CREATION OF A DEVELOPMENT RIGHTS MANAGEMENT MECHANISM USING BLOCKCHAIN TECHNOLOGY

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Abstract
The Transfer of Development Rights (TDR) is an urban planning tool that allows the transfer of building rights from one property (where construction is restricted due to regulations, e.g., historical monuments, protected areas) to another property where increased construction is permitted. The legal framework governing TDR in Greece is Law 4759/2020 (Government Gazette A' 245/09.12.2020) for the modernization of spatial and urban planning legislation, which provides for the establishment and operation of the Digital Land Bank (DLB).

The Digital Land Bank serves as a mechanism for:

- *Recording all transferable development rights available.*
- *Exchanging and transferring development rights between property owners.*
- *Transparency, by providing access to accurate information on the availability of building rights.*

In this research paper, we propose a theoretical framework for the operation of the Digital Land Bank, based on Blockchain technology and the use of smart contracts, including various mechanisms that can further enhance the effectiveness of such an application. The use of Blockchain technology in urban planning tools like TDR through the Digital Land Bank could revolutionize the management of such development rights, generating the following benefits:

- ***Transaction security**: Each transfer of building rights can be recorded with an encrypted signature on the Blockchain, preventing fraud through verifiable transactions.*
- ***Transparency**: The Digital Land Bank allows all participants (e.g., property owners, authorities) to track the path of every building right through a tamper-proof system.*
- ***Elimination of bureaucracy**: Transfer processes become immediate and automated, reducing delays caused by traditional registration systems.*
- ***Interoperability**: Blockchain allows the integration of the Digital Land Bank with other systems (e.g., land registry, taxation systems).*

Nevertheless, investments in technology, legal adjustments, and education are required to overcome challenges and achieve full implementation.

***Keywords**: Transfer of Development Rights, Blockchain, Smart Contracts, Digital Land Bank, Urban Planning, Transparency, Interoperability.*

1. Introduction

Managing urbanization and land usage has long been a challenge for developers, policymakers, and property owners. Because it permits the flexible redistribution of development rights while preserving places that are significant to the environment or culture, the Transfer of Development Rights (TDR) is a crucial tool in urban planning. Development rights are the ability to alter or improve a property, such as by constructing new structures, expanding existing ones, or altering the land's original use. Development Rights are commonly transferable (TDRs), allowing owners to sell or assign them to a third party. Even if owners do not intend to develop their land directly, transferability allows them to capitalize on its development potential. This is especially useful in areas where development is limited due to legal or environmental constraints.

The legal characterization of a TDR title generally recognizes the right it embodies as a real right, a form of property right. This aligns with the view of Hou, Chan, and Li (2018), who explore TDR as an institutional innovation addressing property rights issues. Their research highlights how TDR programs can effectively balance public and private interests in development by enabling property owners to transfer their development rights to designated receiving areas.

Furthermore, Boettke and Candela (2014) underscore the importance of development rights as an integral component of the broader institutional framework of property rights, a framework crucial for economic development. They posit that clearly defined and enforceable property rights, including development rights, are essential for stimulating investment and driving economic growth.

Development rights, as a fundamental aspect of property ownership, are frequently subject to land use policies, planning regulations, and local zoning ordinances. While referred to by various names internationally, including Building Rights and Air Rights, in Greece, the concept is synonymous with "transferable building coefficient."

The law n.4759/2020 establishes the current legislative framework for TDRs in Greece, with the primary goal of creating a mechanism for the Digital Land Bank (DLB). The DLB is primarily an electronic marketplace for the trading of building rights. It can also serve as a funding source for green projects and a compensation mechanism for property owners.

For sellers and buyers of development rights (DR) who use the DLB platform to disclose their real estate assets, the DR transfer procedure will take place electronically, with no mediation or state interference.

The creation of Local Spatial Plans (LSP) by municipalities and the designation of at least a few locations for the distribution of building rights—known as Building Rights Reception Zones (BRRZ)—are prerequisites for the functioning of the DR transfer system. In essence, property owners whose construction rights have been "removed" (either whole or partially) are the potential sellers of building rights on the DLB. The Ministry of Environment will electronically issue a DR transfer title for any property that is planned for sale. The title will then be assessed using a mix of the property's square footage, chronological order, and the zone price of the area. The final stage in the procedure is to register the property with the DLB. The buyer, in turn, submits an electronic application stating their intention to purchase DR and indicating the property in a BRRZ to which the DR will be affixed. The DLB platform speeds up the process by automatically and anonymously matching DR between sellers and purchasers, prioritizing DR transactions within the same municipality.

When the DR transfer is complete, the matching DR is withdrawn from the donor property, and the cadastral office is notified of the changes. DR transfers made through the DLB are subject to a statutory payment to the Green Fund (a public-law body reporting to the Ministry of Environment and Energy) of 5% of the transferred DR's objective value. This cash will be used to fund environmental and urban planning balancing efforts in the municipality where the BRRZ is located.

The Technical Chamber of Greece is tasked with developing and operating the Digital Land Bank (DLB) under a decision issued by the Deputy Minister of Environment and published in the Government Gazette 4605 B/2022. The DLB will consist of a set of separate functions, including at least the following:

a. The establishment of a digital database for donor and recipient properties of building rights and associated transfer titles, along with the management of the records' content, comprises the following:

- Database design (including requirements analysis, entity-relationship diagrams (ERD), conceptual and logical designs, physical and functional designs, and entity/relationship models).
- The deployment and setup of G-Cloud-compatible apps and security measures that make use of cloud computing services (IaaS, PaaS, and SaaS) and facilitate the functioning of the created databases and apps.b. Development of an application for graded user access to the services of the information system based on their designated roles.

c. Creation of a workflow management and monitoring application to support all required processes.

d. Provision of user training services for the system.

e. Ensuring the smooth operation of databases and applications.

f. Provision of maintenance and technical support services for the systems (applications and data).

The information system will be developed in accordance with common interoperability guidelines, leveraging open interfaces, protocols, and formats (together known as open standards).

The above indicates that the project primarily pertains to a cloud-based application that will centrally handle data. Cloud technology excels at scalability, ease of use, and integration, making it suited for managing enormous transaction volumes and frequently changing requirements.

On the other hand, there is a disruptive technology called Blockchain, which is said to change numerous industries. Blockchain is a decentralized, distributed ledger technology first introduced with Bitcoin in 2008 by Satoshi Nakamoto, an unidentified entity. Unlike traditional databases, blockchain provides transparency, security, and immutability by storing transactions in a chain of blocks that are protected by cryptographic hashing and consensus procedures (Swan, 2015).

Unlike cloud computing, which is based on centralized servers, blockchain eliminates the need for middlemen, lowering costs and the risk of single points of failure (Zyskind, Nathan, & Pentland, 2015). It improves security by making data tamper-resistant and provides greater transparency because records are immutable and verifiable by all network members (Pilkington, 2016).

Blockchain's openness, immutability, and security make it ideal for registering property rights. It eliminates fraud, streamlines transactions, and minimizes bureaucratic bottlenecks. Smart contracts can automate property transactions, and tokenization allows for fractional ownership, increasing liquidity and access to real estate markets (Zohar, 2015). Blockchain provides a more secure and efficient framework for managing property rights since it ensures verifiable ownership records.

This paper explores how Blockchain technology can help turn the DLB into a strong, transparent, and efficient system for controlling development rights. Blockchain-based methods can increase stakeholder confidence and involvement by solving critical concerns including fraud, inefficiencies, and bureaucracy.

2. Methodology

To construct a theoretical framework for a Blockchain-powered Digital Land Bank , the following methodologies were employed:

1. **Literature Review**: An extensive review of existing research on Blockchain applications in land management and urban planning was conducted. Key focus areas included transaction security, interoperability, and process automation.
2. **Case Studies**: Examples of Blockchain implementation in land registries, such as those in Sweden and Georgia, were examined to identify best practices and challenges.

2.1. Literature review

As elucidated by Culha (2020), blockchain technology has emerged as a transformative force across a diverse array of technological domains, presenting a complex interplay of opportunities and challenges. Within the realm of property rights registration and management, blockchain has demonstrated exceptional adaptability, finding applications in areas such as resource production, storage, deployment, and the monitoring of supply chains, particularly during crisis scenarios. Below is a synthesis of significant scholarly contributions that explore the application of blockchain technology in property rights registration and management, derived from comprehensive bibliographic research.

- **Allam and Jones (2019)** proposed an innovative model for the transfer of air rights—a form of Transferable Development Rights (TDR)—in New York. Their mechanism leverages smart contracts with rigorously predefined temporal clauses to regulate pricing and the broader air rights market, thereby enhancing market efficiency and transparency.
- **Shahab and Allam (2020)** distinguished between tradable permit schemes (TBS) and Transfer of Development Rights (TDR), categorizing both as market regulation tools. While TBS pertains to the trading of specific rights, such as exploitation rights for natural resources or emission rights for harmful substances, the authors proposed a blockchain-based mechanism aimed at reducing intermediation costs, thereby streamlining the process and enhancing market integrity.
- **Kumara and Gopiprasad (2020)** advocated for the use of blockchain technology to improve the governance of the TDR process in India. They proposed the creation of a digital platform for TDR title trading, designed to ensure transparency and provide real-time updates to all stakeholders. According to the authors, this solution would bolster the credibility of the TDR mechanism while mitigating risks such as cartel formation and the commoditization of TDR titles.
- **Dwivedi et al. (2023)** introduce a novel framework for the tokenization of development rights, emphasizing collaboration with development authorities. Their approach addresses practical challenges related to record-keeping, land verification, and stakeholder identification by integrating publicly available data, thereby ensuring the accurate evaluation of development rights.
- **Konashevych (2020)** provides a critical analysis of the applicability of blockchain and other distributed ledger technologies in real estate, property rights, and public registries. The study offers a multidisciplinary perspective on the constraints and benefits of blockchain, highlighting its potential to serve societal needs in property rights management.
- **Sladić et al. (2021)** examine the current processes for real property transactions within Serbian land administration and explore how modern ledger technologies, such as blockchain, can enhance these processes. The study underscores the potential of blockchain to improve transparency and efficiency in property transactions.
- **Madushanka et al. (2024)** introduce "SecureRights," an advanced blockchain-based digital rights management framework. This innovative solution combines blockchain technology with digital watermarking, perceptual hashing, QR codes, and the Interplanetary File System (IPFS) to strengthen defenses against unauthorized use and streamline the assertion of digital rights.

- **Stefanović et al. (2023)** highlight the growing prominence of non-fungible tokens (NFTs) as a significant application of blockchain technology beyond cryptocurrencies. While NFTs have gained traction in digital art, their potential in fields such as land administration, healthcare, and supply chain management is increasingly being explored. The authors propose a new standard to facilitate fractional ownership of NFTs, expanding their utility across diverse applications. They also provide a practical implementation of this standard using the Solidity programming language.
- **Rudytsia (2022)** outlines the development of a property rights distribution module utilizing NFT fractionalization, based on blockchain technology. By leveraging the Ethereum blockchain and the ERC-1155 standard, this approach enables the creation, fractionalization, and sale of NFTs tied to users' property. The system ensures security and uniqueness through cryptographic algorithms, eliminating the need for third-party intermediaries while maintaining data fidelity and trust. This innovative solution addresses key functional requirements, such as the generation of unique NFTs and the management of fractional ownership, offering a modern approach to decentralized property rights management.

The aforementioned studies collectively underscore the transformative potential of blockchain technology in enhancing the management, security, and transparency of property rights. By addressing critical challenges such as intermediation costs, data integrity, and stakeholder trust, these contributions pave the way for more efficient and equitable systems of property rights registration and management.

2.2. Case studies

In countries like Sweden and Georgia, blockchain technology has been used in land registries, demonstrating it can improve transaction transparency, efficiency and security. Below is a rundown of these cases along with a bibliography for reference.

Sweden - Lantmäteriet's Blockchain Pilot

Lantmäteriet, the Swedish land registry authority has explored the use of the Blockchain technology for property transactions from 2016 onwards as a pilot. The pilot was launched in partnership with Chromaway, a blockchain technology company, some banks and real estate companies to ensure the efficiency, security and transparency of the property transaction system in Sweden (Lantmäteriet, 2016).

As stated above, Lantmäteriet has developed an automated system that uses blockchain technology for property transactions. This system acts as a safe custodial for important documents pertaining to the transaction including but not limited to purchase sales agreements and mortgage documents. In this case, the transactions are automated through smart contracts with ownership records set to update automatically once the precondition is met. This ensures that real-time visibility is available to all stakeholders whether they are buyers, sellers, banks or government authorities facilitating and expediting the processes, removing the manual waiting time. By leveraging the immutability of blockchain, the system ensures that property records remain tamper-proof, thus increasing trust among participants.

The pilot project demonstrated the potential of blockchain to reduce property transaction timelines from months to mere hours while also minimizing reliance on intermediaries and lowering transaction costs for participants (Lantmäteriet, 2016). However, full integration of blockchain into Sweden's land registry faces regulatory and legal challenges. Updates to the existing legal framework are necessary to fully utilize the technology's capabilities (Lantmäteriet, 2016).

Georgia: Blockchain-Based Land Registry

Georgia emerged as a leader in the implementation of blockchain technology for land registration in 2016. This innovative initiative, led by the National Agency of Public Registry (NAPR) in partnership with the blockchain development company Bitfury, aimed to establish a secure and transparent property transaction framework (NAPR, 2016).

Blockchain stores cryptographic hashes of property titles in Georgia, ensuring that land ownership records remain authentic and unalterable. The blockchain seamlessly integrates with Georgia's existing land registry platform, simplifying the verification processes for ownership and transaction histories. Additionally, property owners receive digital certificates backed by blockchain technology, serving as irrefutable proof of ownership. The system significantly reduces vulnerabilities to fraud, forgery, and corruption, thereby strengthening public confidence.

By mid-2017, over 1.5 million land titles had been registered on Georgia's blockchain system. This transparent and reliable approach attracted foreign investors and fostered greater public trust in land transactions (NAPR, 2017). While blockchain secures records, physical land surveying and disputes regarding boundaries remain dependent on traditional methods and legal resolutions (NAPR, 2016).

Both Sweden and Georgia exemplify the transformative potential of blockchain technology in land registries. Sweden's pilot project underscores the efficiency of blockchain in reducing transaction times and costs, while Georgia's implementation highlights its role in building trust and transparency on a national scale. However, broader adoption of blockchain in land registries faces challenges, including necessary regulatory reforms and integration with existing legal systems. These case studies demonstrate the promising future of blockchain in real estate, contingent upon the effective resolution of these hurdles.

3. Conceptual Framework Design

Using literature and case studies as source material, a conceptual structure for the DLB was created. This included:

- Utilizing Blockchain's immutable public ledger, for the recording of TDR transactions.
- Implementation of compliance Check and Transfer Approval using Smart contracts.
- Interoperability with land registries and taxation systems.

The proposed mechanisms utilizes blockchain technology as a decentralized public ledger of immutable land titles and property rights. In addition to acting as a safe storage unit, blockchain technology is also inherently built to manage ownership. With Distributed Ledger Technology (DLT), users can directly manage their properties through peer-to-peer (P2P) transactions, eliminating intermediaries.

Tokenization forms the foundation of this system. Tokens are digital representations of assets, can be fungible (cryptocurrencies) or non-fungible (NFTs), enabling ownership and value transfer within blockchain ecosystems (Regner, Urbach, & Schweizer, 2019). Property rights NFTs provide a secure, transparent, and efficient way to manage property ownership and transactions on the blockchain. Property rights often need to be divided for various legal, financial, and practical reasons, enabling multiple stakeholders to share ownership, usage, or benefits from an asset as is the case in TDR management and transfer. Fractional NFTs (F-NFTs) address some of these issues by dividing property ownership into smaller, tradable shares, making real estate investments more accessible. Each token serves as a unit of account linked to a user's blockchain address, with exclusive control secured through the user's private key. These tokens are technologically integrated with cadastral data (e.g., geospatial information) and encumbrances such as leases, mortgages, superficies, and liens. The integrity of this linkage is ensured by trusted third parties authorized to certify ownership, deeds, and other property-related transactions.

Smart contracts are self-executing agreements with predefined rules stored on the blockchain (Szabo, 1997). They enable automation, reducing the need for third-party enforcement (Buterin, 2014). Tokens, which are digital representations of assets, can be fungible (cryptocurrencies) or non-fungible (NFTs), enabling ownership and value transfer within blockchain ecosystems (Regner, Urbach, & Schweizer, 2019).

Tokens differ fundamentally from cryptocurrencies. While cryptocurrencies are a medium of exchange and a mechanism to incentivize miners maintaining the blockchain infrastructure, tokens represent specific property rights. Moreover, tokens can underpin derivative instruments, facilitating new economic relationships and activities such as Initial Coin Offerings (ICOs), Initial Exchange Offerings (IEOs), and Decentralized Autonomous Organizations (DAOs).

Once land titles and property rights are tokenized, traditional registries, such as cadastral systems, become redundant. Blockchain itself functions as a comprehensive registry, removing the need for repetitive registration processes. Although the initial onboarding of titles requires coordination with land authorities, subsequent transactions occur seamlessly on the blockchain, where data is immutable and irrevocable.

In our system design, we utilized various types of diagrams to effectively model and communicate different aspects of the system. Each diagram serves a distinct purpose and offers a unique perspective, ensuring a well-rounded understanding of the system's design.

Specifically, we employed three key types of diagrams, each addressing a specific dimension of the system:

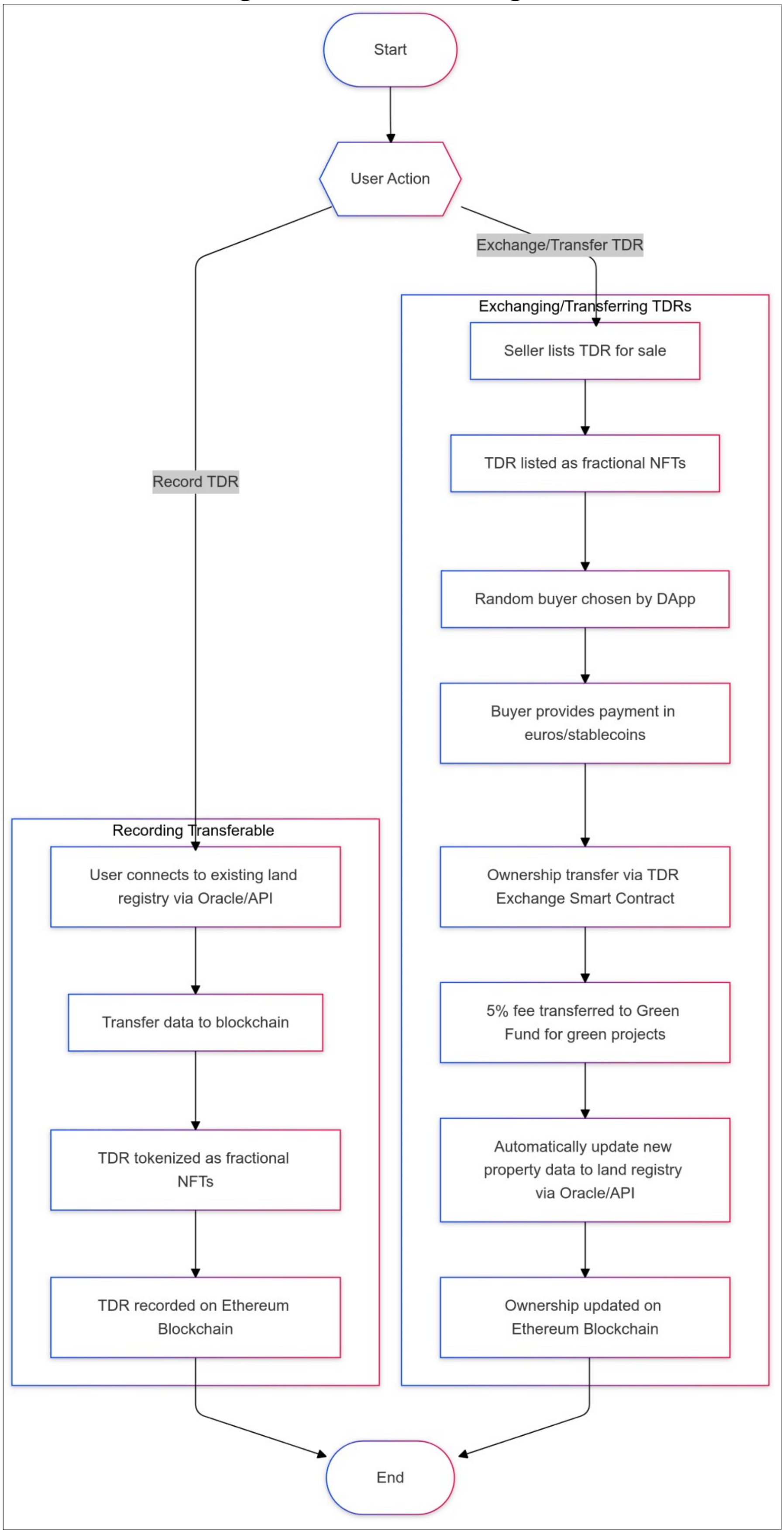
1. **Flowchart Diagrams**: These focus on the **behavioral aspect** of the system, illustrating how processes and workflows operate, including decision points and sequences of actions.
2. **Component Diagrams**: These emphasize the **structural aspect**, showcasing the system's physical or logical components and how they interact with one another.
3. **Class Diagrams**: These highlight the **data and relationships** within the system, detailing the entities, their attributes, methods, and how they relate to one another.

By combining these diagrams, we ensured a comprehensive representation of the system, addressing both its dynamic behavior and static structure, which is essential for effective design, communication, and implementation.

3.1. Flowchart Diagram

The flowchart Diagram (figure 1) is used to represent the flow of processes, logic, or workflows in a system. It visually describes the sequence of steps, decisions, and actions.

Figure 1 : Flowchart Diagram



The logic behind the preceding flowchart is as follows:

1. **Start Node:**
   - The process begins when a user interacts with the dApp.
2. **User Actions:**
   - Users can either record a new TDR or participate in the exchange/transfer of TDRs.
3. **Recording TDRs Flow:**
   - The seller connects to an existing land registry using an **Oracle/API** to transfer their property data to the blockchain.
   - The TDR is tokenized as **fractional NFTs** for easier management and liquidity.
   - The blockchain records the tokenized TDRs, ensuring transparency and immutability.
4. **Exchanging/Transferring TDRs Flow:**
   - The seller lists the TDRs for sale as fractional NFTs.
   - The dApp randomly selects a buyer for the TDR using a deterministic algorithm or VRF (Verifiable Random Function) to ensure fairness.
   - The buyer makes a payment using **euros or stablecoins**, verified by the smart contract.
   - Upon successful payment, ownership is transferred via the **TDR Exchange Smart Contract**, and 5% of the transaction value is sent to the government for green projects.
   - The dApp updates the new property ownership details in the existing land registry via **Oracle/API**.
   - The blockchain records the completed transaction and updated ownership.
5. **End Node:**
   - The process concludes with all records updated both on-chain and in the external land registry.

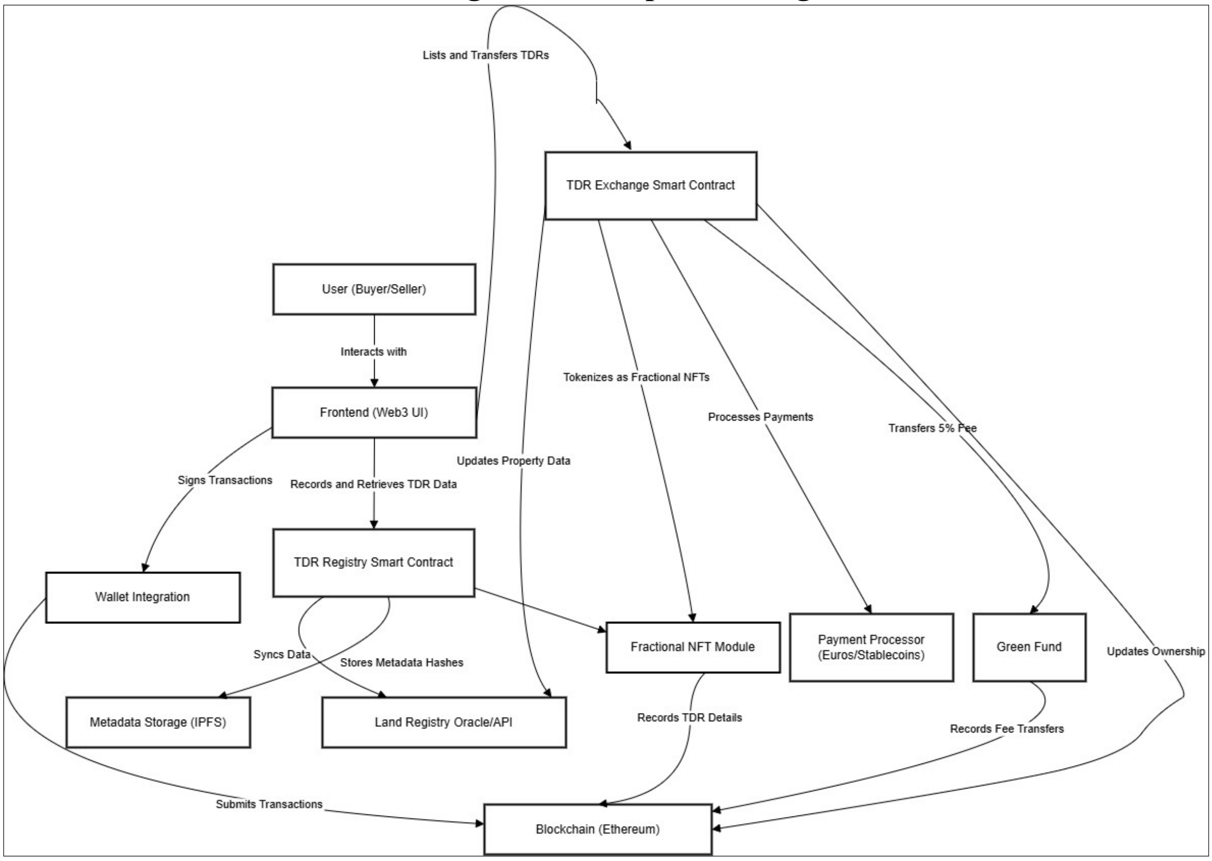
As regards the Key Functionalities Highlighted :

1. **Integration with Existing Land Registry**:
   - Use of Oracle/API for seamless data synchronization.
2. **Fractional NFT Tokenization**:
   - TDRs are tokenized to allow partial ownership and increased liquidity.
3. **Random Buyer Selection**:
   - Ensures fairness and eliminates human intervention in selecting buyers.
4. **Payment in Euros/Stablecoins**:
   - Simplifies currency handling while maintaining compatibility with blockchain-based payments.
5. **Government Fee for Green Projects**:
   - A portion of transaction value supports sustainability initiatives.
6. **Automatic Property Data Updates**:
   - New property ownership details are uploaded to the existing land registry system.

3.2. Component Diagram

The Component diagram is used to represent the physical or logical components of the **Digital Land Bank** dApp (figure 2) and their relationships. It focuses on the high-level structure of the dapp.

Figure 2 : Component Diagram



As regards the Components and Functionalities are the following :

1. **Frontend (Web3 UI)**:
   - User interface enabling buyers and sellers to interact with the dApp.
   - Provides features like TDR listing, recording, and viewing ownership details.
2. **Wallet Integration**:
   - Allows users to sign and authorize blockchain transactions securely using wallets like MetaMask.
3. **Land Registry Oracle/API**:
   - Facilitates data synchronization between the blockchain and an existing land registry system.
   - Ensures that property data is accurately updated post-transaction.
4. **TDR Registry Smart Contract**:
   - Records and manages TDRs on the blockchain.
   - Links TDR metadata to decentralized storage via **IPFS**.
5. **TDR Exchange Smart Contract**:
   - Handles listing, buying, and transferring TDRs.
   - Implements the random buyer selection logic to ensure fairness.
   - Manages fractional NFT tokenization for TDRs.
6. **Fractional NFT Module**:
   - Tokenizes TDRs into fractional NFTs, enabling partial ownership and greater liquidity.
7. **Payment Processor**:
   - Processes payments in euros or stablecoins.

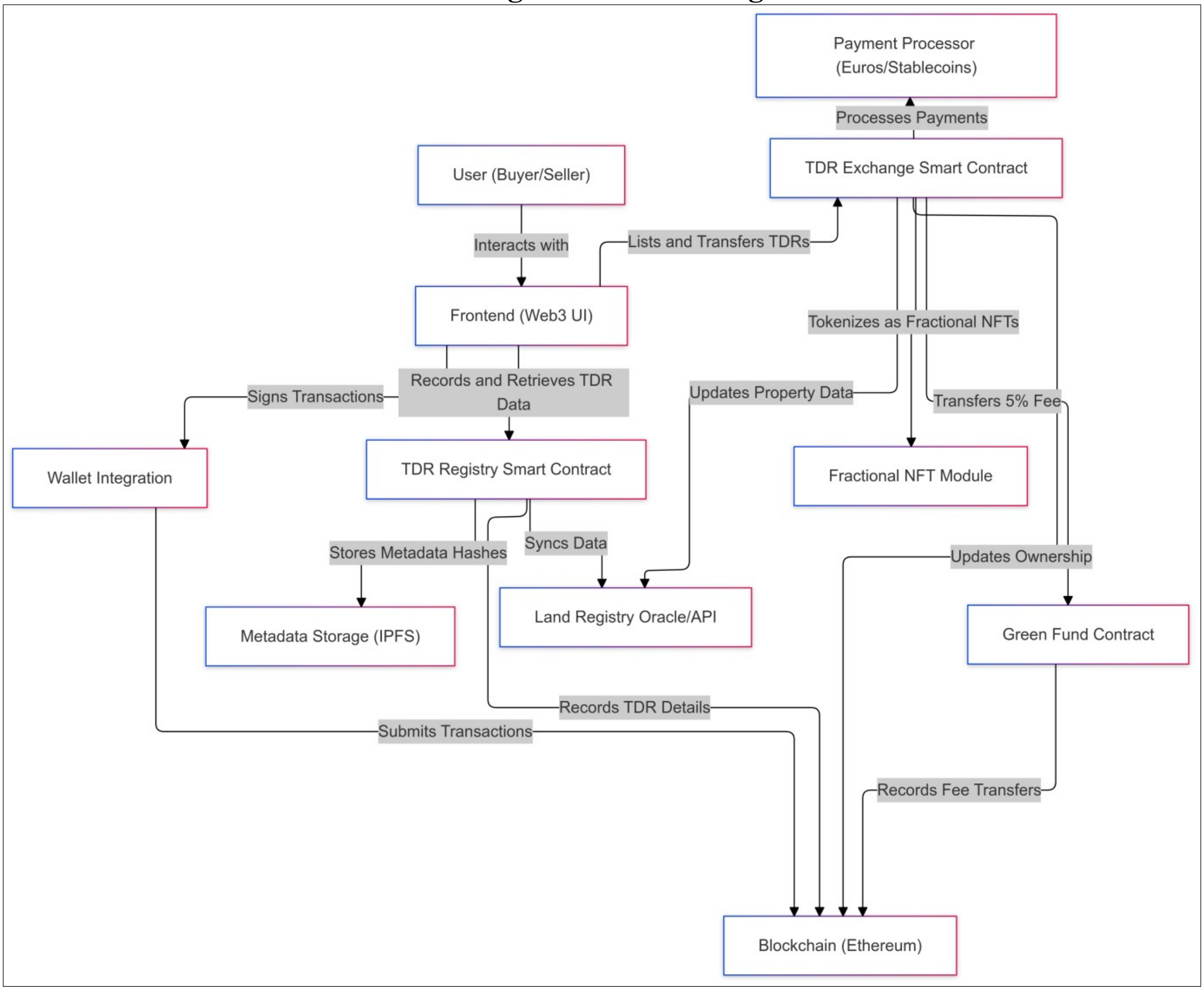
- Validates and transfers funds during TDR transactions.

8. **Government Treasury Contract**:
   - Deducts a 5% fee from each TDR transfer to fund green projects.
   - Records fund transfers transparently on the blockchain.
9. **Metadata Storage (IPFS)**:
   - Decentralized storage for TDR-related metadata, such as maps or legal documents.
10. **Ethereum Blockchain**:
    - The core blockchain platform ensuring transparency, immutability, and decentralized execution of smart contracts.

3.3. Class Diagram

The class diagram (figure 3) is used to represent the static structure of our dapp by showing classes, their attributes, methods, and relationships (e.g., inheritance, associations).

Figure 3 : Class Diagram



The Component Diagram Key Highlights are the following :

1. **Core Classes:**
   - **User:** Represents the general user (both seller and buyer).
   - **TDRRegistry:** Handles TDR recording, linking with the land registry, and metadata storage.

- **TDRExchange:** Manages TDR transfers, buyer selection, and fee deduction.
- **Fractional NFT:** Implements TDR tokenization and NFT-based ownership transfer.

2. **External Integrations:**
   - **LandRegistryAPI:** Connects the dApp with an external land registry for data synchronization.
   - **PaymentProcessor:** Handles payments in euros or stablecoins.
   - **GreenFund:** Receives the 5% transaction fee for green projects.
3. **Ethereum Blockchain:**
   - Serves as the underlying decentralized ledger for storing transaction data and managing NFTs.
4. **Functional Flow:**
   - **Seller:** Lists and tokenizes TDRs through the TDRRegistry and FractionalNFT classes.
   - **Buyer:** Purchases TDRs using the TDRExchange, with payments validated by the PaymentProcessor.
   - **Fee Management:** Ensures a 5% fee is sent to the GovernmentTreasury.
   - **Registry Updates:** Automatically syncs new ownership data with the external LandRegistryAPI.

4. Discussion

It is clear that integrating Blockchain technology represents potential theoretical advantages of maximizing the DLB, but in order to accomplish its full implementation, many obstacles must be overcome. These include:

- Investment in Technology: The infrastructure for Blockchain-based systems require investments in hardware, software, and well-trained people.
- Legal framework: Current legislation should be revised to integrate Blockchain-based processes, which includes recognizing smart contracts legally.
- Addressing Education and Training: There's a need for stakeholders — including property owners, builders and government officials — to be trained in the application of Blockchain and its implications for TDR transactions.

Moreover, concerns about data privacy and scalability need to be addressed. While Blockchain ensures transparency, mechanisms must be in place to protect sensitive information. Additionally, the system should be designed to handle high volumes of transactions efficiently.

Although blockchain technology has a lot of promise to manage development rights by improving efficiency and transparency, there are a number of issues and concerns with its application.

Scalability is one of the main problems. Blockchain networks, especially public blockchains like Ethereum, include a lot of data and transactions involved in controlling development rights, which makes them very scalable. This involves handling a lot of property ownership, zoning, and development approval transactions, which might put a strain on these networks' capabilities. Public blockchains, despite being decentralized and transparent, frequently struggle with transaction throughput—the ability to handle a large number of transactions per second. This causes delays and higher transaction costs, which are especially important for large-scale urban projects that require frequent updates and transfers of development rights. Scalability difficulties become increasingly apparent as more users join the network, putting blockchain technologies' efficiency and cost in real-world development rights management applications to the test. Solutions such as layer 2 scalability, sharding, and other consensus mechanisms are being investigated to address these concerns, but widespread acceptance and effectiveness remain challenges (Vitalik, 2017).

Another problem is integrating with existing systems. Managing development rights requires compliance with legal frameworks, land registries, zoning regulations, and urban planning databases. Many of these existing systems are antiquated, paper-based, or inconsistent across jurisdictions, necessitating significant investment, time, and effort to integrate blockchain technology, posing a barrier to adoption (Grech and Camilleri, 2017).

Legal and regulatory ambiguity also impedes blockchain adoption for development rights. Blockchain applications must adhere to existing property laws, which vary significantly by country. The legal recognition of blockchain-based records, smart contracts, and digital tokens for development rights is still questionable in many jurisdictions, potentially leading to disputes and impeding adoption

High initial costs present another significant concern. Implementing blockchain systems involves substantial expenses for infrastructure development, training, and integration. These upfront costs may not be justifiable for all municipalities, particularly in regions where alternative digital solutions or improvements to existing systems might be more cost-effective (Zhao et al., 2016).

The digital divide and accessibility issues are also critical challenges. Blockchain systems require access to technology, internet connectivity, and digital literacy, which could exclude marginalized or rural populations less equipped to engage with blockchain-based platforms, perpetuating existing inequities in property rights management (Huckle et al., 2016).

Although often a plus, blockchain's immutability also presents difficulties. It is difficult to change a record once it has been added. If inaccurate or fraudulent data is entered, this could be problematic because fixing it can be expensive and time-consuming, which would erode system trust (Crosby et al., 2016).

The energy-intensive nature of some blockchain systems, especially those that use Proof of Work (PoW), raises environmental issues. Concerns about sustainability are brought up by high energy use, particularly for governments or organizations dedicated to achieving climate goals (Vranken, 2017).

Another concern is reliance on smart contracts. Although smart contracts are crucial for automating the maintenance and transfer of development rights, errors or weaknesses in the code may result in exploitation or unexpected consequences. Furthermore, the rigidity of smart contracts may not account for the complexity of real-world scenarios requiring human judgment (Atzei et al., 2017).

Another major obstacle is resistance to change. Adoption may be hampered by opposition from stakeholders, such as governmental organizations, legal experts, and developers used to traditional approaches, as blockchain-based administration of development rights constitutes a significant departure from conventional systems (Swanson, 2015).

Additional difficulties arise from the absence of standards in blockchain implementations for development rights. For users and policymakers, disparities in design, protocols, and governance lead to confusion, fragmentation, and interoperability problems (Hileman & Rauchs, 2017).

Last but not least, blockchain systems may become centralized as a result of reliance on private blockchains or control by certain entities, despite their decentralized promise. This would compromise the transparency and trust that blockchain is meant to offer (Narayanan et al., 2016).

One possible solution to the problems caused by the immutability of blockchain records is to use a Cross-Blockchain Protocol. A framework for "smart laws" is introduced by this protocol to address problems including inheritance disputes, access restoration in the event that private keys are lost, and the execution of court decisions. In this environment, trusted organizations, often known as "Digital Authorities," are essential. With governments enabling the conversion of title documents between formats, citizens are still free to select between traditional and blockchain-based systems. By enabling the use of numerous interconnected blockchains, encouraging technological innovation, and enhancing service quality, the Cross-Blockchain Protocol further increases user autonomy. Maintaining registries is no longer the government's responsibility; instead, it now establishes technical standards and puts smart legislation into effect. By establishing security protocols and regulating the criteria for blockchain inclusion in property registry networks, public authorities ensure system integrity and trustworthiness. Blockchain-enabled real estate tokenization thus transforms the traditional landscape, fostering innovation, efficiency, and enhanced security in property rights management (Zhang & Xue, 2018).

5. Conclusion

The integration of Blockchain technology into the Digital Land Bank represents a transformative approach to managing Transfer of Development Rights in Greece.

The proposed framework addresses key pain points in the current TDR system:

1. **Transaction Security**: Each TDR transaction is recorded as an encrypted block on the Blockchain. Fraudulent actions, such as duplicate sales of the same rights, are eliminated because each transaction is verifiable and immutable.
2. **Transparency:** The Blockchain ledger enables property owners, authorities, and stakeholders to view the history and current status of development rights. Blockchain's tamper-proof nature prevents data from being altered retrospectively, encouraging confidence.
3. **Increased Efficiency and Reduced Bureaucracy:** Smart contracts allow for the automated execution of transactions. For example, when a buyer meets established conditions (e.g., payment of fees, compliance with rules), the transfer of development rights occurs promptly and without user intervention.
4. **Interoperability:** The DLB can communicate with other government systems, such as land registries and tax authorities, using application programming interfaces (APIs). This integration ensures consistency and reduces duplication of data.
5. **Cost reduction:** By automating operations and eliminating the need for intermediaries, the Blockchain-based system can reduce administrative costs.

However, realizing Blockchain's full potential necessitates coordinated efforts in technological development, regulatory reform, and stakeholder education.

Future research should center on piloting the proposed framework and evaluating its performance in real-world circumstances. By overcoming implementation challenges, the Blockchain-powered DLB can serve as a model for future urban planning developments around the world.

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