of the most common issues in the conventional system, namely duplicate or forged certificates, by ensuring immutability and verifiability of records.

Land Certificate Transfer Process (Transfer NFT)

Ownership transfer was implemented as a peer-to-peer transaction. The detail page of a certificate displayed ownership and land information, along with an option to transfer ownership by entering the recipient's wallet address (Figure 5). After transaction confirmation in MetaMask, the ownership was reassigned to the new address, and the ledger preserved the history immutably (Figure 6).

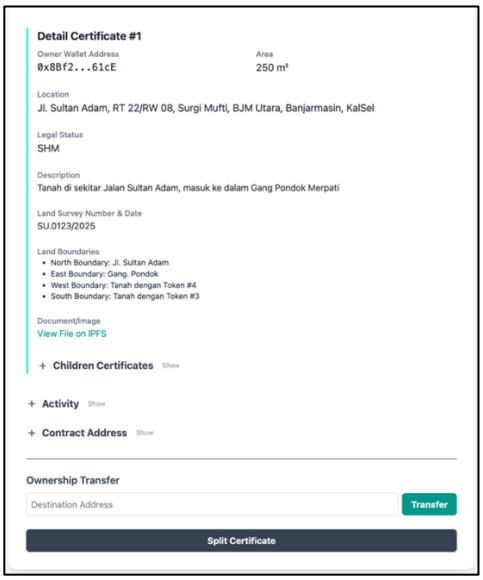

Figure 5. Certificate Detail Interface

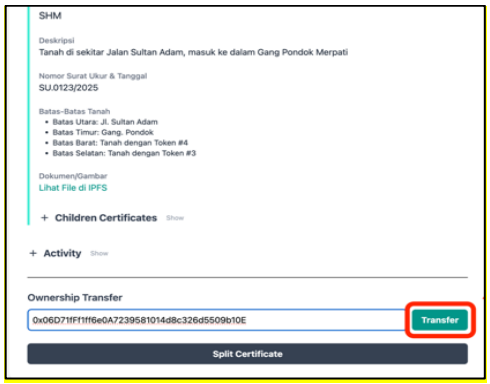

Figure 6. Ownership Transfer Process

The simulation confirmed that unauthorized transfers were impossible without wallet signature validation. This mechanism ensured that only legitimate landowners could initiate ownership changes, reducing fraud risks and eliminating bureaucratic delays common in manual transfers.

Self-Custody

Self-custody was tested by importing NFTs into MetaMask. Users could manually import a token by enter-

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ing the contract address and tokenId (Figure 7). Once imported, the land certificate appeared under the wallet's NFT section (Figure 8).

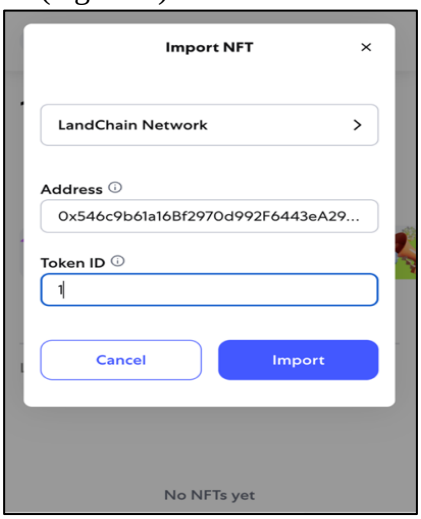

Figure 7. NFT Import Dialog

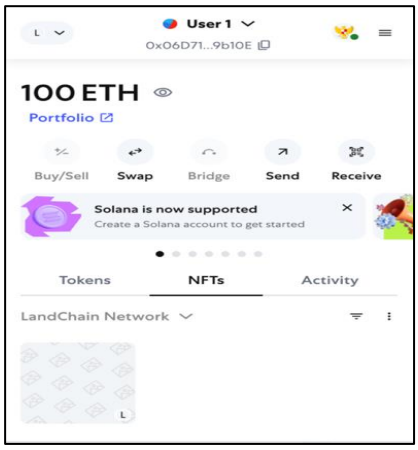

Figure 8. Land Certificate Stored as NFT in MetaMask

This confirmed that certificates were fully controlled by landowners through their wallets, aligning with blockchain's decentralization principle. The approach eliminates risks associated with centralized custodians, ensuring sovereignty and transparency in land ownership.

Land Certificate Splitting Process (Splitting NFT)

The splitting feature allowed institutions to subdivide a parent land certificate into multiple child certificates. As illustrated in Figure 9, users could specify the number of child parcels, along with new metadata for each. Once processed, the parent NFT was deactivated, and new tokenIds were issued for the child certificates. Each child retained a reference to the parent, ensuring traceability of lineage.

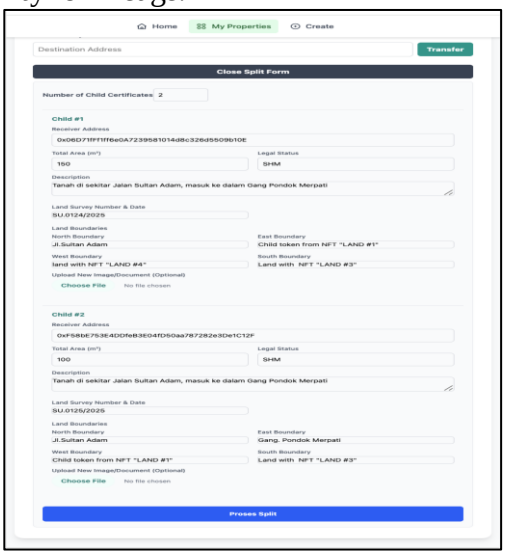

Figure 9. Split Certificate Form

The simulation confirmed that splitting preserved ownership history while generating valid child NFTs with unique identities. This feature is particularly relevant for land inheritance and subdivision cases in Indonesia, where overlapping claims often arise due to unclear records.

Black-box Testing Result

System functionality was validated using black-box testing. Table I summarizes the key scenarios and outcomes.

Table 1. Smart Contract Functions

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Test Scenario	Input/ Action	Expected Output	Result
Mint Certificate (NFT Creation)	Institution fills form, uploads document, confirms transaction	New NFT minted with unique tokenId and CID	Success
Transfer Ownership	Owner inputs destination address and signs transaction	Ownership transferred to new wallet address	Success
Self-Custody in Metamask	User imports NFT by contract address & tokenId into wallet	Certificate displayed under NFTs in MetaMask	Success
Split Certificate (NFT Splitting)	Institution defines child parcels and confirms split	Parent NFT inactive, new child NFTs generated	Success

The results confirmed that all four core functions (minting, transfer, splitting, and self-custody) operated as intended, producing outcomes consistent with expectations.

Discussion

The experimental results validate the feasibility of using blockchain-based DApps for land registration management. The minting process ensures uniqueness and prevents duplication, while transfers provide secure and transparent ownership changes. Splitting supports subdivision with clear lineage tracking, and self-custody gives landowners sovereignty over their assets. Together, these features address major weaknesses of the conventional system, such as duplicate certificates, lengthy bureaucratic procedures, and insecure ownership records.

Compared to traditional processes, the proposed system reduces administrative steps, eliminates dependency on centralized databases, and strengthens data integrity. While scalability, transaction fees, and legal adoption remain challenges for real-world deployment, the prototype demonstrates a strong foundation for modernization of land administration in Indonesia.

CONCLUSION

This study developed and evaluated a blockchain-based decentralized application for land registration using NFTs and IPFS. Four main functions including minting, transfer, splitting, and self-custody were tested through black-box evaluation, and all four scenarios produced results consistent with expectations. The system ensured uniqueness of certificates, prevented duplication, and enabled secure ownership transfer in simulated trials. These findings imply that blockchain integration can streamline processes, strengthen transparency, and reduce risks of fraud in land administration. The prototype provides practical insights for policymakers and institutions seeking to modernize land registration, while further research is required to address scalability, transaction costs, and regulatory adaptation before large-scale implementation.

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