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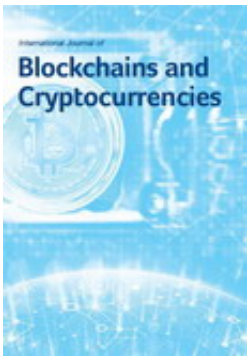

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NFTs and property tokenisation: advancements and applications in blockchain technology

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Abstract: This paper explores the transformative impact of blockchain technology and non-fungible tokens (NFTs) on real estate transactions. Property tokenisation on the blockchain streamlines ownership and transaction processes, offering enhanced security, transparency, and trust. Smart contracts automate these transactions, reducing the need for intermediaries. By converting real estate assets into digital tokens on a blockchain, it enables a seamless transfer of ownership and rights representation. This automated execution ensures efficiency and trust, while also significantly lowering transaction costs. The integration of NFTs, as unique digital representations, act as an additional layer of protection, significantly reducing the risk of fraudulent activities and making property transactions smoother and more reliable. Throughout the paper, we meticulously examine and showcase real-world examples of successful blockchain-based property tokenisation implementations. This investigation highlights the potential for innovation within the real estate industry, pointing toward a future where property transactions are characterised by heightened efficiency, transparency, and cost-effectiveness.

Keywords: NFT; non-fungible token; blockchain; smart contracts; real estate; tokenisation.

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1 Introduction

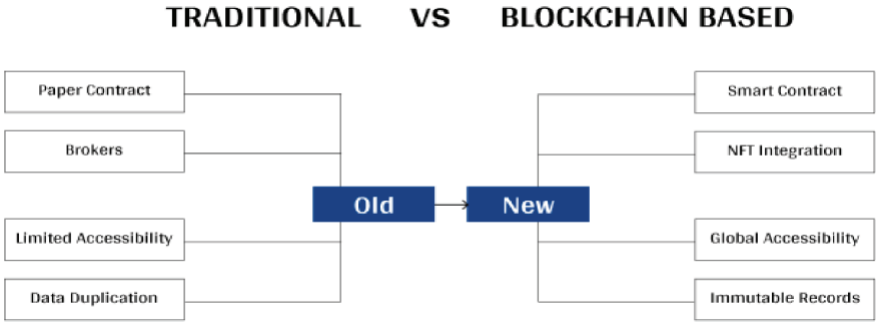
Property is defined as land, permanent structures, such as a residence, or improvements to the land, whether they are natural or man-made. The land transfer is the act of irrevocably transferring the ownership and all the rights of the property from one party to another. It is a deed-based transfer of ownership for a sum of money that has either been paid in full or pledged in parts. The sale deed must be for consideration and is legally needed to be stamped and registered (Chen et al., 2023). Ensuring that the sale deed is correctly stamped and registered is vital to the validity and enforceability of the land transfer, as it establishes a clear and publicly recorded change of ownership. In the conventional procedure, there are two parties: the landlord and the renter/buyer, as well as brokers, attorneys, banks, police, etc. A house renting procedure is based on an owner-tenant agreement for a specific amount of time. In this process, a client in need of a home contacts the homeowner directly or indirectly (through a broker) and prepares an agreement by specifying various terms in accordance with the laws and ordinances that are in effect in the area. When using a manual approach to create simply an affidavit, the agreement is then printed on stamp paper and signed by both parties in the presence of an advocate. The signed contract must be recorded with a sub-registrar office in the local jurisdiction in the event of legal action (Kunjumon et al., 2023). In such a practice, the tenant must first pay the landlord an advance sum as a security deposit before paying the rent in accordance with the contract. In addition, the police verify identities of tenants for security purposes. The standard method of a property transaction entails a pen-and-paper contract, paperwork, a broker charge, cash payments, etc. Additionally, it takes a lot of time, is expensive, unsecure, unreliable, and error-prone. Many drawbacks in this traditional system are double spending, poor record keeping, forgery, selling without authorisation, encroachments, etc. (Maesa et al., 2022). On the internet, a number of online applications have been developed to alleviate problems with the property dealing (Sachan

et al., 2023). These applications organise and store the agreements and property listings in a centralised database. These applications handle transactions using third parties in an irreversible manner. Due to the centralisation, security and trust issues still exist (Ali et al., 2023). Therefore, it is necessary to create a decentralised and reliable system that satisfies the requirements for the process of property transaction and offers transaction security, transparency, immutability, direct interactions between renter and landlord, resistance to failure, and cost effectiveness. An effective option to meet the criteria of the process is tokenisation of property using blockchain, a decentralised distributed ledger, in the form of NFTs and by leveraging the power of smart contracts (Bruschi et al., 2022). Without the involvement of a third party, it provides data security, transparency, and trust. When the established criteria and conditions are satisfied, smart contracts, which are stored on a blockchain and take the form of if-then rules, are automatically executed (Humdullah et al., 2021). In a system for property dealings and renting out houses, smart contracts can help to automatically carry out the terms of the contract depending on the events that have taken place. Real estate tokenisation involves converting real estate assets into digital tokens on the blockchain to enable their digital transfer and ownership (Gupta et al., 2019). The token represents the entire property, including all of its rights and obligations. As a result, anyone who owns a property token is entitled to the underlying real estate property, as well as any profits or losses associated with it. The non-fungible token (NFT) is a type of cryptocurrency that represents a unique digital asset or piece of art (Allenbrand, 2023). Cyber fraud is a common problem associated with digital transactions. The use of blockchain technology and NFT technology, however, allows for higher levels of data security and integrity. It provides protection to both buyers and sellers and makes it much easier to transfer assets without experiencing any difficulties. As a result, by enabling the simultaneous synchronisation of a real estate asset's ownership and transaction data across a network of users, blockchain-based property tokenisation provides various benefits in terms of efficiency and optimisation. The public distributed ledger's immutability of these data provides excellent transparency and lowers the likelihood of human error or misconduct. The contrasting properties of both the processes are shown in Figure 1. The main aim of this paper is to comprehensively investigate and analyse the applications of blockchain in real estate, synthesise existing literature, to showcase various real-world applications and use cases of blockchain-based property tokenisation, highlighting successful implementations and innovative approaches, delve into the integration of NFTs within the context of blockchain-based property tokenisation.

2 Literature survey

In the dynamic realm of technological advancements, blockchain stands out as a revolutionary force reshaping industries. This literature survey delves into key aspects of blockchain technology with a specific focus on its applications in real estate. Beginning with foundational principles and cryptography, we explore the architectural intricacies of decentralised applications. Transitioning to diverse domains, we emphasise the transformative impact of blockchain in real estate management. The survey also scrutinises the popularity and challenges surrounding NFTs before concluding with an exploration of innovative solutions and smart contracts in the real estate sector. This comprehensive overview highlights the intersection of blockchain and real estate, providing insights into the evolving landscape of secure and transparent property management.

Figure 1 Traditional process vs. blockchain integrated systems (see online version for colours)



2.1 Foundations of blockchain technology: principles, cryptography, and smart contracts

Liu (2021) blockchain's foundation in decentralisation ensures that it operates on a distributed network, reducing the risk of single points of control or failure. This groundbreaking concept underlies the trustlessness of blockchain, meaning that participants in the network do not need to rely on intermediaries for verification, enhancing transparency and reducing the need for trust. The reliance on mining, coupled with the Proof of Work consensus algorithm, is crucial for maintaining the security and immutability of blockchain transactions. These complex mathematical processes deter malicious actors from tampering with the blockchain's history. The use of well-defined mathematical algorithms and logical structures governs how transactions are validated and added to the blockchain, providing a standardised framework for its operation. However, while blockchain offers remarkable advantages, it can be resource-intensive. Therefore, integrating it with traditional databases, which have long been used for structured data storage, has become essential. This integration enables organisations to strike a balance between the decentralised, secure, and transparent nature of blockchain and the efficiency and familiarity of traditional databases. This integration also addresses the need for high performance and robust multi-backup support. Traditional databases have well-established mechanisms for data backup and recovery, and by combining them with blockchain technology, organisations can optimise performance while maintaining data integrity and reliability, even in the face of technical issues or malicious attacks. This symbiotic relationship between blockchain and established databases reflects the evolving landscape of secure and decentralised information management, where the strengths of both technologies are leveraged to meet the demands of modern data management and transaction systems.

The robust security of blockchain is intricately tied to the implementation of cryptographic techniques, as highlighted by Fartitchou et al. (2022) and Rizwan et al. (2021). Within the framework of cryptography, blockchain relies heavily on asymmetric cryptography, with a particular emphasis on Rivest-Shamir-Adleman (RSA), digital signature algorithm (DSA), and elliptic curve digital signature algorithm (ECDSA). A comprehensive examination of these cryptographic algorithms reveals that ECDSA, in particular, demonstrates superior efficiency in key generation and signature generation, even when using small keys. This efficiency is of paramount importance in the blockchain ecosystem, where transaction speed and resource utilisation are critical. Notably, simulation results affirm the security of ECDSA, showcasing its resilience, even when compact key

sizes are employed. On the other hand, RSA excels in the domain of signature verification performance, making it an integral part of the blockchain security landscape. In addition to these established cryptographic methods, the exploration of blockchain-based algorithms, as discussed by Baskaran et al. (2023), extends to a comparative analysis with the Quantum Teleportation security algorithm for Blockchain Technology. This pioneering analysis not only broadens the scope of cryptographic methodologies employed in blockchain but also provides valuable insights into potential advancements in securing blockchain transactions through innovative quantum techniques. As the field of quantum computing advances, understanding how it can be harnessed for enhanced security within the blockchain space is of paramount importance, ensuring that the technology remains resilient in the face of evolving threats and challenges. This intersection of blockchain and quantum technology represents an exciting frontier in the ever-evolving landscape of secure and trustworthy information management. Quantum computing possesses the potential to crack existing cryptographic systems, which is why exploring quantum-resistant cryptographic techniques is imperative. The insights gained from this comparative analysis have the potential to reshape the future of blockchain security, providing a foundation for robust, quantum-resistant blockchain networks. As quantum technology matures, these innovative approaches will become increasingly vital in maintaining the integrity and trustworthiness of blockchain transactions.

Smart contracts are a fundamental and indispensable component of the blockchain framework, serving as self-executing programs designed to automate the execution of actions stipulated within agreements or contracts. Valuable insights from the research of Khan et al. (2021), Touloupou et al. (2021) and Martina et al. (2023) shed light on the intricacies and practical applications of these smart contracts within the blockchain ecosystem.

Smart contracts are typically authored using programming languages like Solidity, Vyper, Rust, Java, or Kotlin, depending on the specific blockchain platform employed. These languages allow developers to define the logic and behaviour of the smart contract. For instance, Solidity is widely used for Ethereum-based contracts. The code for a smart contract can be crafted directly within an Integrated Development Environment (IDE) like Remix, streamlining the development and testing process.

As highlighted in the research conducted by Hewa et al. (2021), common risks and vulnerabilities prevalent in the context of smart contracts within blockchain technology encompass several critical areas. Among these, there is the re-entrancy vulnerability, wherein a contract recursively invokes another, potentially leading to unintended and malicious actions. Additionally, a range of threats includes Sybil attacks, majority attacks, contracts susceptible to destruction, and exception disorders, all of which pose significant challenges and demand the implementation of robust security solutions to prevent potential financial losses. Effectively addressing these vulnerabilities assumes paramount importance in the quest to bolster the security of smart contracts. Doing so not only safeguards the integrity of the blockchain-based systems but also upholds their reliability. These protective measures are indispensable for ensuring that blockchain networks can fulfil their promise of providing secure and dependable information management and transaction processing in an increasingly digital and interconnected world.

2.2 Architecture for decentralised applications

Decentralised applications (dApps) represent groundbreaking solutions meticulously designed to excel in terms of speed, energy efficiency, and cost-effectiveness, presenting a revolutionary architectural approach that guarantees superior performance and scalability within the realm of blockchain technology. The foundation of these dApps is the underlying blockchain, which can manifest in one of three distinct types: hybrid, permissioned, or public. Below, we delve into an exploration of various exemplary dApps that have emerged within this dynamic and ever-evolving ecosystem. These dApps exemplify the innovation and versatility that blockchain technology offers. Whether serving in the realms of finance, supply chain management, healthcare, or entertainment, these applications harness the power of blockchain to bring about decentralised, secure, and efficient solutions that can redefine industries and empower users. This fusion of decentralised architecture and blockchain technology not only holds the promise of revolutionising traditional systems but also paves the way for a future where speed, energy efficiency, and cost-effectiveness are paramount, ultimately reshaping how we interact with digital services and information.

In a noteworthy development, Marchesi et al. (2022) introduced a dApp architecture distinguished by the participation of four distinct categories of actors: Validators, Participants, Operators, and External users, each assigned specific roles and permissions. To facilitate the addition of blocks to the blockchain, the architecture employs a consensus mechanism known as Clique consensus or an equivalent alternative. Tailored specifically for industrial applications and built on the Ethereum blockchain, this architecture underscores key attributes such as transparency, immutability, and scalability. Of particular interest is the utilisation of consensus algorithms like Proof-of-Authority or similar alternatives within this architecture. These algorithms empower users with transaction rights, and they participate in the mining of local Ethers. This approach ensures efficient and controlled access to blockchain resources, making it a compelling choice for industrial applications. Furthermore, in the research by Taş and Tanrıöver (2019), the process of setting up a decentralised application (DApp) on the Ethereum blockchain is delineated through key steps and essential tools. This includes configuring node package manager (NPM), leveraging Truffle for development, crafting smart contracts in Solidity, and conducting rigorous testing using tools like Remix and Visual Studio Code. These combined insights underscore the dynamic nature of dApp development and deployment, showcasing the adaptability of blockchain technology to address a wide range of application domains, including industry-specific solutions, while adhering to the principles of transparency, immutability, and scalability. The exploration of consensus algorithms and the utilisation of robust development tools exemplify the ongoing efforts to optimise the performance and functionality of dApps within the blockchain ecosystem.

In the process of developing a decentralised application (dApp), emphasising security holds paramount importance. As underscored by Chen et al. (2023), overlooking security considerations during the crafting of these applications can have far-reaching consequences. Their paper highlights the potential pitfalls, such as the improper design of the consensus mechanism, which can result in issues like blockchain bifurcation and double attacks.

It's essential to acknowledge that malicious actors can exploit poorly designed methods, and any vulnerabilities within the system can be used as attack vectors. Therefore, security design in blockchain systems encompasses multiple facets, including digital currency security and security in multi-party computation. These components are integral to the

system's architecture, as any compromise in these areas can have profound implications for the security and trustworthiness of the dApp.

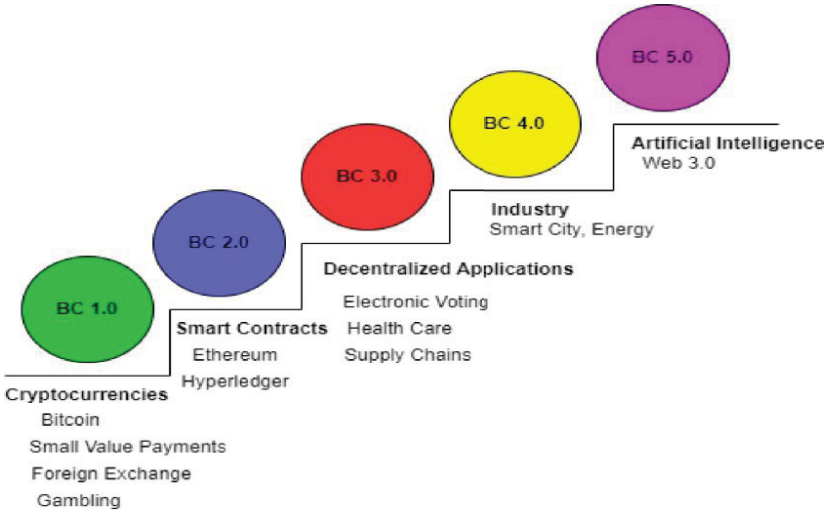
The initial security design specification is a foundational step in ensuring the robustness of the blockchain system's architecture. However, security is an ongoing concern. Continuous improvement of code quality and the application platforms throughout the development stage is equally crucial. This iterative approach is indispensable for maintaining the security and integrity of the dApp over time, as new vulnerabilities may emerge, and the threat landscape evolves.

In summary, the development of dApps is a multifaceted endeavor that demands a relentless focus on security. Establishing a robust initial security design and continually enhancing the quality of code and application platforms are essential practices in safeguarding the integrity of the blockchain system. By prioritising security at every stage, developers can work towards creating dApps that not only deliver on their intended functionality but also provide a resilient and secure user experience in an ever-evolving digital landscape.

2.3 Blockchain applications in diverse domains

As shown in Figure 2 the applications of blockchain has improved and evolved over the years. The forthcoming Table 1 offers a succinct summary of these studies, encapsulating critical information such as authorship, application domain, and methodologies employed. This survey aims to distill key insights from these varied studies, providing a snapshot of the innovative and transformative potential that blockchain technology continues to exhibit across different domains.

Figure 2 Generations of Blockchain applications (see online version for colours)



Source: Fartitchou et al. (2022)

Table 1 Applications of blockchain in different domains

S. no.	*Authors*	*Year*	*Application*	*Domain*	*Methodology*	*Key findings*	*Research gaps*
1.	Bottoni et al. (2022)	2022	Ledger Management Systems	Blockchain Technology, Smart Contracts	Utilisation of Temporal Logic for querying ledger data.	Integration with existing blockchain platforms and protocols.	Implementation in different systems of ledger
2.	Wang and Nixon (2021)	2021	Blockchain Interoperability	Blockchain Interoperability, Security	Leveraging a threshold signature scheme and trusted hardware for interoperability.	Implementing atomic cross-chain communication for interoperable operations.	Contributing to the broader research on blockchain interoperability.
3.	Javaid et al. (2021)	2021	Blockchain in Industry 4.0	Industry 4.0, Blockchain, Supply Chain	Emphasises the need for real-time information and security.	Facilitates secure and efficient flow of products and services. Blockchain and AI complement each other in Industry 4.0.	Addressing scalability, anonymity, and trustworthiness challenges.
4.	Merrell (2022)	2022	Decentralised Governance	Rural Development, Governance	Exploration of blockchain technology's potential in rural governance.	Blockchain can improve participation, transparency, and trust in rural governance.	Investigating the role of NGOs and development agencies in blockchain-based rural governance.
5.	Vangala et al. (2020)	2021	Smart Agriculture	Smart Agriculture, Information Security	Cost and comparative analysis. Study of cryptographic schemes, consensus algorithms, and execution time.	Identification of security requirements and threats in IoT-based agriculture.	Addressing scalability issues in blockchain systems. Ensuring transactional privacy in blockchain.
6.	Xia et al. (2022)	2022	Resource Management	Water Management, Data Security	Application of blockchain, cryptographic techniques, distributed storage, consensus mechanisms, and smart contracts.	Provides a decentralised solution for water resource information management.	Cost-effectiveness and adoption considerations for blockchain solutions.

Table 1 Applications of blockchain in different domains (continued)

S. no.	*Authors*	*Year*	*Application*	*Domain*	*Methodology*	*Key findings*	*Research gaps*
7.	Bruschi et al. (2022)	2022	Fair Token Distribution	Token Distribution, User Onboarding	Smart contracts on Ethereum mainnet. Decentralised system.	Provides a secure and decentralised process for token distribution.	Further investigation into scalability for larger numbers of users and transactions.
8.	Han et al. (2023)	2023	Crowdsourcing	Crowdsourcing, Blockchain, Subtitling	Implements on-chain and off-chain components. Uses IPFS for source file storage. Utilises subtitling token (ST) and video token (VT).	Provides settlement and incentive mechanisms. Real-world evaluation and recommendations for application stage.	Economic and financial implications and sustainability.
9.	Saurabh et al. (2021)	2021	Architecture	Frameworks development	Addresses issues of trust, time-criticality, and democratisation.	Incorporates trace pseudonymous decentralised decision making	Scalability and performance improvements
10.	Mothukuri et al. (2021)	2021	BlockHDFS	Data Security	- Architecture with HDFS cluster, Hyperledger Fabric, and NodeJS Client, Blockchain ledger for intrusion traceability	Immutable ledger for logging attacker intrusion details - Potential to enhance HDFS security	Non-real-time execution of the NodeJS client. Real-time tracking of data in a secure ledger
11.	Maiti et al. (2021)	2021	Future Accounting Framework	Accounting	Development of a potential system architecture	- Changing nature of accounting practices. Benefits of TEA and blockchain	Research gap in TEA and its implementation. Early stages of TEA. Technological and organisational challenges

In their comprehensive study conducted in 2022, Bottoni et al. (2022), embarked on an exploration of Ledger Management Systems within the intricacies of the blockchain technology landscape and the intricate world of smart contracts. Their methodological approach was nothing short of innovative, as it entailed the astute application of Temporal Logic for the purpose of querying ledger data. This methodological choice was underpinned by a firm commitment to introducing a formal and structured dimension to the practice of data management, a decision laden with significant implications. Within the realm of blockchain, where the preservation of data integrity and precision stands as a non-negotiable cornerstone, this approach resonates with particular importance. The findings unveiled through their diligent research underscored the critical necessity of seamlessly integrating the Temporal Logic paradigm with existing blockchain platforms and protocols. The harmony between Temporal Logic and blockchain technology holds transformative potential, particularly concerning the augmentation of data querying, validation, and historical tracing within the ledger. The consequence is a substantial enhancement in the transparency and accountability of all transactions, effectively positioning the technology as an indispensable advancement for the broader blockchain ecosystem. Moreover, Paolo Bottoni and his fellow researchers exhibited a commendable farsightedness, recognising the versatility and adaptability of their findings across various ledger systems. This forward-thinking stance paves a promising path towards the institutionalisation of versatile, standardised, and structured data management practices that transcend the confines of the blockchain domain. Whether their innovative approach is directed at the intricacies of financial transactions, the intricacies of supply chain management, or the complexities of land registration, the amalgamation of Temporal Logic and blockchain technology heralds a new era characterised by heightened levels of trust, efficiency, and accountability. In effect, this paradigm shift has the potential to redefine established norms in data management, transforming data from mere records into irrefutable testaments to the accuracy, transparency, and reliability of information across multifarious sectors and industries.

The paper authored by Gang Wang and his team, as cited in Wang and Nixon (2021), introduces an innovative and efficient blockchain architecture known as InterTrust. InterTrust achieves its objectives through the utilisation of two innovative methodologies. The initial method is a threshold signature scheme, which is crucial for ensuring verifiability and consistency in the blockchain systems of interest. The preservation of transaction integrity and trustworthiness across numerous blockchains is contingent upon the implementation of this scheme. The utilisation of trusted hardware in the second method guarantees that independent blockchain systems can depend on dependable services while engaging in communication. By amalgamating these two advancements, InterTrust establishes a resilient framework that ensures the security and interoperability of blockchain operations. This document provides an in-depth analysis of the design of the InterTrust architecture, explicating its underlying mechanisms and the fundamental principles that underpin its efficacy. It also introduces a cross-AS communication protocol that leverages the fundamental elements of the threshold signature scheme and trusted hardware. The aforementioned protocol is of utmost importance in facilitating smooth communication and collaboration among diverse blockchain systems. A noteworthy aspect of the paper's contribution is the proposal of an efficient atomic cross-AS exchange protocol. This protocol utilises the threshold signature to ensure the atomicity of transactions across blockchains, augmenting the reliability and security of inter-blockchain operations. By addressing the

challenge of atomicity, the paper sets a new standard for the smooth and secure exchange of assets and data across blockchain ecosystems.

The comprehensive literature survey presented by Mohd Javaid in 2021, as documented in Javaid et al. (2021), delves into the intricate synergy of blockchain technology within the transformative landscape of Industry 4.0. This research embodies a systematic exploration of the interplay between blockchain, Industry 4.0, and the critical domain of supply chain management. One of the central themes emphasised in this work is the acute need for real-time information and heightened security within the context of Industry 4.0. This theme encapsulates the pressing demand for the seamless flow of data in an era characterised by rapid technological advancements and automation. The requirement for real-time information is a cornerstone of efficient decision-making processes, a critical component of Industry 4.0's vision.Nonetheless, the research is not blind to the challenges that lie in the path of seamless integration. It acknowledges the critical issues of scalability, anonymity, and trustworthiness that must be addressed for the successful realisation of Industry 4.0's vision. These challenges represent the real-world obstacles that must be surmounted to bring the harmonious integration of blockchain technology and Industry 4.0 to fruition. The comprehensive literature survey conducted by Ian Merrell in the year 2022, as detailed in Merrell (2022), embarks on an insightful journey into the uncharted terrain of decentralised governance, with a particular focus on its applicability to rural development and governance. A fundamental theme underpinning this research is the exploration of blockchain technology's potential in the realm of rural governance. This critical dimension acknowledges the unique challenges and opportunities presented by rural contexts, and how blockchain can offer innovative solutions. The research delves into the transformative capabilities of blockchain in redefining the dynamics of governance in these areas. One of the noteworthy findings highlighted in this literature survey is the remarkable potential of blockchain technology to enhance participation, transparency, and trust in the domain of rural governance. The research underscores how blockchain can serve as a catalyst for increased citizen participation in decision-making processes, fostering a sense of ownership and inclusivity in rural governance. The transparency offered by blockchain's immutable ledger creates a trustworthy and accountable environment, crucial in rural settings where trust is paramount. An intriguing aspect of this work is its investigation into the roles of non-governmental organisations (NGOs) and development agencies in the realm of blockchain-based rural governance. By examining the contributions and potential collaborations between NGOs, development agencies, and blockchain technology, the research lays the foundation for a holistic and inclusive approach to rural governance.

The scholarly work presented in Vangala et al. (2020) by Anusha Vangala, in the year 2021, adopts a conceptual approach to delve into the transformative potential of blockchain technology in the context of smart agriculture. The paper artfully navigates the landscape of information security within the purview of this critical domain. By emphasising a conceptual framework, the research embodies a deliberate and well-thought-out approach to its subject matter, underpinning its gravity. The research extends beyond smart agriculture, venturing into the domain of rural governance. The paper envisions and introduces an entirely new distributed model of governance, one that holds the promise of fostering transparency, accountability, and efficiency in rural settings. While these aspirations are commendable, the paper also acknowledges the formidable barriers and challenges that must be surmounted to facilitate the mass adoption of blockchain technology in rural areas. This level of comprehensive awareness underscores the paper's meticulous approach. Moreover, the paper unfolds a series of compelling use cases where blockchain technology can make

a discernible impact in rural landscapes. By exploring its potential to reduce remittance fees and expedite transfer times, Anusha Vangala's work highlights the tangible benefits that blockchain can deliver in the context of rural financial ecosystems. It underscores the imperative of collaboration between blockchain developers, economic development experts, practitioners of participatory governance, and evaluators in policy initiatives. This recognition of diverse expertise as a cornerstone of effective blockchain implementation in rural governance showcases a pragmatic and holistic approach to solving real-world challenges.

The research presented in Xia et al. (2022) introduces a pioneering decentralised water resource information management system built upon blockchain technology. In the realm of water resource management, this innovative system signifies a departure from traditional data storage practices, ushering in a paradigm shift in how water-related information is handled. A fundamental facet of this research is the encryption and transmission of monitoring and business data through blockchain technology and a peer-to-peer network. This approach replaces the conventional centralised management model with a decentralised one. In this novel system, the responsibility for managing data is distributed across various nodes, effectively improving the efficiency of information transmission and overall data management. This shift in data management is a testament to the transformative potential of blockchain technology in the field of water resource management. The blockchain framework introduced for water resource management comprises four distinct layers: the interaction layer, application layer, blockchain network layer, and data collection and transmission layer. Each of these layers serves a specific function, collectively orchestrating a robust and comprehensive system for water resource management. Within the blockchain network layer, blockchain technology comes into play, providing distributed data storage and facilitating secure data sharing among nodes. The immutable nature of blockchain ensures that data remains tamper-proof, instilling trust and reliability in the management of water resources. Additionally, smart contract code is leveraged to automatically identify and resolve issues, offering a mechanism for promoting good practices and imposing penalties for deviations. The application layer, a critical component of the system, is divided into four distinct modules, each dedicated to the administration of various aspects of water resources. These modules incorporate water source management, water supply management, water utilisation management, and water discharge management. This organisational structure ensures a holistic and comprehensive approach to water resource management.

Bruschi et al. (2022) delves into the realm of fair token distribution through the implementation of smart contracts on the Ethereum mainnet. The proposed system offers a secure and decentralised approach to token distribution, enhancing trust and transparency. However, one notable challenge that emerges is the need for further investigation into the scalability of this system, especially when dealing with larger numbers of users and transactions.

Han et al. (2023) explores the integration of blockchain technology in the context of crowdsourcing and subtitling. The system combines both on-chain and off-chain components and utilises the InterPlanetary File System (IPFS) for source file storage. Furthermore, it introduces subtitling tokens (ST) and video tokens (VT) to incentivise participants. Beyond the technical aspects, the paper emphasises the importance of settlement and incentive mechanisms, underlining their role in driving participation and engagement. A particularly valuable aspect of this study is its real-world evaluation and recommendations for different stages of application development. Furthermore, the paper

raises intriguing questions about the economic and financial implications and sustainability of such blockchain-powered crowdsourcing models.

Saurabh et al. (2021) paper takes a holistic view of blockchain technology by addressing critical issues of trust, time-criticality, and democratisation. The proposed architecture framework incorporates pseudonymous trace and decentralised decision-making processes, shedding light on innovative mechanisms for democratic governance. In the pursuit of implementing decentralised frameworks, the paper highlights the need for scalability and performance improvements, indicating a clear path for future development.

Mothukuri et al. (2021) introduces an architecture that seamlessly combines Hyperledger Fabric, Hadoop distributed file system (HDFS) clusters, and a NodeJS client to enhance data security. The blockchain ledger plays a crucial role in intrusion traceability, offering an immutable record of attacker intrusion details. This approach shows significant promise in enhancing the security of HDFS, despite not being real-time in execution.

Maiti et al. (2021) presents a forward-looking perspective on the development of a potential future accounting framework (TEA) within the context of changing accounting practices. The paper emphasises the benefits of integrating blockchain technology into the accounting landscape. It introduces the concept of TEA and its potential advantages, shedding light on how blockchain can enhance transparency and trust in accounting processes. Nevertheless, it identifies several research gaps in TEA and its implementation, particularly in the early stages of its adoption. The paper also recognises technological and organisational challenges that need to be addressed to fully realise the potential of TEA in accounting.

2.4 Non-fungible tokens (NFTs)

In the paper presented by Bouraga (2021), it is highlighted that NFTs, or non-fungible tokens, are digital assets intricately woven into the fabric of blockchain technology through the use of smart contracts. These tokens have taken the digital world by storm by offering a novel way to designate ownership and uniqueness. Their pervasive allure extends across a diverse spectrum of domains, such as digital art, collectibles, virtual real estate, and in-game items. NFTs stand out from traditional cryptocurrencies due to their non-fungible nature, which means each NFT is entirely distinct and cannot be exchanged on a one-to-one basis with another token. This uniqueness makes them ideal for representing proprietorship of one-of-a-kind digital or corporeal assets. One of the most prevalent standards for creating NFTs is the ERC-721 standard, which was initially introduced on the Ethereum blockchain. This standard defines the essential interface that smart contracts must adhere to in order to construct NFTs. By conforming to the ERC-721 standard, developers ensure that NFTs are compatible with various applications, wallets, and marketplaces, facilitating their seamless integration into the speedily evolving NFT ecosystem.

In the pioneering work of Ali et al. (2023), they introduced ‘NFT Club’, an innovative portal designed to facilitate the trading of NFTs using cryptocurrencies as the primary medium of exchange. This platform caters to both seasoned NFT enthusiasts and newcomers to the space, seeking to simplify the process of purchasing and selling these unique digital assets. For users to participate in ‘NFT Club’, they are required to possess a MetaMask wallet, a popular Ethereum-based wallet, and utilise digital signatures for transactions and secure access to their digital assets. The utilisation of MetaMask and digital signatures not only ensures the safety of users’ assets but also facilitates the trading process within the platform. In the technical underpinnings of ‘NFT Club’, the initiative employs state-of-the-art technologies to provide a seamless user experience. The

front-end of the platform is implemented using the Web3.js library, which enables web applications to interact with the Ethereum blockchain and other decentralised networks. The smart contracts regulating the operation of 'NFT Club' are constructed using Solidity, a widely adopted programming language for developing decentralised applications on the Ethereum blockchain. By leveraging the power of Solidity, 'NFT Club' can assure the trustworthiness and transparency of NFT transactions, thereby augmenting the overall security and reliability of the platform.

2.5 Blockchain innovations in real estate management

The various innovations in real estate management utilising blockchain technology are detailed in Table 2, with accompanying short descriptions provided herein. In the visionary work of Gupta et al. (2019), they introduced 'LandLedger', a transformative blockchain-powered land administration system meticulously designed to address the persistent challenges associated with incomplete and damaged land records within the existing land administration systems of various countries, with a particular focus on India. The main goal of this system is to tackle the recurring challenges related with inadequate and damaged land records that afflict land administration systems in several nations, particularly India. These impediments, which have long hampered the efficient functioning of land management, include concerns such as missing or deteriorating papers, leading to disagreements and inefficiencies in property transactions. 'LandLedger' incorporates a permissioned blockchain, an essential feature that permits regulated access to the system, safeguarding the integrity of land data and transactions. Multiple governmental departments engage in the operation of this unique system, comprising the Registrar's office, the Income Tax department, and the Revenue department. This collaborative approach not only enhances openness but also streamlines the collaboration between multiple ministries, ultimately boosting the overall land management process.

In the original work by Hariharan and Kirupananda (2021), a new system is established, which harnesses the potential of decentralised blockchain technology to improve land transaction record-keeping. This accomplishment protects not just the preservation of data but also the establishment of tamper-proof records of property ownership, marking a tremendous leap forward in land administration. One of the noteworthy characteristics of this system is its implementation of machine learning technology, which enhances its efficacy and utility. By integrating machine learning, the system gives predicted land value capabilities, thereby offering advanced reports through the land registry whenever they are essential. This feature accelerates the valuation process and offers stakeholders with important insights, making informed assessments a viable aim. Another key component is the system's distribution of digital certificates following the successful completion of land or rental registrations. Nonetheless, it is crucial to grasp the system's constraints. Challenges relating to interoperability and integration with current land register systems and databases may develop if this system coexists with pre-existing infrastructure.

Humdullah et al. (2021) did a detailed review of several existing land registration systems and determined their inadequacies.To handle these difficulties, they embarked on the creation of a revolutionary system that combines RSA-based public key encryption coupled with the generation of 16-byte random session keys using advanced encryption standard (AES) for data encryption and decryption, setting a new benchmark for land registration security. The cornerstone of their innovative technology hinges upon a user-friendly online interface. This interface simplifies the land registration process by leading

the proprietor through critical phases. Owners are needed to submit their private keys, the public keys of the prospective buyer, and necessary buyer information, such as their name and ID/passport data. Notably, the address and title of the land remain unaltered, insuring that critical property facts stay unchanged. As an added layer of security, the landowner is needed to provide their private key file for certification. This stage is vital in confirming the legitimacy of the landowner's access rights, creating confidence and responsibility within the system. The framework further increases its security measures by validating the original owner's access. This is performed by successfully decrypting the signed data provided by the landowner. The decrypted data is then securely stored in a block together with all essential properties, ensuring data integrity and facilitating ownership verification. This technique assures that the land registration process is not only secure but also tamper-proof. Salman Humdullah and his team's success signifies a big leap forward in the field of land registration by establishing a highly secure and technologically advanced approach. Their technique boosts the total efficiency and reliability of land registration activities while highlighting the necessity of data security and integrity, helping to the evolution of land administration systems.

In the groundbreaking work of Dubey et al. (2023), a cutting-edge land registration system is introduced, underpinned by the Ethereum blockchain. Their system introduces a user-friendly decentralised application (DApp) designed to streamline property transfers, offering a revolutionary approach to land administration. One of the standout features of this DApp is its embrace of a single central authority model. This design choice prioritises speed and simplicity in property transfers, making the process more accessible and efficient for users. Key functions like 'newRegistration()' and 'propertyVerification()' are central to the system, enabling seamless interactions for landowners and buyers, further enhancing the overall user experience. The system leverages the full potential of blockchain technology to enhance transparency and security. It combines a suite of technologies, including React for the front-end, Solidity for smart contract development, Ethereum for blockchain infrastructure, Ganache for local blockchain testing, Web3.js API for interaction with the Ethereum network, and Hyperledger Explorer for comprehensive blockchain exploration and analysis. This comprehensive technology stack ensures that the land registration system offers a secure and transparent solution for users. The integration of React, Solidity, Ethereum, Ganache, Web3.js, and Hyperledger Explorer demonstrates the team's commitment to developing a robust and trustworthy platform.

Kunjumon et al. (2023) have presented a revolutionary system that blends land registration with NFT creation, with a strong emphasis on decentralisation and user empowerment. In this system, the administrator has the power to build NFTs that reflect specific land assets. Importantly, once these NFTs are generated, the administrator surrenders control over them, ensuring that ownership and upkeep of these digital assets remain fully in the hands of the designated owner. Users participating inside the program receive the capability to engage in peer-to-peer trading of NFT tokens, allowing them to both buy and sell these digital representations of land. This peer-to-peer function adds a layer of decentralisation to the property transfer process, decreasing the need for intermediaries. Furthermore, users have the possibility to attach different blockchain addresses to their account. This versatility proves advantageous for performing various transactions and managing diverse NFT assets, allowing users to keep control and ownership over their digital land holdings. In the land registration process, the administrator plays a critical role in analysing land papers and adding land data to the system. This requires the uploading of scanned copies of crucial land papers, a vital component of the land registration procedure.

The usage of the InterPlanetary File System (IPFS) for document storage provides security. IPFS generates independent cryptographic hashes for each document, enhancing document integrity and accessibility. To construct an NFT reflecting a specific land asset, a mint request is issued to a deployed smart contract on the blockchain.

Kadam et al. (2020) made a big and influential contribution with their "Land Records System Using Hybrid Blockchain". This technique is a new blend of public and private blockchains, giving a unique solution that greatly enhances the security, transparency, and efficiency in the management of property data. By incorporating the strengths of both public and private blockchains, this system delivers a fresh and comprehensive approach to tackling the challenges in storing land records. The hybrid blockchain design delivers various important advantages, with real estate transactions ability to profit in multiple ways. One of the key benefits of this hybrid strategy is the huge improvement in data integrity. Public blockchains are famous for their immutability and decentralised character, which promotes the security and dependability of property records. Simultaneously, private blockchains have the advantage of limited access, guaranteeing that sensitive property data is shielded from illegitimate access. Transparency is another significant advantage given by this hybrid system. Public blockchains are inherently transparent, making all recorded property transactions public to relevant parties. This transparency fosters trust among stakeholders and helps prevent fraudulent activities. Furthermore, the hybrid blockchain design enhances the scalability of the land records system. It enables for a more flexible and effective handling of a rising amount of real estate transactions. As the real estate market expands, its scalability insures that the system can handle expanding needs without impacting its performance. The "Land Records System Using Hybrid Blockchain" proposed by Rishikesh Kadam and his colleagues serves as a suitable paradigm for modernising property record administration.

Madhura and Mahalakshmi (2022) research on blockchain technology in the real estate market focuses on its application in boosting transparency, efficiency, security, and accessibility. The study intends to create a new era of openness to property transactions, allowing all parties involved an incontrovertible view of the transaction history. Efficiency is another pillar, since blockchain technology helps streamline operations, lowering time and resources usually connected with property transactions. Smart contracts automate several parts of real estate transactions, resulting in major time and cost savings. Security is a problem in real estate because of the financial ramifications of transactions. This research represents a key step in modernising the real estate sector with blockchain technology, seeking to enhance the trustworthiness of real estate transactions and benefit all players involved.

In the new research, titled "Blockchain Smart Contract Adoption in Real Estate Deals in Smart Cities", conducted by Ullah and Al-Turjman (2023) begin on an exploration of how blockchain technology might be easily integrated into the domain of real estate transactions. Their work is firmly founded in the concepts of security, efficiency, and openness, and it holds particularly important implications for real estate deals within the context of smart cities. This integration allows a heightened sense of trust and reliability, crucial in the real estate industry. A distinguishing characteristic of their method is the elimination of intermediaries in the real estate process. The use of blockchain technology in real estate dealings not only fortifies the security of transactions but also optimises their execution. The self-executing feature of smart contracts implies that agreements are automatically enforced when predefined circumstances are satisfied. This not only streamlines the transaction process but also decreases the potential for disputes and errors, thus boosting the efficacy

and trustworthiness of real estate transactions. The principle of transparency is another major component of their mission.

Tan and Nguyen (2022) give the "Real Estate Transaction Trace System Model Based on Ethereum Blockchain". This unique solution signifies a huge leap in the real estate arena, with a key focus on enhancing efficiency, transparency, and confidence in property transactions. At the heart of their strategy is the deployment of the Real Estate Transaction Trace (RETT) model onto the Ethereum blockchain, refer Figure 5. This blend of new technologies and conventional real estate processes leads in a dramatic transformation of how property transactions are done and recorded. One of the primary purposes of their profession is to boost the efficiency of real estate transactions. By leveraging the Ethereum blockchain, they give a new degree of automation and precision to the process. Smart contracts on the blockchain permit the automated implementation of agreements when established conditions are satisfied, substantially expediting the transaction process and minimising the likelihood of errors or disagreements. Transparency is another crucial part of their solution.

In their considerable contribution, Stefanović et al. (2022) provides a pioneering method dubbed "Smart Contract for Managing Land Administration System Transactions". This concept revolves around the usage of Ethereum smart contracts to facilitate the management of land administration. Their work serves as a catalyst for boosting the accuracy, efficiency, security, and transparency in the field of land management, transforming traditional systems in the process. Central to their approach is the implementation of Ethereum smart contracts to speed land management processes. Smart contracts, with their self-executing nature, automate the implementation of specified actions and agreements when specific criteria are satisfied. This automation is a significant feature in enhancing the accuracy and efficiency of land administration, lowering the danger of human errors and minimising delays in the process. The concentration on precision is very crucial. By automating administrative procedures with smart contracts, the risk for errors resulting from human data entry and processing is greatly lowered. Land records and transactions become more precise and reliable, creating a stronger degree of trust in the land management system.

In a remarkable fusion of blockchain technology and smart contracts, Hari et al. (2023) has introduced an innovative property management tool known as the "NFT-enabled Property Management and Exchange System". This pioneering system represents a paradigm shift in property exchange and management, emphasising efficiency, security, and transparency as its core principles. One of the standout features of their system is its capacity to significantly enhance the efficiency of property exchange and management. By incorporating blockchain technology and smart contracts, they streamline the entire process. Smart contracts, known for their self-executing nature, automate key aspects of property transactions, resulting in a faster and more efficient exchange process. Security is another fundamental pillar of their work. In the world of real estate, the security of property transactions is of paramount importance. The integration of blockchain technology ensures the robust protection of property data and transactions. Blockchain's cryptographic algorithms make data stored on the ledger highly resistant to tampering and fraud, enhancing the overall security and trustworthiness of property management. A noteworthy aspect of their system is the integration of NFTs into the property exchange process. NFTs are designed to increase the transferability and security of real estate assets. These digital tokens represent unique, indivisible assets, and by incorporating them into property management, the system adds an extra layer of security and authenticity to real estate transactions. Transparency is the fourth cornerstone of their endeavor.

Table 2 Real estate systems using blockchain

S. no.	*Authors*	*Year*	*Methodology*	*Tools*	*Key findings*	*Research gaps*
1	Dubey et al. (2023)	2023	Blockchain development in React and Solidity	Ethereum Blockchain, Ganache, Web3.js API, Hyperledger Explorer	User-friendly DApp for land registration using Ethereum.	Rental systems not included.
2	Kadam et al. (2020)	2020	Hybrid blockchain design, Ethereum Blockchain, Solidity smart contracts	Ethereum Blockchain, Geth, React, Solidity, Web3.js API	Hybrid blockchain-based land records system	Limited data modification access, Exclusion of third parties.
3	Madhura and Mahalakshmi (2022)	2022	Ethereum, Public and Private/Consortium blockchains	Bitcoin, Ethereum, Public and Private/Consortium blockchains	Blockchain implementation in real estate for transparency.	Integration challenges, Scalability concerns, Regulatory and legal challenges, Infrastructure investment.
4	Ullah and Al-Turjman (2023)	2023	Development of Ethereum-based smart contracts, usability testing	Ethereum, Solidity, GoEthereum (Geth), PyEthereum (PyEth)	Blockchain smart contracts in real estate deals for efficiency	Rental systems not included.
5	Tan and Nguyen (2022)	2022	Trace of transactions and registrations	Ethereum Blockchain, Ethereum Virtual Machine (EVM)	System on Ethereum for transparency, efficiency, and trust.	Limited blockchain storage, Backend complexity, Ethereum platform limitations.
6	Stefanović et al. (2022)	2022	Ethereum-based smart contract development, testing	Ethereum, Solidity, Web3 API	Smart contracts for land administration using Ethereum,	Blockchain confirmation challenges, Data storage limitations.
7	Hari et al. (2023)	2023	NFT-enabled property management and exchange system	Ethereum, Ganache, Metamask, PostgreSQL	Blockchain and smart contracts for property management offering security	Scalability, Legal constraints, Adoption challenges, Security vulnerabilities.

Table 2 Real estate systems using blockchain (continued)

S. no.	*Authors*	*Year*	*Methodology*	*Tools*	*Key Findings*	*Research gaps*
8	Yadav et al. (2022)	2022	Development of smart contracts	Hyperledger Blockchain, IPFS, Ganache, PostgreSQL	Trustworthy and secured house rental system with security, transparency, and efficiency.	Scalability, Integration challenges, Performance concerns.
9	Gupta et al. (2019)	2019	Blockchain-powered land administration system	Permissioned blockchain	Addressing challenges associated with incomplete and damaged land records.	Enhancing property ownership and transfer systems.
10	Kunjumon et al. (2023)	2023	Decentralised land registration and NFT creation	Blockchain, IPFS, NFTs	Peer-to-peer trading of land NFT tokens.	Enhancing autonomy in property transactions.
11	Hariharan and Kirupananda (2021)	2021	Decentralised blockchain technology and machine learning	Blockchain, Machine Learning	Predictive land valuation capabilities.	Interoperability, Data Accuracy, Integration with existing systems challenges.
12	Humdullah et al. (2021)	2021	Decentralised and transparent network, Public and private keys	Blockchain	Data storage of land registration. Data security, ownership verification	Evaluation of the framework's effectiveness and scalability. Challenges and limitations in implementation.
13	Laarabi et al. (2022)	2022	Systematic mapping study methodology	Not applicable	Lack of scientific publications regarding research challenges of smart contracts in real estate.	Research gaps in the use of smart contracts in real estate, legal barriers.

Yadav et al. (2022) has made a huge contribution by introducing a cutting-edge solution known as the "Trustworthy and Secured House Rental System". Their groundbreaking solution combines blockchain technology and smart contracts to usher in a new era of security, transparency, and efficiency in the field of house renting operations. At the heart of their strategy is the basic principle of increasing security. In the case of house renting, trust is vital, and their strategy handles this problem with the powerful security qualities of blockchain technology. Data and transactions linked to house rents are recorded in an immutable ledger, providing it highly resistant to unauthorised access and manipulation. This improved security is a vital component of their business. The pursuit of transparency is another key component of their activity. Blockchain technology, with its transparent and irreversible nature, ensures that all parties engaged in house rental activities have a clear and unconstrained view of the transaction history. This transparency fosters confidence between landlords and tenants and minimises the possibility of disputes or misunderstandings. Efficiency is the third pillar of their methodology. By embracing smart contracts, they automate many of the traditionally onerous and time-consuming tasks associated with property renting. These self-executing contracts ease the execution of agreements when preset criteria are satisfied, simplifying the renting process and removing friction between landlords and tenants. Their technique also goes to enhancing the dependability of the property renting operation.

Laarabi et al. (2022) explores the evolving landscape of smart contracts within the real estate domain, shedding light on current research trends, the potential benefits, and the existing gaps that warrant further investigation. The study encompasses an assessment of 68 relevant papers, contributing insights to three key research questions: the current research topics on smart contracts for real estate, how smart contracts can address existing real estate problems, and the gaps in research that necessitate future exploration.

3 Conclusion and future works

In conclusion, this review paper underscores the transformative impact of blockchain-based property tokenisation, with a special emphasis on the integration of NFTs in real estate transactions. The paper highlights how this technology streamlines property transactions, enhances security and transparency, and reduces costs by eliminating the need for intermediaries.

It addresses the underlying ideas of blockchain technology, cryptography, and the function of smart contracts in safeguarding property tokenisation. The report also analyses the larger uses of blockchain in areas including rural government, smart agriculture, and water resource management.

Furthermore, it focuses on the relevance of NFTs as unique digital assets and their function in numerous fields. In summary, the study highlights the potential for blockchain and NFTs to change the real estate business and beyond, delivering efficient, safe, and transparent property transactions.

Future work might concentrate on establishing more efficient and scalable systems that can make property tokenisation more available to a larger variety of users by enabling multi-chain compatibility. Creating new and inventive use cases for property tokenisation. Fractional ownership, digital twins, and virtual worlds are just a few of the possible use cases for property tokenisation. Future studies might investigate new and inventive methods to utilise property tokens to benefit the real estate sector. Property tokenisation creates a

variety of regulatory and legal problems. Future work might concentrate on defining clear and explicit rules for property tokenisation, and on resolving any legal difficulties that may emerge. Also creation of new kinds of property tokens that reflect diverse elements of property ownership, such as rental revenue, voting rights, and development rights might help revolutionise the conventional method of real estate negotiations.

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