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ORIGINAL RESEARCH

Dynamic smart contracts framework on Ethereum private blockchain for real estate management

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Abstract
Blockchain technology enables the recording of information in an immutable manner, making it extremely difficult or nearly impossible to alter, hack, or manipulate. Its adoption is expected to enhance long-term economic sustainability across various industries, including real estate. Traditional real estate transactions typically involve third-party intermediaries to record and validate informal transactions. However, blockchain technology has the potential to revolutionize the real estate sector by transforming how properties are bought and sold. Features such as efficiency, transparency, process automation through smart contracts, robust consensus mechanisms, and enhanced security measures can reshape the real estate landscape by increasing efficiency and reducing costs. This paper explores the challenges currently faced by the real estate industry and reviews the literature on the disruptive impact of blockchain technology in this sector. A conceptual framework for a private blockchain is proposed based on the Ethereum platform, utilizing proof of authority as the consensus mechanism, specifically designed for property transactions. The proposed model integrates self-sovereign identity for secure and decentralized identity management, incorporates digital wallets for transaction management, and leverages smart contracts to automate processes. This approach enhances transparency in digital transactions, thereby fostering greater trust between users and service provider.

1 | INTRODUCTION

The growing significance of big data is leading substantial changes across many industries [1]. Big data encompasses enormous datasets (structured, semi-structured or unstructured) which necessitates novel techniques for storage, management and processing [2]. This swing is progressively penetrating every aspect of our lives, influencing daily decision making across several domains. One sector where data has the potential to be a game changer is the real estate industry [3]. Economic and social development globally hinge on the real estate industry. This sector has significant societal, ecological, and economic importance, representing approximately 60% of global wealth [4]. The growth of the real estate market is expected to be boosted by steady economic growth in both advanced and emerging economies. The global real GDP grew by 3.6% between 2021 and 2023 [5, 6]. Research has indicated real estate markets often face crises triggering economic collapses [7]. Real estate operations have enjoyed lasting popularity because of the high profits prospective obtainable by transitional services in property transactions [8]. This sector functions with obsolete technology bringing about incompetence and conflicts among stakeholders [9]. Purchasing or renting any property involves many different parties such as brokers, banks, lawyers, inspectors, insurers, regulators and tax agencies all maintaining distinct records [10]. This process is costly and time-consuming. Numerous challenges, as depicted in Figure 1, such as lack of transparency, high transaction costs, uncertain timelines, liquidity issues, difficulties with cash flow management, and limited or no access for average investors, are major issues facing the real estate industry

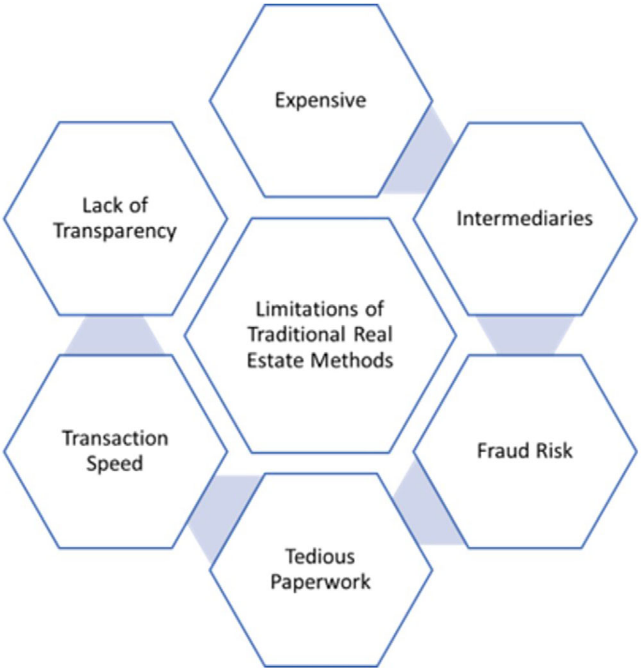

FIGURE 1 Traditional real estate challenges.

[11]. In order to overcome these challenges, the real estate sector necessitates the integration of the emerging and disruptive technologies [12].

Over the past 5 years, blockchain technology has garnered significant attention, and its application in this domain could yield benefits even in a small-scale hybrid environment. [13]. Blockchain technology is emerging as one of the distinctive, disruptive technologies of the contemporary era [14]. Blockchain technology, a decentralized network introduced initially in the form of BitCoin [15] [16] is characterized as a decentralized technology for transaction and data management. These digital records, known as blocks, are connected using cryptography and are verifiable, immutable, distributed, and managed by a peer-to-peer network. [17]. This technology offers industrial advantages and meets financial needs, with Bitcoin representing one of many possible applications [18, 19]. Blockchain technology allows for secure and transparent tracking, recording, and execution of transactions [20, 21]. The decentralized nature of these systems provides a public ledger based on a history of dispersed transactions worldwide, which helps prevent manipulation and fraud [22]. SSI and blockchain distributed ledgers are novel technologies that emphasize individual control and ownership of personal identity information. The integration of SSI with blockchain enhances security by providing an additional layer of trust and authenticity. Participants can validate transactions without the need for a centralized clearing organization [23]. Blockchain technology platforms can be used for a wide range of purposes, such as transferring money, completing transactions, voting, and more, enabling users to store and share data securely [24]. There are numerous applications of blockchain technology, including secure and transparent financial transactions (e.g. cryptocurrencies like Bitcoin) [25], supply chain management, smart contracts for automated processes, identity verification, voting systems, and decentralized applications (DApps) in gaming and social networking [26]. Moreover, blockchain technology is seeking attention in real estate which is a crucial asset for humans as it provides shelter and acts as a major investment for retirement [27]. Blockchain technology holds substantial potential for transforming the real estate industry [28]. Earlier studies have indicated its potential applications across various sectors such as real estate administration, property transactions, land registration, and more [29].

This paper aims to address the issues faced by traditional real estate by proposing a model that implements a private blockchain, specifically focusing on property transactions and aligning with SSI principles. The model leverages the Ethereum platform, using smart contracts to automate and impose transaction terms, which significantly improves efficiency and decreases the need for intermediaries. By integrating SSI principles, entities are authorized with full control over their digital identities, guaranteeing secure and decentralized identity management. Moreover, the use of digital wallets simplifies unified and transparent financial transactions, whereas consensus mechanisms ensure the integrity and validation of each transaction across the distributed network. This comprehensive method not only increases transaction security but correspondingly fosters a more well-organized, transparent, and trustworthy real estate market.

The paper is organized as follows: Section 2 provides an overview of real estate and blockchain technology, followed by a literature review of blockchain technology utilization across diverse domains in real estate and its potential benefits to the sector in Section 3. Section 4 presents the proposed framework and the system's development process. Section 5 discusses the simulation results of the proposed approach. Finally, Sections 6 and 7 conclude the work and discuss potential research opportunities within the field.

2 | BACKGROUND

Globally the real estate sector makes a considerable impact to the country's economic development, as investments in this sector are normally seen as extremely profitable [30, 31]. The real estate sector has demonstrated itself to be one of the most profitable industries worldwide despite the existence of unsteady political circumstances and extensive corruption [32]. Regrettably, the real estate industry is vulnerable to the dominant corruption challenges [33]. Lack of digit record management and decentralized involvement of multiple parties, the real estate transaction procedures are disposed to challenges related to partial information, imprecise property values recording, problems in land procurement, mistrust among buyers and sellers and the prevalence of fraudulent schemes etc. [34]. The inconsistent and imprecise recording of land prices has been recognized as a significant factor contributing to corruption within the real estate sector. Implementing accurate and transparent land valuation practices is essential for reducing corruption and ensuring fair market operations. The real estate

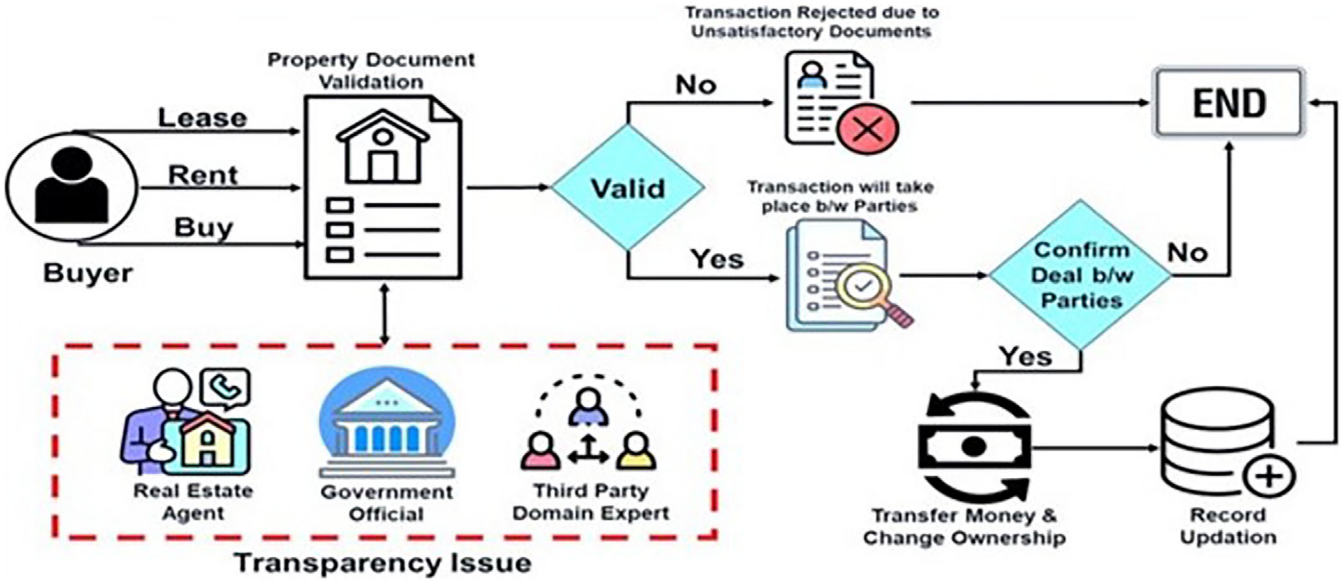

FIGURE 2 Traditional real estate buying process.

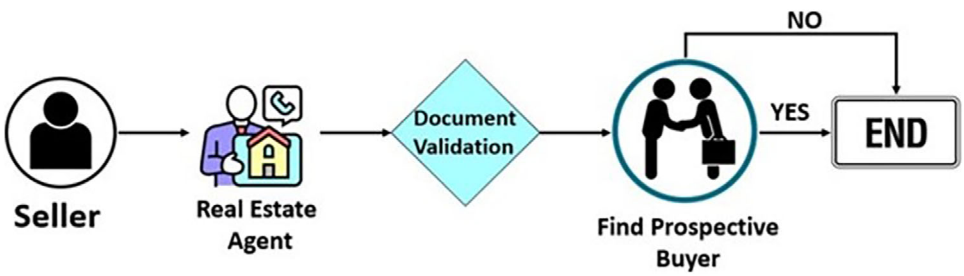

FIGURE 3 Traditional real estate selling process.

industry presents considerable challenges, especially for entities unfamiliar with the extensive laws and regulations governing property transactions [35]. The process involves a substantial amount of documentation, necessitating the involvement of several intermediaries such as investment advisors, brokers, and agents. A high level of trust is placed in real estate agents or brokers, who wield considerable influence in the market due to their access to crucial investment plans and market assessments [36]. Persistent disparities in the availability of information often empower these agents to influence prices, potentially disadvantaging both sellers and buyers. This imbalance of trust can lead to deception and manipulation within the market [37]. Informed decision making is next to impossible due to the absence of digitized land records and their exposure to manipulation. The public lacks awareness about the status of government entities approval of continuing development projects and exclusively depends on the project developer market reputation and making investments [38]. Absence of transparency between buyers and sellers nurtures mistrust. In various occasions, stockholders discover themselves with inadequate choices when it comes to tracking down complete and exact information while making investment decisions. Figures 2 and 3 and demonstrates the traditional real estate buying and selling process.

Blockchain has been characterized as a favourable solution addressing the complexities of real estate transactions, resulting in enhancements in efficiency, transparency, and thereby fostering trust [39, 40]. In contrast to a traditional database [41], a blockchain technology stores data in blocks that are linked together in a chain [42] as illustrated in Figure 4. It does not require intermediaries or centralized trust management and thus reducing time, cost and increasing overall efficiency [43]. Each block includes a unique identifier called a hash, a timestamp of recent valid transactions, and the hash of the previous block [44]. The hash of the previous block helps secure the chain by ensuring that no block can be altered or inserted between two existing blocks making it tamper-resistant. These blocks are connected through peer-to-peer nodes and are often referred to as a "digital ledger" [45]. They are known for creating unchangeable ledgers, or records of transactions that cannot be modified, removed or destroyed [46, 47]. The distributed ledger copies and distributes transactions across a network of computers involved in blockchain technology [48].

In this network, each member maintains their own copy of the information, and all members must validate and store each update collectively. This ensures that every participant always has access to the same information, providing a consistent

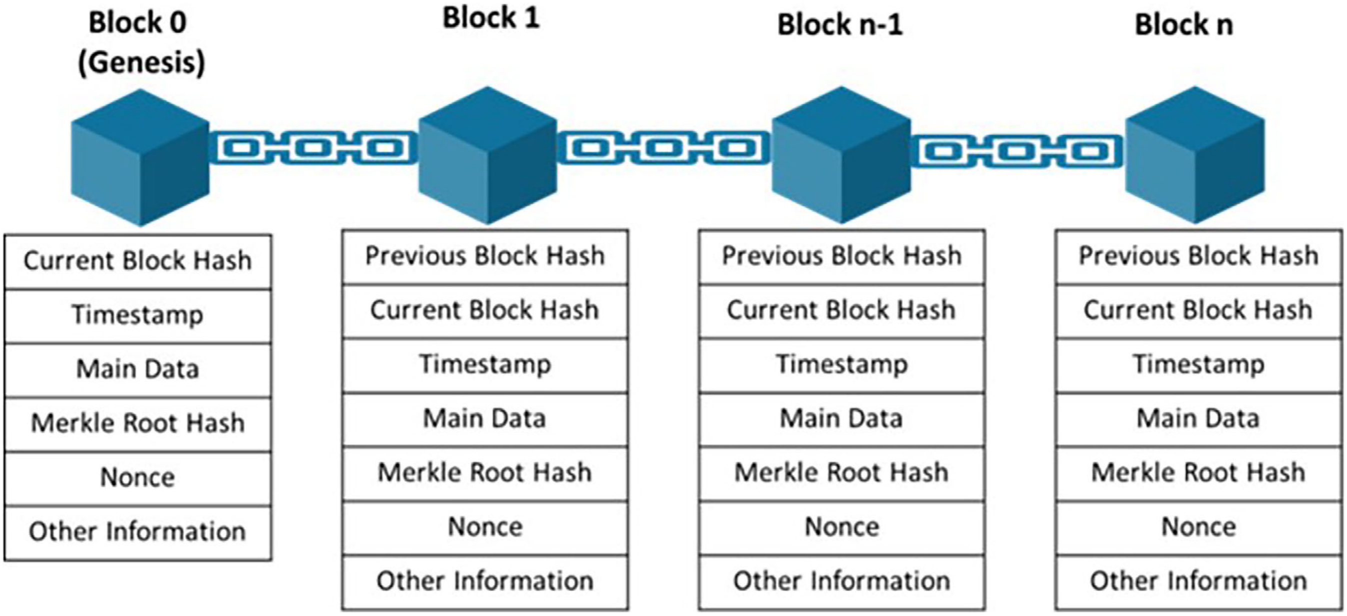

FIGURE 4 Blockchain technology structure.

and reliable source of truth. Each transaction in this ledger is authenticated and protected from tampering by the owner's digital signature. This makes the information stored in the digital ledger very secure [49]. As this technology is of a decentralized nature, it eliminates the need for any intermediary third-party organizations. Blockchain technology serves three main functions that enable a wide range of solutions. First, it facilitates direct peer-to-peer transactions. Second, it provides a transparent and secure means of data storage. Third, it allows for the automation of logic and agreements through smart contracts. These features promote inclusion, transparency, and cooperation within various systems. Key concepts include a shared ledger for transparent record-keeping, permissions for secure transactions, smart contracts for automating agreements, and consensus mechanisms for validating transactions [50].

By using the blockchain, the SSI key principles can be achieved to overcome digital identity issues [51]. Blockchain technology fosters peer-to-peer trust in service authentication and authorization which aligns with the SSI requirement of individuals, organizations, or entities having complete ownership and control over their own data. The key requirement of SSI which blockchain technology can cater are listed in Table 1.

In short, blockchain platforms allow secure and transparent tracking, recording, and execution of transactions. The platform can be used for a wide range of purposes, such as transferring money, completing transactions, voting, and more [52]. They enable users to store and share data securely. These platforms have sophisticated scripting languages that can be used to perform a range of Web3 tasks, such as creating and managing non-fungible tokens (NFTs), initiating and completing transactions, and developing smart contracts. There are various blockchain platforms to choose from, including Ethereum, Cardano, Tron, Ripple, Stellar, Solana, and Polkadot [53].

3 | RELATED WORK

The real estate industry, like many others, have experienced significant change as a result of the Covid-19 pandemic. After the pandemic, there has been a significant shift in how consumers perceive investments, shopping, and business operations [54]. To bounce back from the impact of the pandemic, robust technological approaches are needed. The blockchain technology has been employed in real estate administration [55], real estate investment [56], property transaction [57], leasing, and renting [58, 59].

Land administration involves the recording and dissemination of information concerning the ownership, valuation, and utilization of land and its related assets. Lai in [60] proposed a hypothesis for utilizing smart contracts to manage land administration systems. The solution, written in solidity programming language, is a smart contract that can handle various scenarios in land administration, such as ownership sharing or partial ownership, property transfers, merging or dividing real estate, and preventing illegal trading of real estate. Spielman [61] associated the current system with blockchain technology and discussed its advantages and issues. Further he highlighted this technology as the future of record keeping mechanism, owing to its swift development and advantages over traditional systems. Bennett et al. in [62] proposed a hybrid approach, i.e. integration of conventional database technologies with blockchain technology for land administration. Instead of pursuing extensive sector-wide digital transformation initiatives, this approach focuses on individual land transactions, operations, and stakeholders, with the goal of minimizing disruptions to established institutions and infrastructures and maximizing the benefits facilitated by smart contracts. Also hybrid approaches seem to present a solution for overcoming challenges in adopting

TABLE 1 Principles of SSI.

Principles	Objective	Blockchain-enabled fulfillment
Existence	Individuals own an autonomous identity that cannot be fully replicated in digital mediums.	Guarantees by blockchain by securely registering identities on the distributed ledger, preventing duplication or manipulation.
Control	Individuals should have complete control over the data they own.	The concept of private keys enables individuals to manage access and permissions without relying on centralized authorities.
Access	Individuals should have easy and secure access to their own identity data.	The authentication mechanisms built on cryptographic protocols enable efficient and secure access to digital services in blockchain.
Transparency	Individuals should be able to run processes related to identity, i.e. any alteration is transparent, promoting trust and accountability.	Transparency is an inherent property where all transactions are recorded on a public ledger accessible to all participants, i.e. anyone can view the entire history of transactions.
Persistence	Individuals' information should be durable and resistant to tampering, ensuring its integrity over time.	Digital identities stored on the blockchain are immutable, guaranteeing their persistence over time and resistance to alteration or deletion.
Portability	Individuals should be able to use their identity data anywhere they choose, for instance accessing online services.	Blockchain allows the portability of identities across diverse services and platforms, easing unified interaction without the need for repeated identity verification.
Interoperability	Individuals should be able to work together seamlessly, facilitating the exchange of identity information within compatible infrastructures.	Through standardized protocols, blockchain-based identity systems can effortlessly integrate with existing infrastructures and ecosystems.
Consent	Individuals have the fundamental right to decide whether to allow or deny the use of their identity information; such consent should be informed and explicit.	Blockchain-based smart contracts enable automated execution of consent agreements, allowing individuals to grant or revoke consent for the use of their identity data.
Minimization	Individuals' personal data disclosure should be minimized, safeguarding users' privacy.	Blockchain permits selective disclosure of identity attributes, guaranteeing that only the necessary data is shared.

blockchain. Similarly, an investigator Iftikhar Ahmad [63] used blockchain technology to convert normal real estate systems into blockchain based immutable record management systems. Pinyaphat in his research presented challenges such as scalability, security, and compliance with regulations that must be addressed for successful application of this technology in the real estate sector [64]. Mendi et al. in [65] proposed a blockchain based solution built on the Hyperledger system to try and solve land administration issues between the buyer and seller by incorporating land registry office, bank, municipality, buyer, and seller into a digital system built on the blockchain resulting in completely transparent and traceable property administration. Hence the literature indicates that blockchain has potential to tackle significant challenges in land administration, including inefficiency, fraud, corruption, and trust issues but still its adoption is challenging due to legal and technical issues.

Real estate market presents two investment avenues: direct and indirect. Direct investment involves engaging in property transactions, whereas indirect investment involves purchasing shares in real estate companies. Baum A in [66] proposes that employing an intermediary structure is likely crucial and pragmatic when dividing ownership of a single asset into fractions. As a result, investment funds emerge as more viable candidates for tokenization. Tokenization involves digitally representing real estate through blockchain-based tokens. The author presents findings concerning transactions involving the tokenization of real estate. In [67], Uchani outlines existing applications of blockchain technology in the real estate sector. To enhance its business viability, it presents the insights obtained from industry experts and representatives of real estate tokenization companies. In [68], Ullah et al. considered smart real estate as an urban environment that enhances its resources via user centric, maintainable, and advanced technologies while also distributing vital information to real estate users, managers, and agents. One of the key benefits that blockchain technology brings to commercial real estate is increased safety and security [69] along with efficiencies through the digitization of records. The findings reveal that the concept will disrupt the current real estate market and cause significant changes in revenue generation and asset ownership within a digital framework. Tokenization offers significant benefits, i.e. blockchain can make traditionally large real estate investments accessible, making it easier for more people to invest in real estate. Also, by integrating smart contracts, transactions can be faster, cheaper, and more transparent, ensuring compliance, verifying documents and facilitating trades.

A property transaction comprises activities associated with buying and selling real estate. This includes actions like purchasing, selling, and exchanging property, conducting transactions involving real estate, and determining the value of real estate. Rangineni et al. [70] in suggest using smart contracts on a blockchain to stop fraudulent activities in property transactions. The proposed system tries to fix issues caused by missing ownership records. The system allows digital uploading of the relevant information to the smart contract via a front-end, enabling smart contracts to act as a self-enforcing third party to verify that if the agreed terms are fulfilled. When the terms have been met and verified the transaction is completed. The transaction is logged on to the blockchain and offers a secure and transparent technique of authenticating the owner of a property. Christidis in [71] presented a work detailing the process and features of blockchain technology and smart contracts, including the paybacks and downsides of consuming this technology in the system. Wajde in [72] examines the advantages of utilizing blockchain technology in the real estate sector. It points out that blockchain can streamline real estate transactions by cutting down on intermediaries and their costs, increasing transparency, and minimizing the risk of fraud. Additionally, he highlights that blockchain technology can assign a digital address to each property, which could store information such as occupancy, financing, legal issues, building performance, and physical characteristics and could be accessed and connected online. Karamitsos [73] have explained how their proposed use cases can address current challenges in the real estate industry and provide a design for secure, paperless transactions to improve the management of assets within a smart city. The investigators suggest that this fast and disruptive technology is suitable and a key instrument in the economy. Within a few years this technology has established substantial attention from many institutions and government organizations. Their design incorporates the use of smart contracts, which provide a secure and decentralized ledger of transactions and assets between buyers and sellers. Therefore, for property transactions the main benefits which blockchain is offering are less or no involvement of intermediaries, streamlining the transaction process and decreasing costs and time.

Leasing and renting grants the right to utilize property or its components in exchange for payment. This process generally involves lease-purchase agreements for property. Zheng et al. in [74] used blockchain technology for the implementation of the housing rental system. The transactions were managed using smart contracts. Although the proposed implementation uses blockchain storage security, some design specifications were lacking. Qi-Long et al. in [75] proposed a smart contracts-based leasing system. The suggested approach transforms conventional lease agreements into smart lease contracts through programming. This system enhances overall efficiency and offers legal safeguards for both tenants and landlords. Smart contracts in blockchain automate and uphold rental agreements, diminishing reliance on intermediaries. Lease terms can be encoded into these contracts, guaranteeing transparent and self-executing transactions. This simplifies the rental process, reduces conflicts, and strengthens trust between landlords and tenants.

4 | RELATED WORK BLOCKCHAIN TECHNOLOGY IMPLEMENTATION IN REAL ESTATE VIA SMART CONTRACTS

4.1 | Preliminaries

The proposed system leverages a private blockchain built on Ethereum's smart contracts and adopts the PoA consensus mechanism. By integrating SSI principles and employing MetaMask for secure wallet management, the system permits users with control over their digital identities and assets. MetaMask enables interaction with the blockchain, while the ledger and transaction immutability guarantees a secure Ethereum blockchain platform based real estate industry. This convergence of Smart Contracts offers a decentralized, transparent, and secure system. The components used to implement the proposed system are briefly discussed below:

4.1.1 | Distributed database technology

BigchainDB [76] is a distributed database solution that brings together the scalability of NoSQL databases and the security and immutability of blockchain technology. It is suitable for handling large quantities of data, like high-transaction volumes, metadata, and files. The technology allows for decentralized, tamper-proof storage and sharing of data across various industries such as supply chain management, IoT, and digital asset management. Unlike traditional databases, BigchainDB stores data across a network of nodes rather than a central server, making it more secure and resilient to failures. It also has the capability to integrate with other blockchain technology platforms, like Ethereum and hyper ledger.

4.1.2 | Consensus mechanism

Since blockchain operates as a distributed system, it is essential for all participants in the network to agree on the validity of each block. To enable this distributed consensus, various algorithms have been developed. The consensus mechanisms aid in agreement seeking, collaboration, cooperation, egalitarian, inclusion, and participation. Consensus guarantees that all nodes on the network agree on the current state of the network and the legitimacy of transactions [77]. This process considers two aspects, the first one is the participants of the network responsible for consensus and the second is the algorithm which drives the consensus. This consensus mechanism varies from the type of blockchain used, for instance for a public blockchain proof of work (PoW), proof of stake (PoS), delegated proof of stake (DPoS), proof of space and time (PoST), proof of capacity (PoC), proof of history (PoH) and hybrid consensus can be used, described in Table 2. Whereas for private blockchain the available consensus mechanisms are proof of authority (PoA), practical Byzantine fault tolerance (PBFT), raft consensus, Tendermint, proof of elapsed time (PoET), delegated Byzantine fault tolerance (dBFT) and proof of identity (PoI), described in Table 3.

4.1.3 | Ethereum blockchain platform

Ethereum is a decentralized, permission-less, open-source blockchain technology platform founded in 2013 with its own native cryptocurrency [78]. It is a widely used framework for implementation, compiling, hosting, and testing decentralized blockchain applications. Ethereum functions on a permissionless network of untrusted peers within a distributed and decentralized system. Ether powers transactions that can be completed in just seconds. The core of the Ethereum network

TABLE 2 Consensus mechanism in public blockchain.

Consensus Mechanism	Description
Proof of work (POW)	Proof of work (PoW) entails "nodes" resolving intricate, asymmetric mathematical puzzles to generate new blocks through a process referred to as "mining," thus providing evidence of their work.
Proof of stake (POS)	In a PoS consensus mechanism, an algorithm randomly chooses validators for block creation according to the quantity of tokens that holders commit from their ownership of crypto currency assets. The process begins with the selection of a proposer, followed by the proposal of a block, and finally the validation of the proposed block.
Delegated proof of stake (DPoS)	DPoS adds a voting system where specific individuals validate blocks. These validators can ask a third party to do the work for them. They are called "witnesses" and they make sure everyone
Proof of space and time (PoST)	PoST is a consensus mechanism that combines proof of space, where storage capacity is used to validate transactions, with proof of time, which ensures these actions occur sequentially, enhancing security and reducing energy consumption.
Proof of capacity (PoC)	PoC is a consensus mechanism where miners allocate disk space for storing large datasets, known as plots, which are used to validate transactions and generate new blocks, making it a more energy-efqficient alternative to proof of work.
Proof of history (PoH)	PoH is a consensus mechanism that uses a cryptographic clock to create a verifiable and sequential history of events, enabling faster transaction processing and reducing the need for extensive communication between nodes in a blockchain network.
Hybrid consensus	It combines multiple consensus algorithms, such as proof of work (PoW) and proof of stake (PoS), to leverage the strengths of each, enhancing security, scalability, and energy efficiency in blockchain networks.

TABLE 3 Consensus mechanism in private blockchain.

Consensus mechanism	Description
Proof of authority (PoA)	PoA is a consensus mechanism where validators are pre-approved based on their identity or authority to validate transactions on the blockchain, prioritizing efficiency and scalability.
Practical Byzantine fault tolerance (PBFT)	A consensus mechanism where nodes in a network agree on the validity of transactions through a multi-step voting process, ensuring Byzantine fault tolerance.
Raft consensus	A consensus algorithm designed for managing replicated logs in distributed systems, offering simplicity and fault tolerance by electing a leader to coordinate log replication.
Tendermint	A consensus engine that employs a variant of practical Byzantine fault tolerance (PBFT) to facilitate secure and efficient block creation and validation in blockchain networks.
Proof of elapsed time (PoET)	A consensus mechanism used in permissioned blockchain networks where participants wait for a randomly selected period before proposing a new block, ensuring fairness without excessive energy consumption.
Delegated Byzantine fault tolerance (dBFT)	A consensus protocol where network participants elect a set of trusted nodes to validate transactions and ensure Byzantine fault tolerance, commonly used in blockchain networks with known and verified validators.
Proof of identity (PoI)	A consensus mechanism where participants validate transactions based on their verified identity or reputation, promoting trust and accountability in blockchain networks.

is the Ethereum virtual machine (EVM) [79], which executes smart contracts, i.e. it facilitates transactions based on predetermined conditions through the use of smart contracts. The network of authorized nodes runs the EVM for block verification. Each authorized node in a private blockchain ensures that the same operations are performed, maintaining consistency across the blockchain. The smart contracts are implemented using Solidity, a high-level programming language. These contracts are then compiled into bytecode. This bytecode is then executed by EVM which results in a state transition of the blockchain.

4.1.4 | Smart contracts

Smart property refers to the utilization of blockchain technology to establish digital assets that can be owned and governed through smart contracts [80]. Smart contracts are a kind of digital contract designed to impose contractual terms between non-trusting parties [81]. The parties involved in smart contracts are aware of the outcome and do not require any intermediaries. Smart contracts are self-executing agreements, where the terms of the contract are encoded in lines of code. The contract is executed when a set of predefined conditions are met. The agreement between these nontrusting parties could be property ownership transfer or release of funds etc. These contracts are immutable and every transaction is digitally recorded on the blockchain ledger. These contracts can automatically implement the rules and penalties of the agreement, making them more secure and efficient compared to traditional legal contracts. These contracts have self-verifying, self-executing, and tamper-resistant properties. Smart contracts use a consensus protocol to run a sequence of events, eliminating third-party transactions as well as automating the system. Users have to pay a fee known as a gas fee for the successful execution of smart contracts. Gas measures how many computations are completed and is essential for network security as it prevents an infinite loop of execution [82]. The gas cost of a transaction is calculated based on the computational complexity of the operations it triggers. The total gas cost is determined using Equation (1).

$$\text{Total gas cost} = \sum_{i=1}^{n} \text{Gas}_i \quad (1)$$

where n is the number of operations, and Gas_i is the gas required for the ith operation. The total transaction fee is calculated by multiplying the total gas cost by the gas price as shown in Equation (2)

$$\text{Transaction fee} = \text{Total gas cost} \times \text{Gas price} \quad (2)$$

Before processing a transaction, the network ensures that the gas required does not exceed the gas limit. If the gas cost exceeds the gas limit, the transaction fails, and the sender loses the transaction fee.

In PoA as a consensus mechanism, block validation is carried out by pre-approved validators chosen based on their identity or authority. These validators take turns suggesting and validating new blocks according to a predefined agenda or via mutual consensus, and they are rewarded with a validator reward. The reward is calculated as expressed by Equation (3).

$$\text{Validator reward} = \text{Base reward} + \text{Transaction fees} \quad (3)$$

Where base reward is afixed reward for proposing a new block and transaction fees are the sum of all transaction fees included in the block. In PoA, transaction conclusiveness is realized through the agreement of the validators. Since these validators are pre-approved and trusted, the completion process is both fast and dependable.

4.1.5 | Cryptocurrency wallet

MetaMask [83] is a widely used Ethereum wallet [84] that is accessible as both a browser extension and a mobile application. It enables users to access DApps on the Ethereum blockchain technology, securely storing their private keys, and sign transactions without needing a full Ethereum node. In addition to streamlining user interaction with the Ethereum network, MetaMask prioritizes preeminent security and transparency within the digital currency domain. This is accomplished through its strong security framework, encompassing encrypted storage of private keys at the user's device and a prompt backup feature, preservation against asset loss resulting from misplacement of private keys. It is available for many browsers such as Chrome, and Firefox, as well as for iOS and Android mobile devices.

4.1.6 | Decentralized application

A decentralized application (DApp) is a software application operating on a decentralized network. The peer-to-peer interaction is leveraged using blockchain technology and smart contracts, eliminating the need for intermediaries and providing increased transparency, security, and user control. Front end is implemented using react. React is a JavaScript library created and maintained by Facebook, which specializes in building user interfaces. It's commonly used for building single-page and progressive web applications.

For backend scripting node.js is used. Node.js is an open-source, cross-platform JavaScript environment allowing developers to construct fast, lightweight, and scalable web applications that use JavaScript for both front-end and backend. Node.js is known for its non-blocking I/O model and event-driven architecture which is perfect for building high-performance real-time web applications.

5 | PROPOSED SYSTEM IMPLEMENTATION

For the implementation of the proposed framework for property transactions, a private Ethereum blockchain platform was created to provide a controlled environment for these transactions. Go Ethereum (Geth) is used to set up and configure the private Ethereum network. Since the framework utilizes a private blockchain, a genesis file is configured to define the initial state of the blockchain. This file includes configuration parameters such as chain ID, number of validators, gas limits, consensus mechanisms, and block time.

The consensus mechanism employed in this framework is PoA using the Clique algorithm. Clique is configured within the genesis file to establish a system where pre-approved validators are responsible for block production, ensuring a fast and efficient consensus process. The genesis file acts as a blueprint for the blockchain, dictating how the network will operate and the conditions that must be met for its successful functioning. Once the genesis file is configured, the blockchain is initialized, and the first block, known as the genesis block, is created, serving as the starting point for the entire blockchain. After initialization, the blockchain is launched with the PoA consensus, allowing the specified validators to begin producing blocks using the Clique algorithm, thereby initiating the blockchain's operation. Each validator is associated with a decentralized identifier (DID) to ensure the validator's identity is cryptographically verifiable and self-sovereign.

Following the setup of the private blockchain, smart contracts are deployed on the network. These smart contracts are also used for property listings, making and accepting offers, transferring ownership, and handling payments. Transactions may call functions defined in the smart contracts, which will execute the related business logic and update the blockchain state consequently.

As the proposed framework is for real estate transactions, three smart contracts are designed to handle specific aspects of the system: a seller registration contract, a buyer registration contract, and a property transaction smart contract. These contracts are compiled and deployed on the network using the Truffle development environment. Only authenticated users with verified DIDs are allowed to interact with the contracts. Since

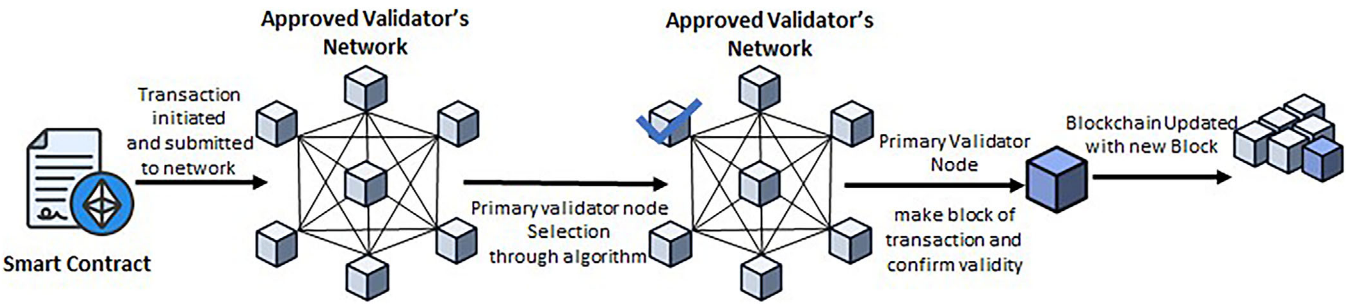

FIGURE 5 Registration of transaction on ledger.

TABLE 4 Activities involved during real estate transaction on blockchain technology network.

Activities	Description
Check user status	MetaMask authenticates the user's address. If the user is a returning participant, they can proceed to login and access the respective dashboard.
New user	This process initiates with a prompt to create a MetaMask account with the option to register as either a buyer or a seller. **Register as buyer**: User's information such as personal and contact details are required. This data supports making a portfolio of the buyer and allows them to personalize property searches, simplifying the buying process. Users are directed towards a verification process to ensure the security and trustworthiness of transactions. **Register as seller**: The registration process for sellers involves personal details, contact details, and comprehensive property details. Sellers are required to provide verification documents to establish ownership. Users are directed towards a verification process to ensure security and trustworthiness.
Preferences and settings	Buyers have the option to define their property preferences and save their search criteria. Sellers have the flexibility to tailor their property listings and pricing.
Transactions	Blockchain technology and smart contract infrastructure ensure transparency, security, and efficiency throughout the complete transaction process.

the proposed framework utilizes BigchainDB to store property information such as property images, documents, transaction history, and user profiles, additional functions are added to the smart contracts to interact with BigchainDB. Finally, the smart contracts are also linked to a web frontend that interacts with MetaMask for user transactions. Users interact with the web frontend using their SSI-enabled identity, verified through MetaMask. This allows users to manage their property-related data and transactions securely and independently.

Figure 5 defines a simple interaction scenario for the above setup. The user verifies their identity using MetaMask, linked to their SSI. Users log into the system, and MetaMask verifies the user's Ethereum address. The web application, implemented using React and Node.js, serves as the main medium for property listing and other transactions. Properties are listed by interacting with smart contracts. The activities involved during a real estate transaction are presented in Table 4.

Figure 6 illustrates the overall flow of transactions in blockchain framework from buyer and seller perspective, eliminating the issues such as transparency, intermediaries, fraud, paperwork and transaction speed as in conventional systems. The processes which are defined in Figure 6, are then converted into the code as shown in Contract 1 (Algorithm 1), Contract 2 (Algorithm 2) and Contract 3 (Algorithms 3, 4).

SSI principles emphasize the importance of decentralized systems where individuals have control over their own identity and data. The proposed system for real estate property transaction utilizes a DApp with a distributed ledger, private keys and cryptographic consensus mechanism, aligning with the principles of SSI. The inherently immutable feature of the blockchain ledger reduces the risk of data manipulation. This decentralized approach ensures any single point of failure, thereby improving the system's resilience. Proposed framework for property transaction can reduce frauds in the real estate markets by providing high degree of due diligence for the identity of the involved parties, facilitating secure interactions among them, thus enabling control over their identity information, establishment of trust through consensus between participants consequently strengthening the integrity and trustworthiness of the transaction data. Also, the system leverages existing identities by integrating meta masks enabling the interoperability principle of SSI.

The ten guiding principles of SSI can be clustered into three dimensions, i.e. security, controllability and mobility. Tables 5–7 maps the SSI principles in three dimensions targeting four areas during property transaction.

6 | SIMULATIONS

The experiment was conducted with the dataset of zameen.com [85]. The dataset size was about 53 MB with 190,905 records. In order to store dataset of real estate property on a Blockchain Technology, the details are represented as digital assets or tokens

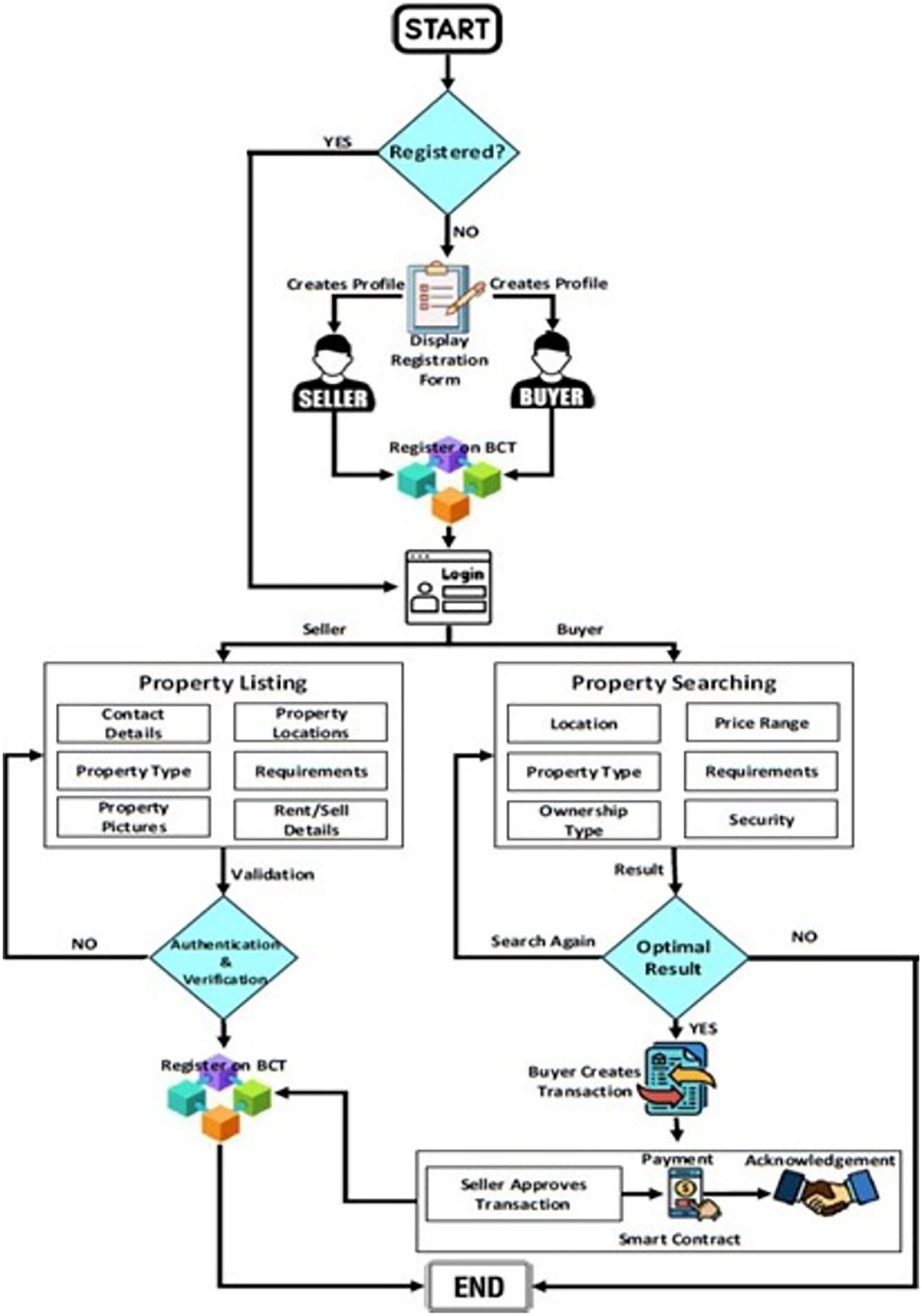

FIGURE 6 Process flow of proposed framework based on private blockchain.

ALGORITHM 1 Proposed framework for property transactions.

START

Step 1: INPUT

Sender, receiver, propertyId, propertyPrice

Step 2: Start transaction

User initiates the transaction specifying property and payment details, using MetaMask and send transaction details to Ethereum PoA blockchain.

Step 3: Trigger smart contract on Ethereum PoA blockchain.

The transaction triggers the relevant smart contract for real estate management on the blockchain.

Step 4: Smart contract interaction with BigchainDB
- Property information storage with the help of BigchainDB
- The smart contract interacts with BigchainDB to retrieve and verify property details, ensuring transaction accuracy and legitimacy.

Step 5: Execute transaction instructions

Validators carry out the transaction steps as per the smart contract.

Step 6: Run EVM for block verification

The Ethereum virtual machine processes and verifies the transaction.

Step 7: Synchronize validators

All validators update their ledgers to reflect the transaction.

Step 8: Evaluate transaction details

Calculate required gas.

Compare required gas with gas set limit.

– If required gas > gas limit, abort transaction and log/issue fees.

Step 9: Validator consensus

Validators agree on the transaction's validity.

Step 10: Update ownership in BigchainDB

On successful transaction, update property ownership in BigchainDB. Reflect changes in property images, documents, transaction history, and user profiles.

END

where each property is associated with a smart contract on the blockchain technology. The block is divided into two parts:

- Block header stores metadata including timestamp, PrevHash, Block Hash and Nonce.
- The transaction body stores property details and transaction history.

The experiment was initially started with the subset of available records. The dataset was fragmented on two criteria: the number of properties versus the number of agents offering the properties. The simulation was conducted with an increasing number of property records (20,000, 40,000, 60,000, 80,000, 100,000, 120,000, 140,000, 160,000, 180,000 and 190,905) and an increasing number of agents (sellers) (1000, 2000, 3000, 4000, 5000, and 6000). The testbed configuration parameters for the property transaction framework are summarized in Table 8.

Table 9 presents a comparison of our proposed models with the conventional real estate method, and existing blockchain-based approach discussed in Mohanty et al. [86]. and Nanda et al. [87]. It highlights the gaps in existing solutions and underscores the novelty of the proposed model. The comparison is based on various attributes related to real estate management, including data governance, consensus mechanisms, identity management, performance metrics, data transfer, query time, and scalability. This comparative analysis establishes the significance of the proposed model and demonstrates its ability to outperform existing approaches in critical areas, making it a robust framework for the future of blockchain-based real estate management.

ALGORITHM 2 Contract definition: transaction_of_property contract.

Begin contract definition: Transaction_of_property

structure: property
- Define: property_location as a string
- Define: property_owner as an address
- Define: property_size as a uint256
- Define: property_use as a string

Mapping: mapping
- Define: mapping from propertyId to property structure

Events: property events
- Define: event: PropertySold as an event (includes: propertyId, buyer, seller, price)

Function: create_new_property
- Inputs: string as property_location, address as property_owner, uint256 as property_size, and string as property_use
- Logic: store in property struct in mapping with propertyId as "id"
- Create event as PropertySold

Function: change_property_ownership
- Inputs: uint256 as propertyId, address as newOwner
- Check if property exists, ensure new owner is valid
- Retrieve property object, transfer to new owner and verify ownership transfer
- Emit event: PropertyTransfer with details

Function: modify_property_attributes
- Inputs: uint256 as propertyId, string as new_use, uint256 as new_size
- Check if property exists, retrieve property
- Update property attributes and emit PropertyUpdated event

Function: verify_ownership
- Inputs: uint256 as propertyId, address as owner
- Logic: retrieve property based on propertyId, ensure owner matches stored owner
- Emit event: OwnershipVerification with propertyId, "valid" as status

Function: report_issues
- Inputs: uint256 as propertyId, string as issue
- Check if property exists, record issue in mapping
- Emit event: IssueReported with propertyId

Function: calculate_taxes
- Inputs: uint256 as propertyId
- Logic: calculate taxes based on property size and usage
- Return calculated tax representation as uint

Finish contract definition

A conventional system where data is stored on a centralized server with no replication. The system performs well when the database size is small, but it faces significant limitations in terms of scalability and transparency. Traditional real estate systems are heavily dependent on intermediaries, which reduces trust between stakeholders and increases costs.

ALGORITHM 3 Contract definition: Buyer_Registration.

1: **Begin contract definition: Buyer_Registration**

2: **Structure: buyer**
- Define: buyer_id as an address
- Define: buyer_name as a string
- Define: buyer_address as a string

3: **Mapping: buyer mapping**
- Define: Mapping from buyer_id to Buyer structure

4: **Events: buyer events**
- Define: event: BuyerRegistered as an event (includes: buyer_id, buyer_name as string, buyer_address as string)

5: **Function: Register_Buyer**
- Inputs: address as buyer_id, string as buyer_name, string as buyer_address
- Logic: Store as new buyer object with buyer_id as id
- Check if buyer_id already exists, register missing parameters and fix
- Emit event: BuyerRegistered with buyer_id and new_name, new_address

6: **Function: Update_Buyer_Info**
- Inputs: address as buyer_id, string as new_name, string as new_address
- Check if buyer exists, retrieve buyer
- Update buyer info and emit BuyerUpdated event

7: **Function: Report_Buyer_Issues**
- Inputs: address as buyer_id, string as issue
- Check if buyer exists, record issue in mapping
- Emit Event: BuyerIssueReported with buyer_id, “issue”, and issue string

8: **Finish contract definition**

ALGORITHM 4 Contract definition: Seller_Registration

1: **Begin contract definition: Seller_Registration**

2: **Structure: seller**
- Define: seller_id as an address
- Define: seller_name as a string
- Define: seller_address as a string

3: **Mapping: seller mapping**
- Define: mapping from seller_id to seller structure

4: **Events: seller events**
- Define: event: SellerRegistered as an event (includes: seller_id, seller_name, seller_address)

5: **Function: Register_Seller**
- Inputs: address as seller_id, string as seller_name, string as seller_address
- Logic: store as new Seller object with seller_id
- Check if seller_id already exists, if not register new seller and emit SellerRegistered event

6: **Function: Update_Seller_Info**
- Inputs: address as seller_id, string as new_name, string as new_address
- Check if seller exists, update seller info and emit SellerUpdated event

7: **Function: Report_Seller_Issues**
- Inputs: address as seller_id, string as issue
- Check if seller exists, record issue, and emit SellerIssueReported event

8: **Utility: validate seller_id**
- Input: address as seller_id
- Convert seller_id to a hexadecimal string
- Return hexadecimal string representation of seller_id

9: **Finish contract definition**

Moreover, they lack mechanisms to guarantee data integrity and security.

The approach proposes in [86] utilizes a blockchain-based framework for smart real estate but lacks implementation details for performance metrics to validate its feasibility. The paper principally emphasizes the theoretical advantages of blockchain, such as decentralization, trust, and transparency, without addressing practical challenges like execution overhead, data transfer inefficiencies, or identity management. Although the proposed framework lays the groundwork for blockchain implementation, its relevance in real-world scenarios remains untested.

The approach in [87] emphasizes the implementation of systems using public or hybrid blockchains with PoW and PoS as consensus mechanisms. The decentralized approach proposed enhances security but comes at the cost of high execution times and data transfer overhead. The identity management in this system is based on public-key infrastructure; therefore, it lacks comprehensive frameworks such as SSI. Although the proposed system addresses scalability issues, it struggles with latency and efficiency when handling large datasets.

By addressing the limitations of existing methods, the framework provided in this research offers a comprehensive solution tailored to the challenges of real estate management.

The execution time for heavy write operations using a conventional, existing and proposed blockchain technology approach is depicted in Figure 7. The graph represents a linear relationship between execution time and number of records. However, the time consumed in execution in a conventional system is less than blockchain technology due to the consensus mechanism of the blockchain technology. The graph compares the execution time for different numbers of property records. The conventional system, which does not rely on a consensus mechanism, achieves the fastest execution time overall. However, this speed comes at the cost of reduced scalability and security. Blockchain-based models exhibit slower speeds compared to the conventional system due to the inclusion of consensus mechanisms. [86] lacks the optimizations implemented by [87] and our proposed model, resulting in moderate execution times. The slower execution time in the [87] is attributed to the use of computationally intensive consensus mechanisms like PoW. In contrast, our proposed model strikes an optimal balance between speed and security by employing PoA, achieving faster execution times than [87] system while maintaining decentralized operation and scalability.

Figure 8 illustrates the operational effectiveness of conventional, existing, and proposed blockchain technology models in relation to the volume of data transferred. The graph demonstrates that the volume of data transmitted in blockchain-based systems is higher compared to conventional systems. This is because every updated record is broadcast to all participating

TABLE 5 Security-dimension of SSI principles

Area targeted	SSI principle with solution
Property listing and search	• Protection: storing property data on a private blockchain eliminates unauthorized access. • Persistence: storing property data persistently on the blockchain, ensures accessibility over time resulting in integrity of historical data. • Minimization: by using smart contracts intermediaries can be minimized, reducing the risk of errors, delays, and fraudulent activities.
Property evaluation	• Protection: evaluators can trust the integrity and accuracy of the data stored on blockchain and can rely on it for property evaluations. • Persistence: blockchain provides a transparent and immutable record of property assessments over time enabling stakeholders to access and verify historical assessment data as needed. • Minimization: smart contracts automate aspects of the property evaluation process reduces the potential of human error or bias in evaluation outcomes.
Contract management	• Protection: smart contracts are protected against tampering or unauthorized amendments, safeguarding the integrity and authenticity of contract documents. • Persistence: contract data persistent recording on the blockchain, provides an immutable record of contract transactions. Enabling the availability and integrity of contract documents over time. • Minimization: automated contract execution, implementation, and administration, minimizes the need for intermediaries and reduces the risk of errors or disputes.
Transaction processing	• Protection: cryptographic security features, ensures that sensitive transaction data is secure and confidential. • Persistence: transparent and immutable record of transaction history ensures the integrity and availability of transaction data over time. • Minimization: automated transaction processing tasks, minimizing the need for manual interference and reducing the potential for errors or delays in transaction execution.

TABLE 6 Controllability-dimension of SSI principles.

Area targeted	SSI principle with solution
Property listing and search	• Control: users have control over their property listings and search preferences. Allowing them to modify, or remove listings based on their needs. • Consent: users have the ability to grant or withdraw consent for their property listings to be accessible in search results and viewed by other parties. • Existence: property listings on the blockchain serve as immutable records, confirming their existence at over time, thus assuring the integrity and accessibility of property information.
Property evaluation	• Control: evaluators exercise control over the entire evaluation process, including the criteria used, methodologies applied, and conclusions drawn. • Consent: sellers provide consent for evaluators to access and analyse their property information for evaluation purposes. • Existence: Property evaluation reports exist as immutable records on the blockchain, acting as a proof of evaluation procedure and its results.
Contract management	• Control: parties involved in transactions have control over the creation, negotiation, and execution of contracts. • Consent: parties provide consent to enter into contractual agreements, signifying their agreement to the terms and conditions defined in the contract. • Existence: contract documents exist as immutable records on the blockchain, providing proof of their existence and validity.
Transaction processing	• Control: participants can authorize and verify transaction details according to their roles and responsibilities. • Consent: parties involved in transactions provide consent for the exchange of assets or services as defined by the terms of the transaction. • Existence: transaction records exist as immutable records on the blockchain, providing evidence of transactional activities and outcomes.

peer nodes in the network. Additionally, peer nodes distribute the block's data, including the hash, to all other nodes, enhancing the data transmission process. The conventional centralized system shows the lowest data transfer rate, as a single central server manages and transfers records without replication across the network. In contrast, conceptual blockchain frameworks proposed for real estate exhibit better transfer rates compared to the conventional system. A similar implementation in [87], which uses smart contracts and pBFT in a public blockchain system, achieves a significant increase in data transfer rates due to global replication and metadata transmission. However, our proposed model outperforms these systems, achieving higher data transfer efficiency through local replication. With full decentralization, it is more efficient than the systems proposed in [86] and [87].

Figure 9 compares the execution times of conventional and blockchain-based models when querying property data from the database. The graph clearly demonstrates that the proposed model achieves shorter execution times compared to the traditional system. This difference arises primarily because, in the conventional model, data retrieval requires querying the centralized database where the specific record resides, whereas in the proposed private blockchain, data retrieval occurs from a locally stored ledger copy available across all nodes. Similarly, comparisons of the existing blockchain-based solutions with the traditional and proposed approaches are also presented. The query processing time in [86] is the highest due to the use of an unoptimized blockchain structure. In contrast, [87] demonstrates better performance compared to both the traditional system and [86], owing to its distributed ledger architecture.

7 | DISCUSSION

The adoption of blockchain technology in third-world countries can indeed bring about several benefits and address challenges inherent in property transactions. Using blockchain in the real estate industry for property transactions may help in reducing corruption, streamline transaction activities, and provide

TABLE 7 Mobility-dimension of SSI principles.

Area targeted	SSI principle with solution
Property listing and search	• Interoperability: proposed framework enables authorized stakeholder to effortlessly access and distribute property listings across multiple platforms, thereby improving connectivity and information sharing within the real estate industry. • Transparency: accurate and immutable property information recorded on blockchain promote transparency and is accessible to authorized parties. • Portability: users can access and manage their property listings from various devices or platforms, ensuring flexibility and convenience in the listing process. • Access: authorized [roperty evaluators can access and analyse property data, ensuring confidentiality and integrity in the evaluation process.
Property evaluation	• Interoperability: evaluators can access and analyse property data from various sources, enhancing interoperability and collaboration in the evaluation process. • Transparency: property evaluation data is transparent and verifiable by authorized parties. • Portability: property evaluation reports can be made portable across different platforms that support blockchain technology. • Access: authorized property evaluators can access and analyse property
Contract Management	• Interoperability: parties involved in transactions can integrate contract management processes with existing workflows in order to enhance interoperability and efficiency. • Transparency: contract documents recorded on the blockchain are transparent and auditable by authorized parties. • Portability: authorized stakeholders can access and manage contract documents from various devices or locations, ensuring flexibility and convenience. • Access: contract functionalities are accessible to authorized parties through secure authentication mechanisms.
Transaction processing	• Interoperability: use of MetaMask facilitate interoperability in transaction processing by acting as a bridge between the blockchain network and external payment gateways. • Transparency: transactions on the blockchain are transparent and immutable, providing a reliable audit trail of transaction activities

TABLE 8 Testbed configuration parameters.

Parameter	Description	Value
Total nodes	Nodes participating in the network	100
Head nodes	Nodes that play a leadership or coordination role	10
Consensus nodes	Nodes involve in the consensus process	20
Initial balance	Starting amount of Ether (ETH)	1000 Ether
Blockchain platform	Type of Ethereum network	Private (Geth)
Chain ID	Unique identifier for the blockchain network	1337
Consensus mechanism	Consensus algorithm for block production	Proof of authority (PoA)
Clique signers	Number of pre-approved validators (signers)	3
Block time	Average time between blocks	5 s
Gas limit	Maximum gas per block	10 million
Genesis block	Configuration file used to initialize the blockchain	Custom genesis file
Validators	Number of validators (nodes)	3
Smart contracts deployed	Total number of smart contracts deployed	3
External storage	System used to store off-chain data	BigchainDB
Web frontend	User interface for interactions	React + Node.js
Identity management	Verification mechanism	MetaMask (SSI)
Dataset used	Dataset for the simulation	Zameen.com (53 MB, 190,905 records)
Number of property records	Increasing number of property records used in the simulation	20,000–190,905
Number of agents	Increasing number of agents (sellers) involved in the simulation	1,000–6,000
Simulation phases	Execution with different subsets of records	10 phases
Block structure	Structure of blocks in the blockchain	Header (timestamp, hashes, nonce) and Transaction Body (property details, history)

TABLE 9 Comparison of blockchain-based models for real estate management.

Aspect	Conventional method	Mohanty et al. [86]	Nanda et al. [87]	Proposed model
Consensus mechanism	None (centralized system)	pBFT	PoW/PoS	PoA (proof of authority)
Data transfer	Low (minimal replication)	Estimated: moderate (pBFT overhead)	high (global replication)	Moderate (optimized local replication)
Query time	Slow (centralized queries)	Estimated: 0.12–0.706 ms	Fast (distributed ledger)	Fastest (0.1–0.5 ms with local ledger access)
Execution time	Fast for small datasets	Conceptual, not measured	Moderate to high (consensus overhead)	Moderate (Efficient PoA Consensus)
Scalability	Limited (central server bottlenecks)	Theoretical scalability	High (varies by blockchain type)	High (optimized for private blockchain)
Energy efficiency	High (low computational requirements)	Moderate (pBFT message overhead)	Low (Energy-Intensive PoW Models)	High (Efficient PoA-Based Consensus)
Security	Relatively low (single point of failure)	High (pBFT ensures Byzantine fault tolerance)	Very high (immutable public blockchain)	High (PoA ensures trust and transparency)
Fault tolerance	Low (prone to server outages)	High (resistant to Byzantine faults)	High (distributed nodes offer redundancy)	High (minimal failure due to controlled nodes)
Identity management	Basic username–password system	Public keys with basic cryptographic verification	Public keys with limited SSI adoption	Full self-sovereign identity (SSI) integration

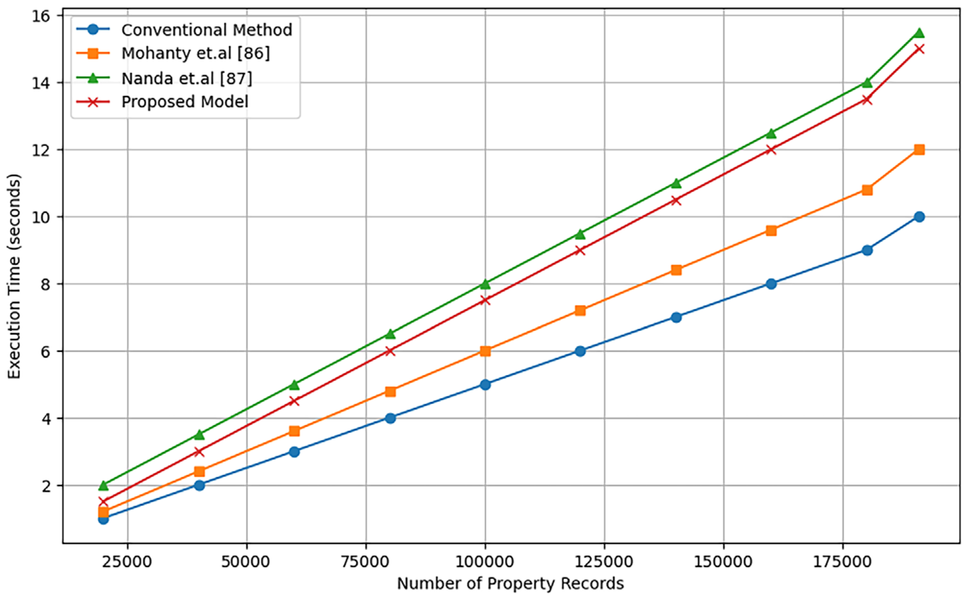

FIGURE 7 Relation between execution time and property records in working consensus mechanism.

transparency and security. Blockchain technology leads to identifying actual present property owners which is not always achievable to retract in a long chain ownership. Major issue with this system is the rightness of their state, i.e. the information is not in concordance with the actual spatial, legal and topographic situation, which results in incorrect data gathering, processing, and data misuse. The main purpose of the proposed system is to create a permanent and accessible record of all transactions, which improves property financing, provides access to capital for real estate development, enabling infrastructure growth. Additionally, it aligns with the principles of SSI by addressing concerns related to digital identity. The proposed system enables control, consent, and existence across all aspects of property transactions, empowering stakeholders with autonomy, transparency, and reliability in the real estate market. Moreover, it guarantees protection, persistence, and minimization, thereby boosting security and efficiency. Furthermore, the system promotes interoperability, transparency, portability, and access, thus enhancing connectivity, trust, and competence in the real estate sector. As the blockchain inherently adopts SSI

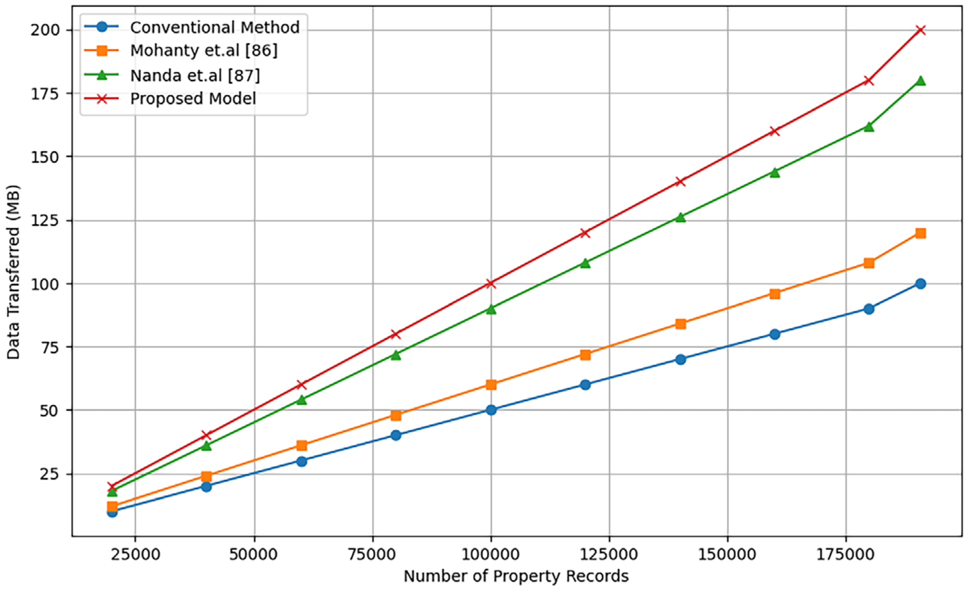

FIGURE 8 Relation between data transfer and the number of property records.

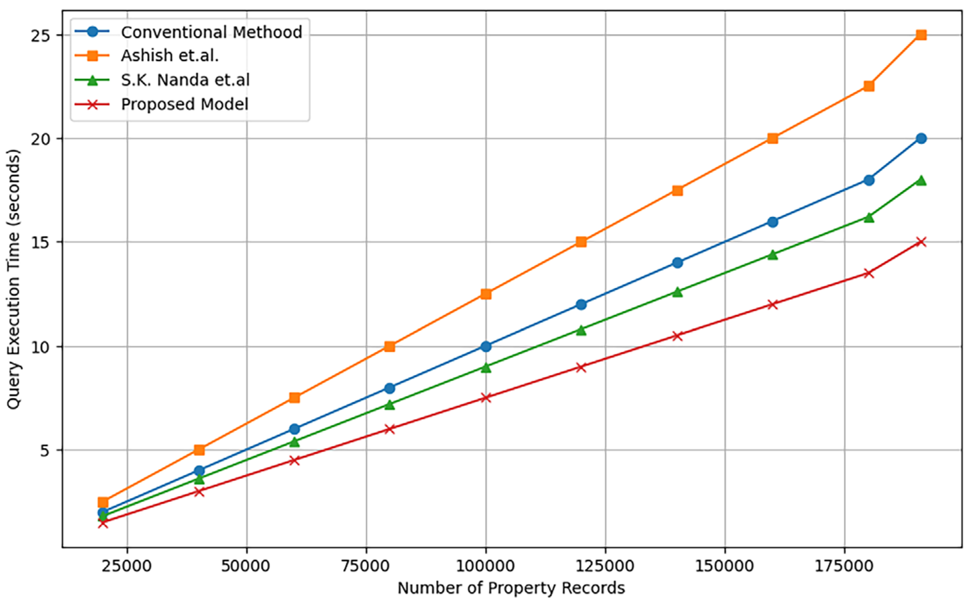

FIGURE 9 Relation between querying property records and execution time.

principles, the proposed system can be further enhanced by integrating a separate decentralized identity management solution such as uPort for comprehensive implementation of SSI. This will empower users with greater control over their digital identities and foster heightened trust, security, and transparency within the system. The experiment was conducted.

However, third-world countries face regulatory issues which include establishment of legal frameworks that recognize blockchain technology-based transactions and ensure its compliance with existing laws. Acceptable technological infrastructure is crucial for blockchain technology implementation [88–93]. In such countries with limited technological progressions, infrastructure development turns out to be a prerequisite. Secondly, education and awareness is very important. Lack of understanding about blockchain technology among stakeholders could hinder its implementation. Most importantly cost of implementation will obstruct its adoption as initial setup costs might pose financial challenges, especially in resource-constrained settings. Start-ups that seek to take advantage of this opportunity are more likely to succeed if they form consortiums with existing industry players rather than going it alone [94, 95]. Some private companies and government organizations are currently investigating the use of blockchain technology in the real estate industry. On the other hand, the financial sector is understood as a main user of the blockchain technology notion due to the concept of crypto-currency, Bitcoin which is a well-known application of this technology.

8 | CONCLUSIONS

At present, the real estate industry is facing numerous challenges such as excessive transaction fees, a lack of transparency, and fraud. This is due to the adoption of obsolete mechanisms that involve several intermediaries, resulting in inefficiencies and conflicts among stakeholders. Blockchain technology has the potential to improve transparency and security in real estate transactions. In this paper we proposed a system that utilizes a private blockchain built on Ethereum's smart contracts. This system will operate on a private blockchain network, providing a controlled environment for real estate transactions thus enhancing privacy and security. Numerous functions such as property listings, purchase agreements, ownership transfers, and payment settlements will be facilitated by smart contract. PoA as a consensus mechanism ensures fast transaction processing and high network throughput, making it suitable for private blockchain networks. In addition to this, the paper provides a foundation for aligning with key aspects of SSI, including user control, minimal disclosure, transparency, data security, interoperability, and portability. A secure and transparent digital management of land record would undeniably benefit individuals involved in real estate transactions. Both industry leaders and governments are exploring and implementing blockchain technology in various applications. However, wider adoption of the technology will require further standardization and clear regulations. In addition, the issues like digital literacy, regulatory frameworks, and data security need attention in various blockchain based applications.

AUTHOR CONTRIBUTIONS

Huma Jamshed: Conceptualization; data curation; methodology; resources; software; validation; writing—review & editing. **Urooj Waheed**: Conceptualization; formal analysis; methodology; supervision; validation; writing—original draft. **Shahid Iqbal**: Formal analysis; Visualization; Writing—review & editing. **Muhammad Faheem**: Data curation; investigation; project administration; supervision. **Muhammad Waqar Ashraf**: Supervision; validation. **Yusra Mansoor**: Conceptualization; methodology; writing—original draft.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The dataset used in this study is publicly available and can be accessed through Kaggle. The data can be found at the following link: https://www.kaggle.com/datasets/huzzefakhan/zameencom-property-data-pakistan.

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