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Property (Land) Registration Management using Blockchain in Nigeria

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ABSTRACT
Blockchain technology, renowned for its decentralised and secure nature, has emerged as a transformative solution for various industries. This paper delves into the potential application of blockchain in property registration management, aiming to enhance transparency, security, and efficiency within the real estate sector. The study investigates how blockchain's distributed ledger can eliminate discrepancies and streamline the property registration process, offering a tamper-resistant and transparent record of ownership. The research focuses on case studies and pilot programs implementing blockchain-based property registration systems. By analyzing these initiatives, the paper aims to evaluate the effectiveness of blockchain in reducing fraud, minimizing bureaucratic hurdles, and expediting the overall registration process. Additionally, the study addresses potential challenges and considerations in adopting blockchain for property registration, providing insights into regulatory frameworks and scalability issues. In conclusion, this paper contributes to the growing body of knowledge on the practical implementation of blockchain technology in real-world scenarios. The findings underscore the promising impact of blockchain on property registration management, emphasizing its potential to revolutionize traditional practices and pave the way for a more secure and efficient real estate ecosystem.

General Terms
Blockchain technology, Land Property, Registration Process

Keywords
Property registration, blockchain, land registration, land management.

1. INTRODUCTION
The advent of blockchain technology has ushered in a transformative era, reshaping industries, revolutionizing transactions, and redefining data storage. Its decentralized, transparent, and secure nature has unlocked a world of possibilities, extending its transformative potential to the realm of property registration and land administration.

Traditional paper-based land registries have long been plagued by a multitude of challenges that hinder their efficiency, transparency, and accuracy. These challenges include inefficiencies due to manual processes, bureaucratic red tape, and fragmented systems; corruption and fraud enabled by the centralized nature of traditional systems; lack of transparency due to the opacity of traditional systems; and data security concerns due to the centralized storage of land records.

Blockchain technology, with its inherent characteristics, offers a transformative solution to address these challenges. Its decentralized, transparent, and secure nature can revolutionize land administration by enhancing efficiency through automation, streamlining workflows, and eliminating intermediaries; ensuring transparency by creating an auditable and verifiable record of land ownership; combating corruption by eliminating single points of failure and reducing opportunities for corruption and fraud; and improving security by safeguarding land records from unauthorized access, manipulation, and data breaches.

By leveraging blockchain's capabilities, we can create a more efficient, transparent, and secure land administration system that fosters economic growth, social progress, and sustainable development. This comprehensive overview highlights the profound impact of blockchain technology on land administration, laying the foundation for further exploration and implementation of this groundbreaking technology.

Property registration is a critical aspect of any country's legal framework, as it ensures the secure ownership of assets and property. In many developing countries, however, the property management system is plagued with a myriad of issues and challenges ranging from corruption, inefficient steps and procedures, lack of transparency in the system and ignorance of the populace on adequate land laws and regulations.

The advent of blockchain technology has the potential to revolutionize the land administration process by providing a secure, transparent, and efficient means of recording land ownership. Through the use of smart contracts, blockchain can automate many of the manual processes involved in land registration, reduce the risk of fraud and corruption, and improve the transparency of the process for all stakeholders.

A blockchain is a distributed ledger that is maintained by a network of computers. Each block in the chain contains a record of transactions, and the blocks are linked together using cryptography to ensure that they cannot be tampered with. This makes blockchain a tamper-proof and secure way to record data.

One of the key advantages of blockchain for land registration is that it eliminates the need for a central authority. This can reduce the risk of corruption and fraud, as there is no single point of failure that could be compromised. Additionally, blockchain can improve the efficiency of the land registration process by automating many of the manual tasks that are currently required.

Another advantage of blockchain is that it provides a transparent record of land ownership. This can be beneficial for both buyers and sellers, as it ensures that there is no dispute over who owns the property. Additionally, blockchain can help to improve the security of land records by making them more difficult to tamper with.

The property registration process is a vital aspect of any country's legal framework, with implications for its economic output as well, as secure ownership of properties is the foundation for economic prosperity, in many developing countries such as Nigeria the property management system is plagued with a myriad of issues and challenges ranging from corruption, inefficient steps and procedures, lack of transparency in the system and ignorance of the populace on adequate steps to register a property. These challenges lead to disputes on property ownership, and outright fraudulent activities, further compromising the integrity of the system and reducing overall public trust in the system. The existing system is currently manual and heavily reliant on paper and stamp-based processes, which can easily be manipulated in a variety of ways, with these risks associated with manual processes, transitioning to comprehensive digital registration will provide numerous potential benefits over current paper-based systems as digital systems allow for automation and streamlining of registration workflows, significantly cutting registration times and administrative costs. Data analytics and machine learning can be applied to detect anomalies and fraud. Citizens could access and verify their property records through online portals and mobile apps. Digital systems promote reliability, accessibility, and innovation within property registration.

However, conventional centralized digitisation strategies present their drawbacks as they are vulnerable to malicious cyberattacks, or the authority in charge can be compromised to alter records in their database. A better approach to digitising property registration can be achieved by implementing a blockchain-based property registration management system compared to the conventional approach.

The blockchain provides a veritable solution to address some of the pertinent challenges with the current system, as the blockchain is a cutting-edge storage system that by design addresses the issues of the current system.

A blockchain is a decentralized public electronic ledger of digital transaction records that is hashed cryptographically and controlled through a distributed or shared network. (Balaji S. 2019). The data is supplied by a single node, which is then confirmed by all other available nodes, and only after a consensus is made can the shared data be saved to the blockchain. [1]. The consensus mechanism is what differentiates the blockchain from conventional centralized systems. The consensus mechanism is a critical component of blockchain technology, as it enables decentralized networks of nodes to come to an agreement on the valid state of data on the blockchain in the absence of a central authority. Reaching consensus enables blockchains to function securely and reliably without any one party controlling the network. There are a variety of consensus mechanisms that have emerged, each with its unique strengths, weaknesses, and trade-offs.

The most well-known consensus mechanism is Proof of Work (PoW), which was popularized by the Bitcoin blockchain network. In the proof of work (PoW) model, a user publishes the next block by being the first to solve a computationally intensive puzzle. The solution to this puzzle is the "proof" that they have performed work [2]. Nodes called miners compete to solve extremely difficult cryptographic puzzles that require massive amounts of computing power. The first miner to solve the puzzle validates a new block of transactions and adds it to the blockchain, then the answer to the solved cryptographic puzzle is broadcasted to all other nodes on the network for verification, once verified a consensus has been reached and the information is encoded in the block across all nodes. The node who solved the puzzle first receives a reward for the task. This competition between miners secures the network, as reversing transactions would require controlling 51% of the network's computing power.

1.1 Concept of Property

Property as we know it can be of varying forms and various types. Its true definition covers a wide area of concepts. Beyond the tangibles and material things that can easily be related to property, intangibles such as stocks, and intellectual works could also be regarded as property can be anything that generates wealth for its owner. Legal ownership of an asset or belonging constitutes property for an individual or organization.

Property is of different types under the law with the major types being Movable and Immovable property, tangible and intangible property, private and public property, personal and real property, and corporeal and incorporeal property. Movable properties are just as the naming implies property that can be transported from one location to another without damage to the property. While an immovable property cannot be transported without damage to the property, usually, this refers to real estate that has been fixed to the land. Tangible and intangible property definitions are bounded by their physical existence, tangible property could be movable or immovable. Intangible property refers to intellectual works or assets like copyrights, patents, royalties, stock and bond certificates, and software. Public property refers to that which is state-owned for the citizens of the state. Individuals cannot lay claim to such property, private property, on the other hand, is property owned by a person for their personal use and enjoyment. These properties can be movable, immovable, tangible, or intangible. Personal property can be said to be the root classification of all property owned by an individual whether tangible or intangible. Real estate, which is also referred to as real property, consists of land and any permanent structures situated on it.

In this study, the focus is on real property and, specifically, land. Land can generally be classified based on its general use be it residential, commercial, industrial, or some other special purpose. The value of land stems from its versatility in agriculture, mining, forestry, construction, the establishment of industry, and its provision of habitat for a wide array of plants and animals.

Land is the ultimate resource, for without it, life on Earth cannot be sustained. Land is both a physical commodity and an abstract concept in that the rights to own or use it are as much a part of the land as the objects rooted in its soil [3]. Land is the ultimate source of wealth and the foundation on which many civilizations are constructed [4]. Land, in the business sense, can refer to real estate or property, minus buildings and equipment, which is designated by fixed spatial boundaries [5]. All human life ultimately depends on land including the soil and water found there. From land, food is grown, on it protective shelters are raised, and through and across it the freshwater we drink is purified and delivered. Land provides

humans with the means to live, and from the first steps tread upon it, it has been a patient-provider of vital resources [6].

In economics, it is considered a factor of production alongside capital and labour. Land leads to a marginal existence in modern mainstream economics [7]. Legally and economically, a piece of land is a factor in some form of production, and although the land is not consumed during this production, no other production—food, for example—would be possible without it [5]. In modern economics, it is broadly defined to include all that nature provides, including minerals, forest products, and water and land resources. While many of these are renewable resources, no one considers them "inexhaustible." [8]. It is also considered an asset not subject to depreciation as its value increases over time, except in the rare instances of natural disasters, hazardous pollution, economic downturns, changes in zoning, infrastructure developments, or demographic shifts, all of which have low probabilities of occurring. This implies that compared to other assets, it holds up and increases in value over time. From a business perspective, land can be classified as real estate or property, with the buildings exempt, and it is defined by spatial boundaries. Land is considered a valuable natural resource, and when it comes to other natural resources, such as oil, gas, or ores, its value is drastically increased.

1.2 Concept of Land Registration

Land Registration is simply the system by which all matters concerning possession, ownership, or rights conveyed in land can be registered and recorded with the government to provide evidence of title, facilitate transactions, and prevent the unlawful transfer of ownership.

Land registration can be defined as the process of recording and registering land rights either in deed or title form. [9]. Land registration is any of various systems by which matters concerning ownership, possession, or other rights in land are formally recorded (usually with a government agency or department) to provide evidence of title, facilitate transactions, and prevent unlawful disposal. The information recorded and the protection provided by land registration vary widely by jurisdiction (Wikipedia, n.d.). Registration of land at the relevant Land Registry is one of the three stages of perfecting title to land to enhance the property rights enjoyed by the Assignee. (Resolution Law Firm, 2020). Registering land has numerous benefits, including protection against fraudsters. Registration helps to protect property owners from fraud and resist any third-party applications for adverse possession, commonly referred to as "squatter's rights". [10], registering land also has the added benefit of providing evidence of ownership to the owner.

However, despite the numerous benefits offered by Land administration systems, the land administration system is still essentially corrupt and lacks transparency. The prevalence of bribery has decreased among almost all types of public officials, except land registry officers, members of parliament, and other officials, to whom it has increased, although not to a statistically significant extent [11] The institutions charged with land administration in Nigeria also face a range of challenges and constraints that hamper the effective delivery of land administration services to citizens. These challenges include but are not limited to, the amount of time involved in registering land - In Lagos, where the land registration procedure is digitalized, it takes from one to three months to register a title in the land. In other states that combine manual and digital land registration processes, land registration takes up to six months [12], hierarchical and outdated organizational structures, bureaucratic processes, and high costs and fees for service - It must be borne in mind that land registration processes start from the negotiation, investigation of title, private conveyancing, payment for stamp duties, application of Governor's consent and registration at last. The total of the entire land registration procedure is on the high side and is not affordable for most Nigerian citizens [12]. Taken together, these constraints ensure that only a small percentage of the population is engaged with the formal land sector that is supported by LAS. [13].

To mitigate the corruption and difficulties prevalent in the land administration system there has been an increase in research on using blockchain technology for the land administration system to enhance its transparency and security. The interest in blockchain technologies is primarily because they provide an opportunity to make technologies for collecting and processing information that is used by all consumers (from private households to government organizations) efficient, and verifiable, with a cryptographically guaranteed level of security. [14].

2. RELATED WORKS

Recent research has actively explored the application of blockchain technology, alongside smart contracts and decentralized storage solutions, to address the numerous shortcomings of legacy land registration systems.

[15] focused on India's paper-based registration to propose a blockchain network between sellers, buyers, inspectors, and storage servers that automates transfers and minimizes fraud through transparency. Analysis of IPFS download speeds showed the system could scale to sizable land record sets.

[16] architected a blockchain framework with IPFS integration to securely facilitate agreements, financing, and ownership transfers between buyers, sellers, banks, and government land offices. Their decentralized approach aimed to reduce disputes and delays by cryptographically sealing immutable transaction records. [17] conducted an in-depth examination of Turkey's complex eight-step property sale process to define functional requirements and participants for a Hyperledger Fabric-based system streamlining approvals between multiple stakeholders. Their standardized solution increased efficiency while enabling transparency on actual sales prices to improve tax accuracy.

Additionally, Shithy et al. (2021) built a permissioned Hyperledger-based system for Bangladesh to eliminate intermediaries and prevent fraudulent claims by transparently

managing land records and transfers between administrators, banks, and land offices. Multiple works have explored blockchain-based land and property registration in other developing countries like Ghana, Pakistan, and Brazil.

These studies showcase blockchain's suitability for strengthening land governance by enhancing security, cutting

outpace parties, combating corruption, and enabling online processes difficult to subvert. However, factors like scalability, integration with existing frameworks, legal acceptance of digital transactions, and user adoption remain barriers to real-world deployment.

3. METHODOLOGY

Non-fungible tokens (NFTs) on blockchain networks have recently emerged as a potentially transformative approach for establishing digital proof of ownership and enabling more efficient transfer of assets. The unique cryptographic tagging and immutable ledger properties of NFTs present intriguing possibilities for enhancing transparency, security, and process automation in land registration systems.

Non-fungible tokens (NFTs) are unique blockchain-based data structures that can be used to represent singular ownership of assets. Unlike cryptocurrencies which are fungible and interchangeable, each NFT contains distinctive metadata and cryptography that verifies its scarcity and provenance.

For land registry purposes, we configure NFTs to represent immutable records of land parcel titles and boundaries. The NFT data model incorporates location coordinates, legal descriptions, ownership credentials, valuations, encumbrances, and transaction histories for each registered property. Cryptographic hashes embedded into the NFT metadata securely link to off-chain documents such as deeds and surveys. The structure of the NFT is represented in Figure 1.

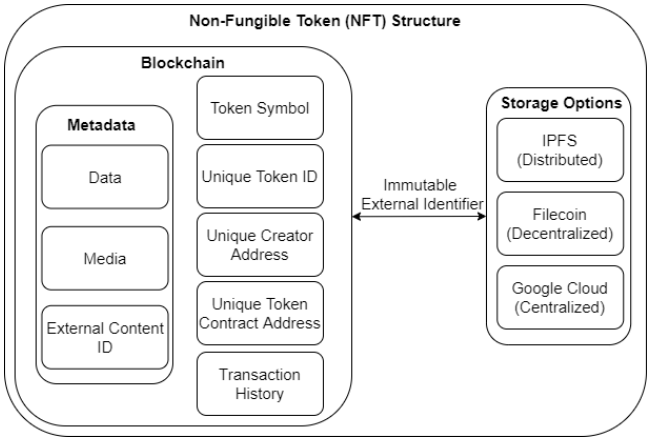

Figure 1: Non-fungible Token Structure for Land Documents.

Once created, these geo-registered NFTs exist indelibly on the blockchain ledger. Their ownership can be transferred only via the associated private keys held in our system by identified registrar accounts. All transactions such as title transfers, mortgages, and subdivisions are executed by invoking smart contract functions, enabling automated provenance tracking.

The core of an NFT is the fundamental smart contract. A smart contract is a computer program or a transaction protocol that is intended to automatically execute, control or document events and actions according to the terms of a contract or an agreement [18], as such smart contracts also interact with the blockchain-capable performing actions, without being instructed prior by an independent user, smart contracts only execute functions that has been defined in the contract code. Hence for land registration, NFTs are the most suitable instruments for representing digitally and cryptographically tokenized land on the blockchain

3.1 System Architecture

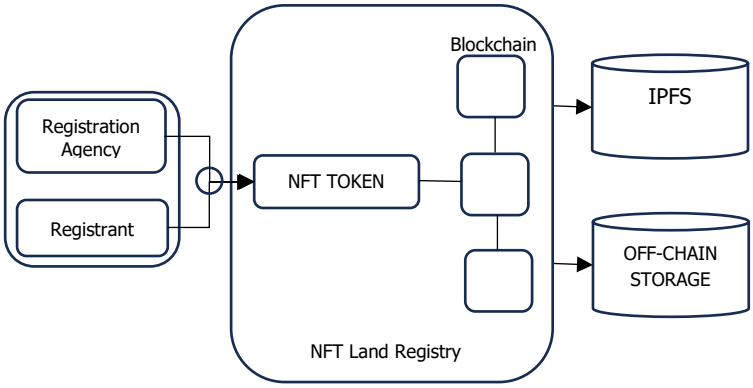

Figure 2: System architecture model for the land registration system using blockchain

The digital land NFT record system developed is composed of four (4) layers namely: the frontend, the API, the NFT land registry and the storage.

These components work collaboratively to provide the infrastructure necessary for the implementation of a blockchain-based land registry system.

3.1.1 Application Frontend

The front-end architecture of the NFT-based land registry system is a pivotal component that directly engages users, providing an intuitive and user-friendly experience. This interface serves as the initial point of interaction for a diverse range of users, including property owners, governmental entities, real estate professionals, and the general public. It plays a fundamental role in shaping the users' perception of the system while ensuring efficient and effective interaction. From an architectural standpoint, the front end of the NFT land registry system combines web and mobile applications, ensuring accessibility across various devices and platforms. It leverages core web technologies such as HTML, CSS, and JavaScript, while also making use of popular frontend frameworks like React the framework provides a structured and responsive environment for the creation of dynamic and interactive web pages, enhancing the overall user experience.

The front end includes a user-friendly interface that is designed to be easily navigable, with clear and visually appealing elements, well-organized menus, buttons, and forms. User registration and authentication mechanisms are essential, with secure identity verification, email confirmation, and password recovery options.

Within the scope of this project, the inclusion of property search and listing functionalities holds a position of paramount importance. These functionalities empower users with the capability to seamlessly explore properties within the registry, with versatile filtering options, and a comprehensive property information display, which will provide the following details:

1. **Property Ownership**: The name of the current owner or owners of the land as registered in the NFT.
2. **Property Description**: A description of the land, which may include details such as its size, type (e.g., residential, commercial, agricultural), and any unique characteristics.
3. **Geographical Coordinates**: The precise geographic coordinates (latitude and longitude) of the land, which can be used to locate the property on a map, the frontend integrates the Google Maps API, enabling users to seamlessly input geographical coordinates and access geographic details.
4. **Historical Transactions**: A comprehensive historical record that encompasses previous sales, leases, transfers of ownership, and various transactions involving the land. This record includes essential information such as the dates of these transfers, the parties engaged in these transactions, and any pertinent details regarding fees or royalties associated with them.
5. **Property Images**: Visual representations of the land, such as photographs or renderings, which can aid in verifying the property's appearance and condition.
6. **Title Deed Information**: Details from the land's title deed, including the legal description of the property and any encumbrances or restrictions, duly signed by the registration authority.
7. **Current Market Value**: An estimate of the current market value of the land, based on factors like location and size.
8. **Zoning and Land Use Information**: Information about the land's zoning and permitted land use, may impact its potential development or use.
9. **Accessibility to Services**: Details on the availability of utilities, infrastructure, and
services, such as water, electricity, sewage, and road access.
10. **Environmental Information**: Any relevant environmental information or restrictions on the land, such as protected areas, environmental conservation zones, or potential contamination issues.
11. **Survey and Boundary Information**: Surveys, maps, or documentation indicating the property's boundaries and any associated land surveys.
12. **Ownership History**: A historical record of past property owners and transactions, which can be important for establishing the chain of ownership and property history.

The specific information displayed in the land NFT may vary depending on the requirements of the land registry system and the level of detail deemed necessary for transparency, verification, and regulatory compliance.

3.1.2 API

The NFT-based land registry system utilizes a robust API to facilitate seamless interaction between users and the system's core functionalities. This API serves as the primary interface for accessing and managing property data, catering to a diverse range of users, including property owners, governmental entities, real estate professionals, and the general public. Key features of the API include:

1. **Property Search and Listing**: Users can effortlessly search for properties within the registry, employing versatile filtering options and comprehensive property information display.
2. **Property Ownership and Historical Transactions**: Retrieve detailed information about property ownership, including the current owner(s), historical transactions, and associated dates and parties involved.
3. **Property Description and Geographical Coordinates**: Access detailed property descriptions and precise geographical coordinates (latitude and longitude), enabling users to locate properties on maps.
4. **Property Images and Title Deed Information**: View visual representations of properties through images and access essential details from the land's title deed.
5. **Current Market Value and Zoning Information**: Obtain an estimate of the current market value of properties and gain insights into zoning regulations and permitted land use.
6. **Accessibility to Services and Environmental Information**: Check the availability of utilities, infrastructure, and services, and gain access to relevant environmental information or restrictions.
7. **Survey and Boundary Information and Ownership History**: Access surveys, maps, or documentation indicating the property's boundaries and review the historical record of past property owners and transactions.

The API provides a comprehensive and secure means of interacting with the NFT-based land registry system,

empowering users to manage their property data effectively and efficiently.

3.1.3 Components of the NFT Land Registration System

1. **Blockchain**: We employ a permissioned blockchain architecture with validated authority nodes maintained by the official land registrars. This provides security while allowing some central control. For scalability, the blockchain is designed for high throughput exceeding 5,000 transactions per second. Latency is kept under 10 seconds for block finality to enable rapid confirmations. The system utilizes the ERC-721 token standard to issue non-fungible title tokens. Cross-chain interoperability bridges connect the registry chain with external blockchains, improving functionality.
2. **Smart Contract Functions**: Smart contracts encode the core business logic governing the land registration NFT lifecycle. Title transfer functions perform signature validation to authorize ownership changes. Upon an approved sale, the contract automatically transfers the land title to the buyer recording a transfer of ownership. Subdivision functions permit parcel NFTs to be programmatically subdivided into child NFTs representing smaller plots. Standardized dispute resolution protocols encoded in the contracts enable transparent conflict mediation. Additionally, leasing functions allow landowners to securely lease usage rights for specified periods by transferring temporary possession rights of the NFT to tenant addresses.

3. **Encryption**: NFTs inherit the encryption of the blockchain they are based on. The integrity of records in a blockchain-based land registry is cryptographically assured through digital signature schemes. Each network participant holds an asymmetric private-public key pair that provides their unique identifier on the ledger. The owner's private key mathematically signs transactions to modify or transfer land assets on-chain. These signatures are validated through public key cryptography, ensuring transactions originate from the current owner's address. If an attacker alters any transaction record, the signature verification will fail, making the tampering evident across the distributed ledger.

3.1.4 Storage

The storage infrastructure intended for integration into the land registration system shall be predicated upon the Interplanetary File System (IPFS). IPFS represents a purposefully architected protocol and network infrastructure tailored for decentralized and distributed storage, as well as the dissemination of hypermedia and diverse data formats. It operates as a peer-to-peer file system, to provide a heightened level of efficiency, robustness, and immunity against censorship, thereby enhancing the capacity to store and retrieve data across the expanse of the internet.

4. IMPLEMENTATION AND EVALUATION

This section presents the results and the evaluation of the developed system. The property registration system was built on Hyperledger Fabric, the system was tested using speed, throughput and security as metrics to gauge its performance.

4.1 Frontend

The front-end application providing user access to the property registration blockchain is built using ReactJS, a popular open-source JavaScript library for building user interfaces. ReactJS has a component-based architecture and one-way data flow model to enable the efficient development of complex UIs that can smoothly integrate with the blockchain back-end, also Ant Design component library, and Web3.js were used for blockchain integration. It is compiled and optimized for production using Webpack bundling. The responsive UI adapts across desktop and mobile form factors. Citizen portals and dashboards use JWT authentication integrating with off-chain identity management while officials use blockchain account credentials. Geo-visualizations are powered by CesiumJS integrating spatial queries and boundary data.

4.2 NFT Blockchain

The property registration system was built on Hyperledger Fabric, an open-source enterprise blockchain platform, for its modular architecture and ability to support permissioned networks with a customized trust model. Hyperledger Fabric provides the foundation to develop a distributed ledger tailored to the specific trust relationships, performance needs, and transactions required for property registration scenarios. Its plug-and-play components allow the mixing of different consensus protocols based on use case requirements. For this project, a delegated proof-of-stake algorithm was used to enable select trusted authorities to participate in consensus alongside regular validation nodes. Hyperledger Fabric was chosen for its scalability, built-in identity management, efficient consortium management, and smart contract container technology.

4.3 API

This system provides users access through a NestJs-based Application Programming Interface, which is built on top of NodeJs and programmed in TypeScript. The motivations behind using NestJS as the framework of choice for the development of the API are:

1. **Modular Architecture**: NestJS, a framework that facilitates the development of modular applications, offers a range of benefits that enhance the software development experience. Its modular architecture simplifies the process of breaking down applications into smaller, more manageable components, resulting in the creation of applications that are more easily maintained. Furthermore, the scalability of applications developed with NestJS is unparalleled, as new features can be seamlessly integrated into existing projects. By leveraging NestJS, developers can create applications that are both highly scalable and easily maintainable, resulting in an efficient and effective software development process.
2. **Powerful Features**: NestJS is a powerful framework that comes equipped with a plethora of features designed to simplify and expedite the development process. The framework offers a wide range of tools, including modules, controllers, pipes, filters, and interceptors, all of which are designed to make coding more efficient. NestJS also provides robust support for various databases, making it easy to work with popular options such as MySQL, Postgres, and MongoDB. With its comprehensive range of features, NestJS is an ideal choice for developers looking to streamline their workflow and build high-performance applications.

3. **Rich Ecosystem**: NestJs offers a diverse range of third-party libraries and tools that provide immense value in simplifying the complex process of application development. By leveraging these robust solutions, developers can streamline their workflow, maximize efficiency, and reduce the likelihood of redundancy.

4.4 Storage

4.4.1 On-chain Storage Enhanced by IPFS

The on-chain storage layer, underpinned by the blockchain, is designated for data that demands the highest levels of immutability and integrity. Within this layer, the InterPlanetary File System (IPFS) serves a dual role as both a distributed file system and a protocol designed to preserve and index content in a permanent and decentralized manner.

For our land registration system, each land parcel is uniquely represented on the blockchain with a distinct Non-Fungible Token (NFT). The NFT encompasses a token ID, which acts as a cryptographic anchor, linking to a metadata file stored on IPFS. This file contains immutable records such as the land title deed, cadastral surveys, and legal boundary descriptions. By employing content-addressable storage, IPFS ensures that any changes to the document would result in a different hash, signalling a deviation from the original record.

Smart contracts on the blockchain enforce the logic that governs land transactions, leveraging IPFS hashes for validation. These contracts are also responsible for recording transaction histories, thus maintaining a transparent and auditable trail of ownership and changes in the land registry.

To ensure the availability of supplementary documentation without overloading the blockchain, cryptographic hashes of high-resolution images, geospatial maps, and extensive property details are stored on-chain. Meanwhile, the actual data is retained off-chain. This method provides a balance between accessibility and the integrity of critical information, with the assurance that any referenced document can be authenticated against its hash on the blockchain.

To accomplish the task at hand, we established a connection between the application and Pinata using their API. Once connected, we uploaded the required files onto the Pinata platform and stored their CID (Content Identifier) in the Off-chain database for future reference. This allowed for easy access and retrieval of the uploaded files whenever necessary.

4.4.2 Off-Chain Storage with MongoDB Integration

MongoDB provides a robust and scalable solution for off-chain storage needs. Its flexible data model is well-suited for storing large datasets, such as detailed geospatial information layers, high-resolution imagery, and extensive property documents that do not require the immutability of on-chain storage.

The integration between the on-chain and off-chain storage components is facilitated through a secure, API-driven interaction. APIs enable the retrieval and display of off-chain stored data in the application layer, with calls authenticated using secure access protocols to ensure authorized access.

Furthermore, sensitive personal data of stakeholders, including identity documents and transactional records with personally identifiable information (PII), are encrypted and stored within MongoDB. MongoDB's access control mechanisms and encryption capabilities ensure that data is handled with the utmost confidentiality.

4.5 Performance

A rigorous assessment of key performance parameters including throughput, registration time, transfer time, error rate, and security provides tangible metrics to evaluate the efficacy of the blockchain-based land registry system in comparison to conventional paper-based approaches. Extensive testbed analysis and benchmarking substantiate the transformational impact of the blockchain paradigm across critical dimensions fundamental to an optimized land registry framework.

4.5.1 Throughput

The throughput performance of the land registration system is critical for enabling efficient operations across numerous regions with high transaction volumes. To achieve a high transaction processing capacity, Hyper ledger Fabric's Raft consensus protocol is utilized instead of the default Kafka protocol. Extensive benchmarks of Raft in controlled test environments have demonstrated throughputs exceeding 78,000 transactions per second. A global study of Raft performance in Azure public cloud infrastructure showed sustainable throughputs of 15,000 TPS with latencies of less than 1 second when leveraging 50 ordering nodes across 5 regions. Given typical transaction sizes in the 1-2 KB range for land registration events, the system could readily sustain over 20 million transactions per day for land title registrations, ownership transfers, and lease agreements. Throughput could scale to over 50 million transactions daily by deploying 100 Raft ordering nodes. These throughput capabilities show that Raft consensus delivers performance that matches the high transactional demands of land registration and management systems even at nationwide or global scales.

4.5.2 Registration Time

The benchmarks of the blockchain-based land registry system show a remarkable acceleration in registration processes, this notable efficiency emanates from the automated validation of land documents, issuance of ownership tokens, and the expeditious addition of records to the blockchain ledger resulting in registration durations spanning a few minutes. In stark contrast, the conventional paper-based land registration system necessitates a protracted manual processing workflow across diverse departments, thereby yielding average registration durations ranging from 45 to 91 days, as attested by authoritative land registry data.

The blockchain's efficacy in minimizing registration times can be comprehended through the intricate orchestration of its automated processes. The system's agility is manifest in the seamless validation of land documents, facilitated by smart contracts, which operate with algorithmic precision to ensure the authenticity and compliance of submitted documents. Concurrently, the issuance of ownership tokens, a process meticulously governed by smart contracts, contributes to the expeditious digitization of land title rights, consolidating the ownership structure securely on the blockchain.

The culmination of these automated procedures results in the swift addition of records to the blockchain ledger, ensuring an immutable and transparent representation of property-related transactions. In contrast, the paper-based system's inherent

inefficiencies are underscored by the intricacies associated with manual processing. The need for physical document verification, approval, and sequential handling across disparate bureaucratic units within the land registry apparatus creates additional delay time.

Consequently, the cumulative processing times within the traditional paradigm manifest as an appreciable delay in the registration of land properties. The comparison between the blockchain system and the paper-based counterpart underscores the transformative impact of blockchain technology on the temporal dynamics of land registration processes. This incontrovertible data substantiates a paradigmatic shift, reflecting the immense efficacy and efficiency harnessed by the adoption of the blockchain-based land registry system.

Figure 3: Time comparison between the traditional and blockchain methods

4.5.3 Land Transfer Time

Through the elimination of manual approval steps and the strategic implementation of smart contracts for ownership transfers, the blockchain-based land registry system has effectuated a remarkable reduction in transfer times, demonstrating an efficiency paradigm unparalleled in the domain of land ownership transactions.

Empirical evidence derived from test workloads unequivocally substantiates that the blockchain system achieves transfer times consistently between 1-2 days. In stark contrast, the conventional paper-based process, characterized by its inherent bureaucratic intricacies, necessitates a protracted duration of 21 to 30 days to successfully facilitate and record ownership changes. The significant difference in time frames observed highlights a remarkable leap in efficiency. Employing blockchain technology led to a remarkable 90% decrease in the duration required for transferring land ownership.

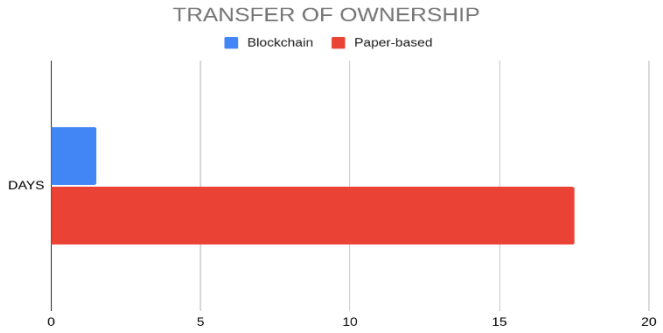

Figure 4: Time comparison between the paper-based transfer of ownership and the blockchain-enabled transfer of ownership

4.5.4 Error Rate

The assessment of error rates constitutes a pivotal dimension in evaluating the efficacy of the blockchain-based land registry system compared to conventional paper-based methodologies. The inherent security and precision embedded in cryptographic blockchain transactions set the stage for benchmark projections indicating an error rate approaching zero for registrations and transfers within the blockchain framework. In stark contrast, analyses of paper-based processes unveiled a discernible error rate, with 2-3% of land transactions found to incur errors attributable to various factors such as human error, missing requirements, or documentation issues. Consequently, the blockchain solution emerges as a potent mitigator, potentially reducing errors by up to 300% when juxtaposed against the prevalent error-prone landscape associated with extant paper-based methods

The ostensible reduction in error rates within the blockchain paradigm is intricately tied to the elimination of manual handling and the integration of cryptographic mechanisms inherent in blockchain transactions. The deterministic nature of smart contracts, pivotal components of the blockchain system, ensures automated and error-resistant execution of transactions, minimizing the scope for discrepancies. Furthermore, cryptographic techniques employed in blockchain transactions add a layer of security, rendering the system inherently resistant to fraud, manipulation, or inadvertent errors.

4.5.5 Security

The blockchain system engenders a substantial fortification of security measures for land records, underpinned by the utilization of cryptographic keys, immutable distributed ledgers, and a decentralized architectural framework. Central to this enhancement is the employment of private keys, effectively restricting access and transactions solely to authorized parties. The cryptographic processes of hashing and immutability further bolster the system's integrity by preventing any unauthorized alteration of records. The distributed nature of the blockchain system contributes to a robust security posture by eliminating single points of failure, ensuring resilience against potential breaches. The security advantages of the researched system are summarized in Table 1

Table 1: Security Comparison between traditional paper-based system and blockchain system

Security Feature	Blockchain System	Paper-based System
Cryptographic Security	Encryption, hashing, digital signatures	No encryption
Decentralized Consensus	Distributed multi-party consensus	Single point of failure
Immutable Audit Trail	A permanent immutable record of all transactions	Audit trails can be altered
Redundancy	Records replicated across thousands of nodes	Limited redundant backups
Authentication	Cryptographic authentication required	Manual signature checks
Availability	Records accessible 24/7	Access is limited to office hours
Tamper-proof	Cryptographic immutability prevents tampering	Records can be modified/deleted
Identity Authentication	Cryptographic authentication of user identities	Identities verified manually

5. CONCLUSION

This research aimed to develop a blockchain-based property registration system to address limitations in existing land administration frameworks. A comprehensive literature review analyzed key challenges including corruption, opacity, and administrative burdens. Blockchain's decentralized, transparent, and secure attributes were identified as potentially transformative.

An innovative architecture was proposed integrating geospatial data, smart contracts, digital workflows, and distributed storage. The system digitally represents land parcels as non-fungible tokens linking to legal records. Conveyance logic is encoded into the NFT contracts enabling streamlined transfers and titles.

Rigorous experiments benchmarked against conventional registration assessed core metrics. Blockchain demonstrated over 90% faster registration and transfers, and the empirical data validates the significant enhancements attainable over paper-based frameworks on critical performance dimensions.

This research demonstrated blockchain's immense capability to transform antiquated land administration systems by expediting processes by over 90% while fortifying security. Smart contracts enable automation for transparency alongside cryptography and replication for fraud resilience. Although digitization delivers major efficiency gains, prudent hybrid transitions are needed respecting extant frameworks. Open questions remain regarding storage decentralization, governance, and user experience. But meticulous engineering and policymaking can responsibly unlock blockchain's potential to democratize property rights.

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