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Blockchain for real estate provenance: an infrastructural step toward secure transactions in real estate E-Business

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Abstract

In the rapidly evolving digital era, the growing trend of conducting real estate e-business transactions through online platforms has led to escalated challenges in ensuring transactional security and trust. These challenges underscore the importance of balancing transparency with data privacy and enhancing accountability in this field. As an extension of our previously published work (Abualhamayl AJ, Almalki MA, Al-Doghman F, Alyoubi AA, Hussain FK (2023) Towards fractional NFTs for joint ownership and provenance in real estate. In: 2023 IEEE international conference on e-business engineering (ICEBE), p. 143–8. 10.1109/ICEBE59045.2023.00022.), this paper introduces the Global Real Estate Platform (GREP), a novel hybrid blockchain system that utilizes real estate provenance to establish a secure and trustworthy environment for real estate e-business, specifically focusing on two key challenges: ensuring data authenticity and effectively managing access rights. Integral to GREP's design is the involvement of government entities, which is essential for maintaining the required balance between transparency, privacy, and high levels of accountability. This proposed framework is explained conceptually and demonstrated practically, offering an innovative perspective on the integration of hybrid blockchain technology in the real estate system. Furthermore, our research encompasses a detailed implementation, using various tools, and an in-depth examination of three use cases. This combined analysis effectively demonstrates GREP's efficacy in addressing the targeted challenges in the field. While acknowledging the system's limitations, including challenges in user adoption and performance variability under different network conditions, our findings open new avenues for further exploration, such as landlords' payment histories and utility bills, and using blockchain as a secondary user identifier. These features collectively highlight the transformative potential of blockchain technology in real estate e-business.

Keywords Blockchain technology · Real estate provenance · Real estate transaction security · Real estate E-Business · Hybrid blockchain system · Global real estate platform

1 Introduction

The digital era has profoundly transformed real estate transactions, introducing an era of unprecedented complexity and implications [2–4]. This transformation has catalyzed a major shift towards online platforms, leading the real estate industry to increasingly embrace various electronic business activities, commonly referred to as e-business. These digital platforms, powered by advanced technology, are essential in improving the accuracy and efficiency of tracking and recording real estate activities [5]. Real estate provenance, which captures the documented history of these activities, includes details such as previous ownership, transaction records, or any historical information related to the real estate's origin. Accurate provenance tracking not only ensures transparency [6] and builds trust [7, 8]. But also offers numerous benefits such as fraud prevention, risk mitigation, and support for informed decision-making. Access to accurate and complete historical data further enables market analysis and uncovers investment opportunities. Despite these advantages, the pursuit of maintaining transactional integrity and verifying historical data within real estate transactions introduces several challenges.

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These challenges in real estate e-business, especially highlighted by the shift to digital platforms, are crucial to address. They emerge primarily from the digital world's complexities and the ongoing evolution of online real estate dealings. The first challenge is ensuring data authenticity in real estate transactions where the risk of fraud and data manipulation is elevated [9]. In the digital era, the integrity of online-stored property records and histories becomes paramount. Ensuring the authenticity of these documents is crucial for preventing fraudulent activities and ownership disputes. For instance, according to the National Association of Realtors, in the U.S., real estate wire fraud, a specific form of fraud involving the use of the internet to unlawfully divert funds, resulted in estimated losses exceeding $210 million in 2020 [10]. This underscores the ongoing challenges and risks associated with e-business transactions in this sector.

Another challenge in real estate e-business lies in effectively managing access rights, a crucial factor that profoundly influences both the security and integrity of the transaction process. Effectively managing access enhances the integrity of transactions, which is vital for fostering trust among the parties involved in real estate e-business [11, 12]. Ensuring that only authorized individuals have the ability to view, alter, or approve transactional data is paramount. This not only safeguards against unauthorized access and potential data breaches but also reinforces the reliability of the transaction process. Addressing these challenges in real estate e-business requires the adoption of an innovative technological solution to establish a reliable and anti-fraud environment.

As a potential technological solution in business [13], blockchain offers significant advancements in managing real estate provenance. Its decentralized ledger system ensures transparency and immutability in property history records [14, 15], thus enhancing provenance tracking accuracy. Moreover, blockchain's transparency enhances stakeholders' trustworthiness by providing verifiable and tamper-proof transaction records [16]. Utilizing these features, blockchain significantly improves security in real estate transactions, accordingly reducing the risk of fraud and data manipulation and fostering a trusted e-business environment.

Integrating the previously mentioned benefits of blockchain technology, we propose the Global Real Estate Platform (GREP), a blockchain-based solution specifically designed to address the challenges in real estate transactions. The platform utilizes a hybrid blockchain architecture, which combines the advantages of both private and public blockchains. This approach can effectively address the challenges of blockchain adoption by minimizing disruption and maximizing the benefits of smart contracts [17]. The system's aim is to enhance trustworthiness in real estate e-business through accurate and transparent property provenance recording using blockchain. Additionally, GREP enhances security, utilizing blockchain's inherent features to protect transactional data against unauthorized access and manipulation. Furthermore, a crucial aspect of GREP's design is the integral involvement of government entities. This engagement goes beyond mere regulatory compliance. It also ensures higher levels of accountability in real estate transactions, as we discuss later. Ultimately, GREP lays the foundation for establishing secure and trustworthy transactions in real estate e-business.

This research presents an integrated approach to secure and trusted real estate e-business transactions using blockchain technology. Primarily, this paper makes the following contributions:

- Development of the Global Real Estate Platform (GREP): a hybrid blockchain system uniquely utilizing real estate provenance to establish a secure and trustworthy environment for real estate e-business while ensuring balanced transparency and full accountability.
- Theoretical and practical integration of blockchain in the real estate system.
- Addressing the key challenges in real estate e-business, ensuring data authenticity and managing access rights.
- Detailed examination of three use cases, addressing the current challenges in implementation using various tools.

The rest of the paper is structured as follows. The next section provides an overview of the related literature from different perspectives. In Sect. 3, we explore the conceptual development of our framework and address the corresponding challenges in this field. Section 4 explores the practical application of our proposed blockchain-based solution through various use cases, assessing system setup, functionalities, and its impact on e-business. The paper concludes in Sect. 5 by summarizing our findings and suggesting directions for future research in the application of blockchain in this field.

2 Related work

In this section, we review the existing literature relevant to developing a hybrid blockchain-based platform aimed at enhancing security and trustworthiness in real estate e-business. By integrating blockchain features with real estate provenance, this platform contributes significantly to the advancement of e-business infrastructure. To provide a thorough and well-rounded analysis, our review is methodically structured around four areas: we begin by revisiting our prior work with the JOINFT system; this is followed by an exploration of adjustments to the level of authority and access in blockchain systems; next, we delve into the role of blockchain in real estate provenance; and conclude with its application in e-business. We concentrate our research on reliable, peer-reviewed sources to ensure accuracy and relevance. A notable observation from our review is the significant gap between the conceptual solutions proposed in the literature and their limited practical implementation and validation in this field.

In our preceding research [1], we introduced JOINFT, a project employing fractional non-fungible tokens (F-NFTs) and a trust scoring system to facilitate joint ownership in real estate. The objective of JOINFT is to foster cost-effectiveness, enable personal participation in property ownership, and improve accessibility, which addresses specific needs within the real estate market. Despite differences in primary objectives, methodologies, and tools used between JOINFT and our current project, JOINFT represents one of many potential applications that could greatly benefit from the robust and secure infrastructure proposed in our current work.

In the realm of blockchain technology for real estate transactions, the importance of adjusting authority levels for each participant is paramount. The work in [18] proposes a blockchain system where a government-designated super admin exercises comprehensive control, ensuring that no buying or selling transactions proceed without their approval. This system highlights the critical role of authority in blockchain applications, aimed at enhancing transaction security and integrity. Additionally, [18] discusses the vulnerabilities of traditional property ownership records, such as paper deeds being prone to loss, damage, or theft, and government records facing similar risks.

Similarly, [19] proposes a blockchain-based approach for facilitating online real estate transactions. Their system, a permissioned blockchain, operates entirely under the oversight of the Saudi government. In contrast with the role-based access control highlighted in the previous literature, Ali et al.'s system enables real estate agents to access and retrieve property records. This design significantly enhances transparency and aids decision-making in the real estate e-business.

Another aspect that needs to be considered when adjusting authority levels in blockchain systems for real estate transactions is accountability and transparency. These elements are paramount in e-business, particularly in real estate transactions. Addressing the aspect of accountability, [20] introduced LandLedger, a system tailored for managing land transactions in India. This system mandates the involvement of four government departments before uploading any data to the blockchain, thereby significantly enhancing accountability in real estate e-business transactions. In terms of transparency, [21] proposed the RETT system, aimed at improving the real estate experience in Vietnam for various stakeholders such as owners, notaries, buyers, and sellers. RETT enables all users to trace every transaction, thus ensuring a high degree of transparency in the property dealing process. Both these systems, in their unique ways, contribute significantly to addressing the crucial needs for accountability and transparency in real estate e-business.

Integrating provenance information into blockchain-based systems can significantly aid in preventing fraud, especially in the context of real estate transactions. An example of this integration is found in the work of [22], which proposed a reliable cloud service model. Their approach utilized provenance data to enhance the trustworthiness of cloud services, with their methodology backed by detailed experimentation. Similarly, [23] proposed and implemented a framework for material provenance using blockchain technology. A notable challenge in Xu's work was determining the appropriate authorities to oversee the system, debating between governmental bodies and large corporations. This highlights the complexities involved in governance and authority allocation in blockchain systems. Another work that utilizes provenance information in the context of real estate is presented in [1]. In this study, the authors employed the concept of provenance to document the historical participation of users in various groups within their proposed platform. By securely logging all activities related to these groups over time, their method provides valuable insights into the users' level of engagement and dependability. This approach highlights the utility of provenance data in assessing commitment and reliability within real estate platforms.

Exploring the application of blockchain technology in e-business reveals a range of potential benefits and innovative uses. A study by [24] highlights blockchain as a fitting infrastructure for entrepreneurs, challenging the notion that a fully decentralized system is indispensable for effective blockchain implementation. This perspective suggests the viability of hybrid blockchain models [25]. Focuses on the transformative impact of blockchain in enhancing cross-border e-business transactions. Li's findings indicate that blockchain technology can significantly enhance security, improve efficiency, and reduce costs in international e-business activities, underscoring its potential to streamline and optimize complex business operations on a global scale.

However, a critical observation made in [25] is the notable lack of practical implementation and comprehensive evaluation in the existing literature. This observation aligns with our findings and underscores the importance of our hybrid blockchain system. By providing both a innovative exploration and practical implementation, our study directly addresses this gap, marking a significant contribution to literature.

3 Developing the proposed solution

3.1 Problem overview

In our endeavor to develop the GREP, which aims to enhance the infrastructure for real estate e-business, we encounter a variety of challenges. Figure 1 displays the primary challenges in developing GREP. By integrating blockchain technology, we aim to mitigate several of these key challenges, providing a potential solution that is further detailed in the following subsection.

3.2 Conceptual framework

Blockchain, with its immutable and tamper-proof ledger, provides a viable answer to the risk of fraud and data tampering prevalent in paper-based systems. In contrast to traditional web-based solutions, which are often vulnerable to cyber-attacks and hacking, a blockchain-based approach offers enhanced security and integrity. Leveraging these qualities, GREP employs blockchain technology to ensure the authenticity of real estate data.

Central to this framework is the utilization of real estate provenance data. It provides stakeholders with a comprehensive historical record of the property, including previous ownership, transaction history, and any significant events or changes. This approach builds trust, improves data authenticity, prevents fraud, and aids in making better-informed decisions, ultimately enhancing confidence in the real estate market.

In addressing the critical issue of access rights management in real estate e-business, it is essential to understand the required levels of transparency and accountability. Although a traditional public blockchain inherently offers high transparency [26], this comes with the risk of excessive data exposure [27]. To strike a balance, the proposed solution shall ensure adequate transparency while maintaining data privacy. Furthermore, accountability, especially in real estate transactions, is of paramount importance. Recognizing this, the government's involvement is a key step in reinforcing accountability and establishing public trust. The participation of government entities extends beyond mere regulatory compliance; it is also a realistic decision considering the substantial financial interests that governments have in real estate markets [28]. Based on these considerations, we propose GREP, a hybrid blockchain system designed to offer conditional transparency while ensuring full accountability. This is achieved through the integration of an authorized entity, as suggested in [1]. The establishment of such an entity provides a more secure framework in the context of real estate transactions.

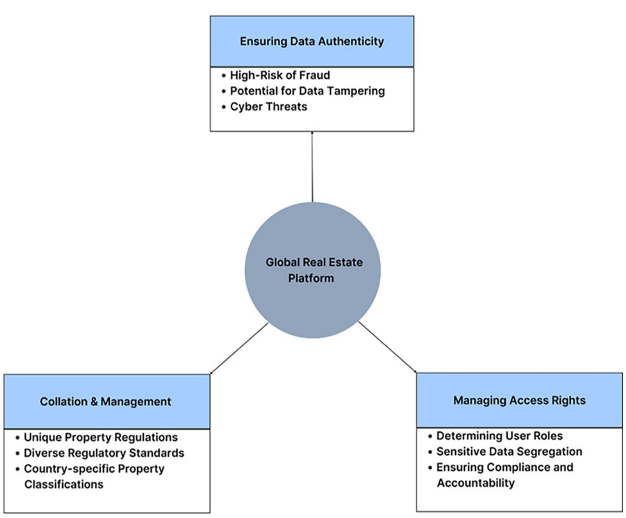

Fig. 1 Key challenges and sub-issues in developing a global real estate platform

In the conceptual framework of GREP, there are two primary categories of participants:

- *Stakeholders* This broad category encompasses all parties involved in real estate transactions, including property owners, prospective buyers, and insurance companies. They have the capability to navigate through the system, either to view provenance information or to request the addition of such information, particularly if they are property owners.
- *Government Bodies* Representing the administrative side, these entities exert control over the system, overseeing and validating transactions.

Figure 2 provides a detailed illustration of the sequential steps a property owner follows within GREP, from enrollment in the initialization stage to the government's finalization of the transaction in the execution stage. It is worth mentioning that we acknowledge the diverse requirements that different countries may have. Each nation has the autonomy to decide its specific needs and how they are integrated within the framework. This flexibility is crucial for global applicability, ensuring that the system is adaptable to various regulatory environments.

On the other side, government bodies receive and process requests from stakeholders, interacting directly with the smart contract to manage and finalize transactions. Figure 3 provides an in-depth system overview, illustrating this dynamic between the two groups and showcasing the various components within GREP that facilitate these interactions.

In response to the challenge of managing access rights in real estate e-business, we employ the role-based access control (RBAC) method [29]. Under this model, participants

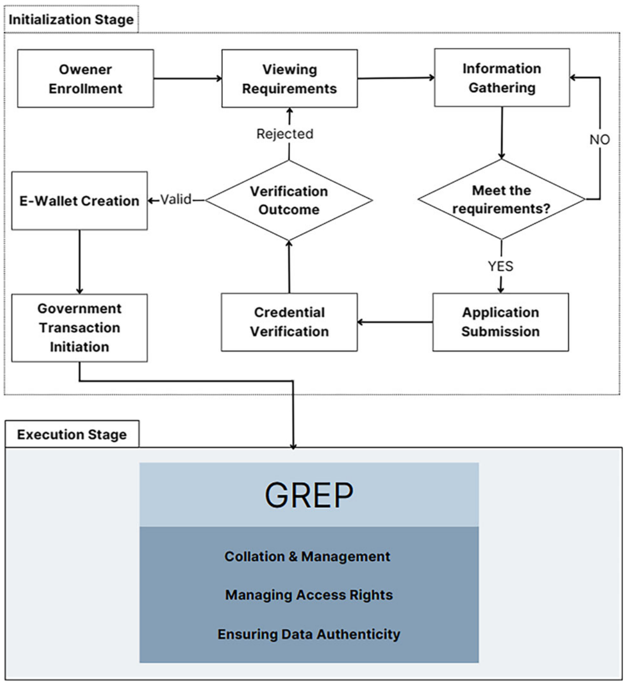

Fig. 2 Workflow diagram for property owners in GREP

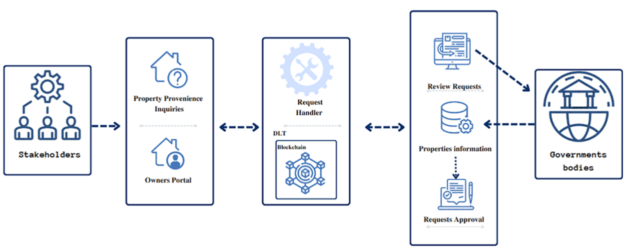

Fig. 3 The GREP framework

are assigned into three distinct user roles, each with varying levels of authority and system access:

- *Super Admin* This role is assigned to users who have full authority over the system. Typically, this could be a national government entity.
- *Admin* Users selected by the super admin to perform specific and limited tasks. This role could be fitting for local government bodies like municipalities.
- *Regular User* This category includes all other stakeholders, such as property owners, prospective buyers, or any other participants in the real estate transaction process.

Table 1 outlines the specific permissions associated with each user role in GREP. Notably, Regular Users are granted viewing access only upon providing a property ID and a corresponding key, reflecting an additional layer of protection designed to safeguard sensitive data within our system. This structure supports the global nature of our system as it opens the market to foreign investors who may not have direct insights into the properties, allowing them to participate globally.

4 Implementation and analysis

This section explores the practical application of blockchain in the real estate sector through a series of targeted use cases. Our examination encompasses the system setup, the selected dataset, the specialized functionality for super admin roles, and the complexities of property information access. Then, we discuss the outcomes of these use cases, assessing the challenges encountered and the Impact of our blockchain solution on establishing a secure and trusted infrastructure in e-business, particularly in the context of real estate transactions.

4.1 System setup and implementation tools

In the implementation of our hybrid blockchain for real estate provenance, we conducted our experiments on a 64-bit Windows operating system. The setup featured a 13th Gen Intel® Core™ i9-13900H processor and was equipped with 32 GB of RAM.

We used different tools at each level of our system implementation. Remix – Ethereum IDE version 0.38.1 served as our primary development environment for creating and initially testing our smart contracts. Locally, we used Ganache version 2.7.1 to mimic our blockchain behavior and interactions in a controlled environment. Visual Studio Code version 1.84.2 was employed for additional coding and scripting needs, particularly for JavaScript development. Furthermore, for real-time interaction with the Ethereum network, Web3.js was integral, especially its WebSocketProvider functionality, which enabled us to connect seamlessly to the Sepolia testnet via Infura. This was crucial for testing and validating our smart contract's behavior in a more realistic network environment. In'hese processes, Node.js was utilized as the runtime environment, providing a stable and efficient platform for running our JavaScript code and Web3.js for blockchain interactions. We used Sepolia faucet via MetaMask to perform our transactions, ensuring an authentic and efficient transaction management process. Additionally, HTML was utilized to create visualizations, such as line charts, effectively presenting data and illustrating the outcomes of our blockchain experiments. Table 2 provides an overview of the tools and their respective usage in our implementation.

4.2 The selected dataset

Our research employs a public dataset, which is available at the data world website [30], which provides ownership

Table 1 User role permissions in GREP

Role	Deploy contract	Modify roles	Access all data	Modify records	View data
Super Admin	✓	✓	✓	✓	✓
Admin			✓		✓
Regular user					(requires property ID and key)

Table 2 Summary of tools and technologies used in the blockchain Implementation with their respective versions and usage

Tool	Description/Usage
Remix—Ethereum IDE v0.38.1	Primary environment for smart contract development and testing
Ganache v2.7.1	Simulates local blockchain for testing and interaction control
Visual Studio Code v1.84.2	Used for coding and scripting, especially in JavaScript
Web3.js v1.3.6	Facilitates real-time Ethereum network interaction, using WebSocketProvider
Node.js v20.9.0	Runtime environment for JavaScript and Web3.js scripts
Infura v3	Gateway for connecting to the Sepolia testnet for network testing
MetaMask v11.4.1	Wallet for managing Ethereum transactions
Sepolia Faucet	Provides test Ether for Sepolia testnet transactions
HTML5	Utilized for data visualization and presentation, like line charts

records for nursing homes. This dataset is selected for its relevance in testing our blockchain prototype's capabilities in managing real estate provenance. To prepare the dataset for our study, we removed extraneous columns such as 'Processing Date' and 'Ownership Percentage', eliminated redundant entries, and also addressed missing data to ensure the dataset accurately reflects the scenarios our system is designed to handle. Table 3 displays the specific titles and descriptions of rows in the dataset.

4.3 Use case demonstration

This section showcases three pivotal use cases that encapsulate the core functionalities of GREP. Using provenance data, the first use case demonstrates blockchain's ability to securely manage property provenance records, a fundamental step in establishing trustworthy e-business transactions.

Table 3 Contents of the real estate dataset with descriptions

Column name	Description
Federal provider number	Unique identification number for each nursing home assigned by the federal government, used as the property ID in this project
Provider name	Name of the nursing home or care facility
Provider location	Consolidated location information of the nursing home, including street address, city, state, and zip code
Owner type	Specifies whether the owner is an individual, an organization, or another type of entity
Owner name	Name of the owner or managerial Individual/Entity of the nursing home
Association date	Date from which the listed owner or manager has been associated with the nursing home
Federal provider number	Unique identification number for each nursing home assigned by the federal government, used as the property ID in this project
Provider name	Name of the nursing home or care facility
Provider location	Consolidated location information of the nursing home, including street address, city, state, and zip code

The second use case emphasizes blockchain's role in providing controlled access to property information, which creates a secure and private environment for e-business transactions. The final use case illustrates blockchain's capacity for dynamic user role management, including the promotion and demotion of admins, thereby showcasing the system's adaptability and its focus on maintaining privacy and integrity in property transactions. Together, these three use cases demonstrate the system's effectiveness in enhancing secure and trustworthy e-business transactions in real estate, reflecting the core objectives of blockchain application in real estate provenance as outlined in our study.

```
                [vm]from: 0x5B3...eddC4
                to: GlobalRealEstatePlatform.addProvenance
                (uint256,string,string,string,string,string,string,string,string)
                0xd91...39138 value: 0 wei data: 0x70d...00000 logs: 1 hash:
0xd83...d328f

status          0x1 Transaction mined and execution succeed
transaction hash
                0xd8319e90a2f6f59d71729f80c38b54eb6a174e34347d18251a9793fb9
31d328f
block hash
                0x75e3fba565906ccc603ce2b3f7bc1887bcebdb7379d06218bc0b420b
ae67ed30
block number    7
from            0x5B38Da6a701c568545dCfcB03FcB875f56beddC4
to              GlobalRealEstatePlatform.addProvenance(uint256,string,string,string,
                string,string,string,string,string)
                0xd9145CCE52D386f254917e481eB44e9943F39138

decoded input   {
                "uint256 propertyId": "265711",
                "string ownerName": a,
                "string providerName": b,
                "string ownerType": "Orgnization",
                "string propertyLocation": c,
                "string CityandState": "Fenton, Mo",
                "string associationDate": d,
                "string basicKey": "666",
                "string detailedKey": "777"
```

Fig. 4 Detailed view of the seventh property data entry

4.3.1 Use case 1: super admin adds property records

In the first use case, we focus on the execution stage where a super admin, an authorized entity in our proposed system, adds property records, as visualized in Fig. 2. Given the original dataset's considerable size, we extracted sub-datasets, each containing 3–13 rows of provenance information for a single property. These sub-datasets were used to realistically simulate the provenance data entries. Reflecting our system's authoritative structure, only the super admin is granted the privilege to deploy the smart contract.

Our experimentation was divided into two separate sections:

Local-based test environment In a controlled test environment, we tested our smart contract initially using Remix VM and subsequently with Ganache. The deployment began in the Remix VM environment, where the super admin's address was used to deploy the smart contract. We then entered the extracted sub-datasets, which were initially ordered by property location. To mitigate any potential acceleration of data entry due to this ordering, we randomized the sub-datasets to form a more realistic scenario. After compilation using Remix's built-in compiler, the smart contract was deployed locally. Figure 4 specifically illustrates a successful data entry for the seventh transaction by the super admin, showing the decoded input for property "265,177", while Table 4 summarizes the first seven transactions of property data entry.

We also tested our smart contract on Ganache, a tool that enables developers to create a private Ethereum blockchain which can be used for testing and development purposes. Differing from Remix VM, Ganache provides a more realistic blockchain environment suitable for use on a local machine.

We began by integrating the smart contract environment with Ganache, adjusting the Remix environment to connect

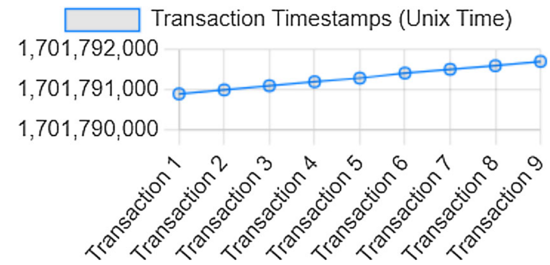

Fig. 5 Timestamps of property data entry transactions

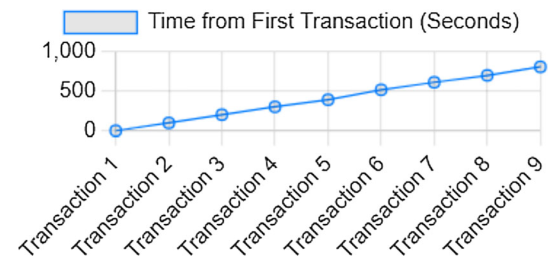

Fig. 6 Duration of each data entry transaction

via Ganache's JSON-RPC endpoint. To ensure the highest data accuracy and automate the timestamp collection, we utilized event listeners. By employing the Ethers.js library, we efficiently recorded the timestamp of each property data entry, specifically those emitting the 'ProvenanceAdded' event from our smart contract's 'addProvenance' function. For data analysis, we initially collected these transaction timestamps in Unix format. Subsequently, using a JavaScript conversion code implemented in Visual Studio Code, we transformed them into a human-readable date and time format. After the conversion, we calculated the duration of each transaction by subtracting the start timestamp from the end timestamp. This process allowed us to determine the total time taken for each transaction. The line charts in Figs. 5 and 6 display the timestamps and durations for data entry across nine transactions, starting from the first transaction.

Network-based test environment In this section, our objective is to elevate our testing environment to encompass more realistic scenarios. We initiated this advanced phase by integrating our smart contract with MetaMask, a popular Ethereum wallet and gateway to blockchain applications. MetaMask facilitates direct interaction with Ethereum's blockchain via a web browser, making it ideal for simulating real-world user interactions. To utilize MetaMask in a test network mode, we selected the Sepolia test network, which closely mimics the Ethereum mainnet's functionalities.

For our experiment, we created three different accounts within MetaMask, representing a super admin, an admin, and a regular user. Each account was funded with Ethereum from the Sepolia faucet, a necessary provision for executing

Table 4 Summary of first seven property data entry transactions

Transaction No	Initiated by super admin	Transaction hash	Timestamp	Property ID
1	0 × 5B38…eddC4	0xadc3ec63ca65bea03d58686946a99585e6644704 1efdde90ea08c771825e56e3	–	–
2	0 × 5B38…eddC4	0 × 834b7fdf872260e80668abab583860cd8ee9f38a2 33ad7df1eabe6281ab07fef	1,701,701,941	75,329
3	0 × 5B38…eddC4	0 × 1e5766e9edb189579826ed52514c4447c4439049 da59c24c8a9b43334f0384a1	1,701,702,099	395,502
4	0 × 5B38…eddC4	0xd95529b01ead9fcdcdf212e62236784ca8f9bb799 98aa8558aef3a575b6210b3	1,701,702,232	265,711
5	0 × 5B38…eddC4	0xc4c21d4a89f990066cea5a432409f499df4d13a59 048f1fbe5622af8af4af02d	1,701,702,364	75,329
6	0 × 5B38…eddC4	0 × 555fb5b690bf9fb56aa871d4b5dd27e29be64363d f91a85edca45c3be5e289a0	1,701,702,472	395,502
7	0 × 5B38…eddC4	0xd8319e90a2f6f59d71729f80c38b54eb6a174e34 347d18251a9793fb931d328f	1,701,702,612	265,711

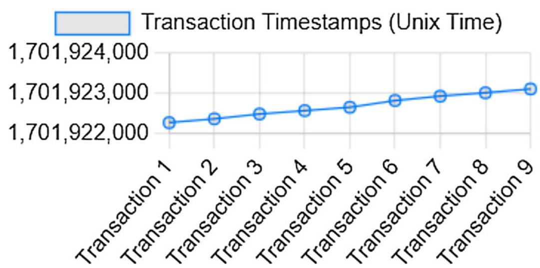

Fig. 7 The timestamps for each transaction conducted by the super admin

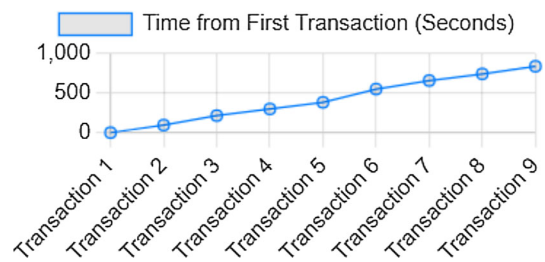

Fig. 8 The time taken for each transaction relative to the first

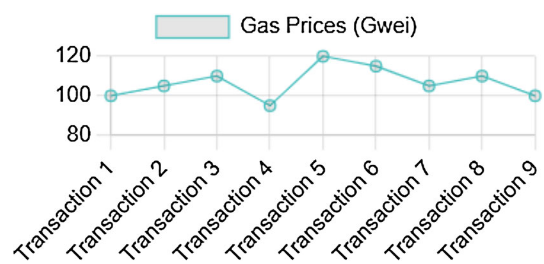

Fig. 9 The gas costs for each transaction

transactions on the test network. This setup was instrumental in realistically simulating transactional processes among various user roles within our blockchain environment.

Furthermore, we integrated Infura into our setup. Infura provides a scalable infrastructure that is crucial for ensuring reliable and efficient access to the Ethereum blockchain. This integration played a pivotal role in facilitating the complex interactions that are typically encountered in decentralized environments.

By integrating MetaMask with the Sepolia test network and our smart contract, we established a realistic blockchain test environment, crucial for simulating a super admin's role in securely adding property records. By employing event listeners and the provided tools, we conducted a targeted assessment of the blockchain transactions. Key metrics recorded included the timestamps of each transaction (Fig. 7), the time elapsed from the first transaction (Fig. 8), gas prices (Fig. 9), and the overall transaction costs (Fig. 10).

4.3.2 Use case 2: user access to property information

In the second use case, we address the crucial aspect of displaying property provenance information to regular users within GREP. The expected output of this use case is a two-tiered access system that allows users to view property provenance information based on their level of access. This system is designed to regulate information exposure and prevent potential data leaks.

The setup for this experiment utilizes the property information entered by the super admin in the first scenario. We divided the property information into two levels: basic and detailed.

Access to basic details In the basic level, users with a basic key can access fundamental details about real estate provenance. This level is specifically designed for scenarios

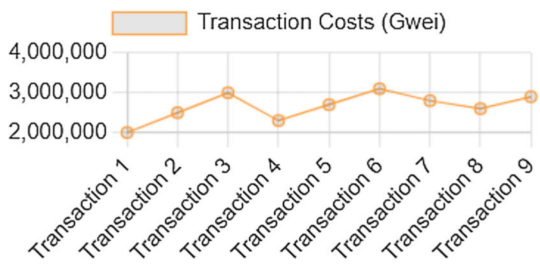

Fig. 10 The overall costs of each transaction

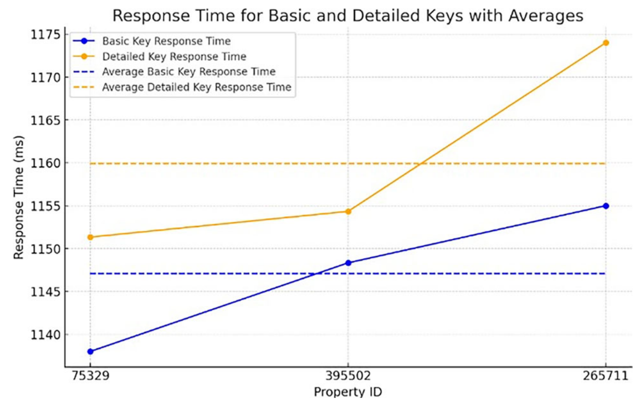

Fig. 11 Provenance information response time visualization

where a property owner prefers to share limited information with less trusted parties, such as prospective buyers. For instance, an owner can share the basic key, along with the property's identification number, with interested parties who do not require detailed data. This allows buyers to access and claim essential provenance data through the system using this basic key, effectively balancing information accessibility with security.

Table 5 illustrates this process by providing a detailed view of a typical transaction, including the interaction method, user and contract addresses, and the specific data exchanged when accessing basic property information.

Access to detailed information In the second level, users with a detailed key can access comprehensive information about real estate provenance. This level is tailored for situations where a property owner fully trusts another party and opts to share in-depth property details. A typical scenario could involve an owner providing the detailed key, along with the property's identification number, to an insurance company seeking extensive data on the property's history and condition. This access enables such entities to review all available provenance data within the system, using the detailed key. Table 6 offers a detailed view of a transaction involving the detailed key and showcases the comprehensive property information accessed in this process. It details the specific data exchanged, including the interaction method, as well as the user and contract addresses involved in accessing this deeper level of property provenance information.

To evaluate the efficiency of our system in handling different access levels, we measured the response times for accessing both basic and detailed provenance information. This was achieved using a function that calculated the time elapsed from initiating to completing each provenance information request. Figure 11 presents this data in a bar chart format, visually comparing the response times for accessing basic and detailed provenance information and includes the average response time for both.

4.3.3 Use case 3: promoting and demoting admins

In our third use case, we explore the super admin's authority within GREP to promote regular users to admin roles and to demote them, as detailed in Table 1. This case aims to demonstrate effective user role management, emphasizing the crucial role of admins in maintaining privacy and controlling access to sensitive functions.

This experiment builds upon the first scenario where the super admin added property provenance, including a detailed key. To illustrate this experiment, we incorporated the 'getBasicKey' function into our smart contract. This function is critical as it allows access to light-weight property information, yet only authorized entities like super admins or admins can use it, whereas regular users cannot. The aim of this test is to validate the system's role-based access control mechanisms, particularly focusing on the super admin's ability to promote a user to an admin status and the newly promoted admin's ability to access the 'getBasicKey' function.

The actual verification in this scenario begins with the super admin promoting a specific regular user to an admin role. A detailed visualization of this transaction is demonstrated in Table 7.

Following the promotion, this new admin address gains the right to call the 'getBasicKey' function and access its contents. Table 8 demonstrates the execution of this function by the newly promoted admin.

The super admin's possess the capability to demote admins back to regular user status. In our experiment, we demonstrated this by demoting the same user who was previously promoted to an admin. This process is depicted in Table 9. As a result of the demotion, when the user attempted to call the 'getBasicKey' function, an error message was triggered, stating "execution reverted: only an admin or super admin can call this function." This confirms that the user had effectively lost admin privileges.

Table 5 Basic provenance information retrieval details

Feature showcase: user access basic property information		
Detail	Value	Description
Call function	GlobalRealEstatePlatform.getProvenance(uint256, string)	Indicates the contract method being called for retrieving property information
From (Caller)	0xC13ec36b7a178C510360B047B2E484351bd33E71	The Ethereum address of the regular user attempting to access property information
To (Contract Method)	GlobalRealEstatePlatform.getProvenance(uint256, string) 0 × 71dF8CEcC5d5aB764027498Cdafb6018EFA7D671	Specifies the contract and method attempted by the user to retrieve information
Decoded Input	{ "uint256 propertyId": "75,329", "string key": "222"}	The input data, the users provided the property ID "75,329" and the key "222" to access the property information
Decoded Output	{ "0": "string: Owner: A, Property Location: B = = = = Owner: C, Property Location: B = = = = Owner: D, Property Location: B"}	The output data, showing the limited information about the property provenance with the basic key "222"

Table 6 Detailed provenance information access details

Feature showcase: user access detailed property information		
Detail	Value	Description
Call Function	GlobalRealEstatePlatform.getProvenance(uint256, string)	Method for calling to retrieve detailed property information
From (Caller)	0 × 2C0449898062532Ce5A3826f219a32B94D7F08bb	The Ethereum address of the trusted user
To (Contract Method)	GlobalRealEstatePlatform.getProvenance(uint256, string) 0 × 71dF8CEcC5d5aB764027498Cdafb6018EFA7D671	Specifies the contract method and address the user interacted with to retrieve information
Decoded Input	{ "uint256 propertyId": "75,329", "string key": "333"}	The user used property ID "75,329" and the key "333" to access the detailed information
Decoded Output	{ "0": "string: Owner: A, provider Name: B, Owner Type: Organization, Property Location: C, City and State: Bristol, CT, Association Date: Since 01/01/1984 = = = = Owner: D, provider Name: B, Owner Type: Individual, Property Location: C, City and State: Bristol, CT, Association Date: since 01/01/2003 = = = = Owner: E, provider Name: B, Owner Type: Individual, Property Location: C, City and State: Bristol, CT, Association Date: since01/01/2005"}	The output data, showing extensive information about the property provenance with the detailed key "333"

Table 7 Admin promotion transaction visualization

Feature showcase: super admin promoting a user		
Attribute	Value	Description
Transaction Hash	0 × 8d35c021a8737c931435e062fcc2820fe7c0ba0f488ee0deb7509b48582d8589	Unique identifier of the transaction
From (Sender)	0 × 8d642c343998d03628AcE3F3CdbFb7dBc88f9b6a	Ethereum address of the Super Admin initiating the transaction
To (Contract Method)	GlobalRealEstatePlatform.promoteToAdmin(address)	Smart contract method called to promote a user to admin
Decoded Input	{ "address _admin": "0 × 2C0449898062532Ce5A3826f219a32B94D7F08bb"}	The input data, specifying the admin address being promoted

Table 8 Execution of 'getBasicKey' function by new admin

Feature showcase: new admin performing a call		
Attribute	Value	Description
From (Sender)	0 × 2C0449898062532Ce5A3826f219a32B94D7F08bb	Ethereum address of the new admin performing the call
To (Contract Method)	GlobalRealEstatePlatform.getBasicKey(uint256)	Smart contract method called to retrieve a basic key
Decoded Input	{ "uint256 propertyId": "75,329"}	The input data, showing the property ID for which the basic key is requested
Decoded Output	{ "0": "string: 222"}	The output data, showing a successful retrieve for the basic key

To assess the system's efficiency in managing user role changes in Use Case 3, we monitored the system's performance through a series of role modification transactions. This involved a sequence of user promotions and demotions to evaluate the system's responsiveness during these critical operations. We recorded the timestamps of each transaction to analyze the time dynamics involved in these role changes. Figure 12 visually presents the timestamps for each of these transactions.

4.4 Discussion

This section provides a detailed analysis of the outcomes of our experimentation in each use case. We explore the key findings, the challenges encountered, and the impact of these results on establishing a secure and trustworthy environment for e-business, with particular emphasis on the real estate perspective.

Use case 1 We conducted multiple tests to analyze the process of a super admin adding property records across various environments. Every entry made by the super admin was carefully compared with the original dataset to ensure accuracy and consistency. Figure 4 and Table 4 illustrate the details of the information entered by the super admin in the Remix local VM. Additionally, Tables 5 and 6 confirm the successful and accurate data entry on our system, as evidenced by the comparison with the original dataset.

To provide insight into the system's performance and its real-world applicability, we extended these tests to a local-based and network-based environment. A key metric we focused on was the recording of timestamps for each transaction, which are crucial for tracking the exact moment each transaction is processed within the blockchain. Although slightly less critical in controlled environments, they provide essential insights into system performance. Figures 5 and 7 illustrate the timestamps in local and network environments, respectively. The analysis reveals that the network environment, as shown in Fig. 7, demonstrates an increasing trend with less stable increments, which can be reasonably attributed to the increased transaction time associated with local addresses compared to those using the MetaMask wallet. This direct comparison highlights the impact of network conditions on transaction times. Similarly, the metric of time elapsed from the first transaction provides instrumental insights into activity patterns and internal processing efficiency, as depicted in Figs. 6 and 8. Shifting our focus to financial aspects, we considered the following two metrics for budgeting and financial planning:

1. *Gas prices* Fig. 9 presents a line chart of gas prices for 9 transactions within our government-controlled hybrid blockchain system, with all transactions maintaining gas prices between 90 to 120 Gwei. This relatively narrow range demonstrates the effectiveness of our regulatory mechanisms in stabilizing gas prices, despite the inherent fluctuations typical in blockchain systems. The consistency observed in the gas price range underscores our system's ability to provide a predictable environment for financial planning and budgeting in blockchain-based transactions.
2. *Transaction Costs* similarly, Fig. 10 illustrates the transaction costs associated with the same set of transactions and shows that despite fluctuations, the costs stay within a relatively predictable range. This predictability mirrors the stability observed in gas prices and underscores our hybrid blockchain's ability to provide financial predictability and stability.

In Use Case 1, we encountered the following challenges during the implementation:

- Tool compatibility and downgrading. During our implementation phase, a major challenge was compatibility issues in our development stack, as shown in Table 3. We faced errors suggesting incompatibilities between different versions of our tools and libraries. This issue was

Table 9 Failure call execution for demoted admin

Feature showcase: admin demotion and access check

Detail	Value	**Description**
Status	0 × 1 Transaction mined and execution succeed	Indicates the transaction was successfully processed
Transaction Hash	0 × 31cd16502cff8ac89d8dc54fa81187a46022563d3938b40c993c3c3df38e765c	Unique identifier for the transaction
From (Sender)	0 × 8d642c343998d03628ace3f3cdbfb7dbc88f9b6a	The Ethereum address of the super admin initiating the demotion
To (Contract Method)	GlobalRealEstatePlatform.demoteFromAdmin(address) 0 × 71df8cecc5d5ab764027498cdafb6018efa7d671	Indicates the contract method being called for demoting an admin
Decoded Input	{ "address _admin": "0 × 2C0449898062532Ce5A3826f219a32B94D7F08bb"}	The input data, specifying the admin's address to be successfully demoted
Call function (Attempt)	GlobalRealEstatePlatform.getBasicKey(uint256)	The demoted admin's attempted call to the "getBasicKey" function
Error message	execution reverted: Only an Admin or Super-Admin can call this function	Transaction failed as explained in the error message

particularly apparent with ethers.js, where we encountered functionality problems due to unresolved bugs and unsupported changes in its newer versions. Similar compatibility issues were experienced with Node.js versions, web3.js, and the Solidity compiler. Our solution often involved downgrading to more stable versions of these tools. Notably, the versions of the tools outlined in Table 3 are not the latest, implying the complexities inherent in blockchain development.

- Managing smart contract complexity and security. In addressing the security concerns related to data exposure, our focus extended beyond mere data entry to encompass the expected outputs of the system. We implemented features to show provenance using both basic and detailed keys, which were set by the super admin. While these enhancements were crucial for ensuring data security and preventing later unwanted consequences, they inevitably led to a more complex and heavier smart contract.
- Realism in data entry. During our implementation, we faced a challenge in the data entry process. Our original dataset was extensive, and when sorted by provider location and date, it provided the provenance data for specific properties. However, entering this data in a sorted order could unrealistically speed up the process, as certain parameters such as PropertyId, Provider Name, and Provider Location would be repeatedly used without change. To avoid creating an unrealistic scenario and to better mimic real-world conditions, we randomized the sub-datasets, resulting in the data being unsorted.

While this use case primarily focuses on data entry for real estate provenance, it sets the groundwork for future advancements in secure and efficient transactions. Our analysis of gas prices and transaction costs offer insights into the economic aspects of these transactions. Ultimately, this highlights the crucial contribution of blockchain technology in strengthening the integrity and trustworthiness of e-business practices, particularly in the real estate industry.

Use case 2 In Use Case 2, we developed a two-tiered access system to display property provenance information. Users, such as foreign investors, can access basic details with a basic key, which is ideal for limited information sharing. For more comprehensive data, a detailed key enables access to in-depth property information. Our approach successfully called both keys with the desired and accurate output, as demonstrated in Tables 5 and 6 respectively. This not only demonstrates the functionality of this use case, but also validates the successful data entry process started in Use Case 1.

To evaluate the efficiency of our system in Use Case 2, we selected response time as our key metric. In a hybrid blockchain, assessing response times helps in benchmarking the system's performance. This is especially important for

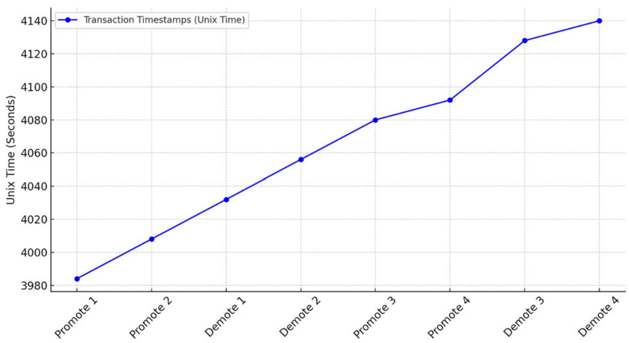

Fig. 12 Timestamp analysis of role modification transactions

government-controlled environments, where efficiency and reliability are paramount. Figure 11 offers a visual comparison of the response times for accessing basic and detailed provenance information across a network test environment, including the average response time associated with each key type. Notably, the response times for accessing detailed information are understandably longer due to the greater volume of data involved.

A primary challenge we faced was the detection and tracking of function calls within the blockchain environment. Unlike event listeners that readily capture and log transactions, as seen with adding provenance data in Use Case 1, tracking function calls required a more intricate approach. Our approach involved implementing an asynchronous function to measure response times accurately. However, this method demanded rigorous execution to ensure precise monitoring and analysis, which highlighted the complexities of function call tracking.

Use Case 2 in our study represents our proposed infrastructural step towards secure and trustworthy transactions in e-business, particularly in the real estate sector. The implementation of a two-tiered access system for property provenance information on GREP notably advances the security and trustworthiness of online transactions. It achieves this primarily by ensuring balanced transparency and full accountability, a critical aspect that directly tackles our primary challenge of effectively managing access rights. This innovative system not only grants users access to information based on their authorization levels but also could serve as a secondary identifier to boost security protocols. The importance of such features is increasingly recognized in preventing fraud. Additionally, this system enables foreign investors, who may not have direct insights into local properties, to actively participate in the market, thereby significantly enhancing the global accessibility of the real estate market. Ultimately, Use Case 2 contributes to creating a more secure, reliable, and inclusive digital real estate environment, showcasing the transformative potential of blockchain technology in real estate e-business.

Use case 3 In Use Case 3, we effectively demonstrated role-based access control within GREP, specifically highlighting the super admin's ability to promote and demote user roles. Initially, a regular user, identified by an address ending in 'F08bb,' was promoted to an admin role. This promotion enabled access to specific functions like 'getBasicKey' and 'getDetailKey,' which were previously inaccessible. The successful transition and newly granted access were clearly demonstrated, as shown in Table 7. Further, when this user, now an admin, called 'getBasicKey' for property '75,329,' the system correctly returned the basic key '222', as depicted in Table 8. Continuing the experiment, we demoted this user back to regular status and attempted to access the 'getBasicKey' function again. As expected, the system effectively prevented the now regular user from obtaining the basic key, reinforcing the access control measures, as presented in Table 9.

In our analysis, which focused on evaluating the system's performance in managing user role changes, we mainly monitored performance through a series of role modification transactions. These transactions included sequences of user promotions and demotions, aimed at assessing the system's responsiveness during these critical operations. To gain insights into the time dynamics involved, we recorded the timestamps of each transaction. The line chart, as illustrated in Fig. 12, indicates that both promotion and demotion transactions consistently maintained a near-constant time. This consistency suggests a high level of predictability in the system's response which highlights its reliability in efficiently managing user role changes.

Notably, we encountered a challenge due to testnet faucet limitations. Previously accessible test networks that used to offer up to 100 ETH were no longer available, leading us to a faucet that provided only 0.5 ETH every 24 h. While this limitation did not substantially slow our progress, it imposed a sense of caution and consideration with each transaction we conducted.

In Use Case 3, the effective management of user permissions is crucial in addressing both key challenges: managing access rights and ensuring data authenticity. This strategic approach is vital in preventing unauthorized access and ensuring the authenticity of real estate provenance information, as a result encouraging confidence in the system's capabilities. Coupled with the advancements showcased in Use Case 2, these improvements collectively lay the groundwork for a more secure and reliable infrastructure, essential for e-business transactions.

5 Conclusion and future work

In conclusion, this study introduces GREP, a novel hybrid blockchain framework that employs real estate provenance to establish a secure and reliable setting for conducting real estate e-business. Acknowledging the need for more empirical research and practical applications in this field, we have presented GREP both theoretically and practically. Our detailed process, including the development, implementation, and testing of our framework, further demonstrates its novelty and sheds light on the current challenges faced in such implementations. Additionally, our study includes a detailed examination and evaluation of three specific use cases of GREP, which showcases its practical utility in real-world scenarios.

Reflecting on our research goals, the detailed examination of the three specific use cases within our research underscores the effectiveness of GREP in the realm of real estate e-business. These examples showcase the system's operational capabilities, particularly how the blockchain system ensures data authenticity. Furthermore, the super administrators, representing government entities, contribute significantly to managing access rights and effectively maintaining the balance between transparency and accountability in the system. Additionally, our system creates opportunities for foreign investor participation which could enhance market diversity and foster a more inclusive environment. Collectively, these case studies, along with the features they revealed, mark a substantial step forward in building an infrastructure conducive to secure and trustworthy e-business transactions.

While our system has shown promising results, we acknowledge certain limitations both on a conceptual and practical basis. On a conceptual basis, a significant challenge lies in user adoption. As part of our future work to enhance acceptance and incentivize usage, we plan to augment GREP by introducing an ownership system. This addition aims to incentivize usage and establish secure and trusted trading environments in e-business, aligning with our goal of enhancing transactional security and continuing with our work presented in [1]. On a practical basis, our system exhibited potential performance variability under different network conditions, and it may not fully encapsulate the complexities of real-world real estate transactions. This became particularly evident as we moved from controlled environments like Remix to Ganache, and then to broader network-based settings, where the complexity of experimentation notably increased. Such limitations are acknowledged as part of the development process and are expected in our prototype phase, providing valuable insights for future enhancements.

As we consider future enhancements and research arising from our findings, several key insights have emerged that go beyond our initial research goals. These insights present promising directions for future research, including:

- Broader utility beyond property information: Future work could expand our system's scope to encompass a wider range of property-related information. This includes integrating data on average electricity and water bills, as well as landlords' payment reputations, to provide a more comprehensive view of property management.
- Owner provenance as indicators: Exploring the potential of our system to serve as an indicator of owners' provenance is a promising area for future research. This feature could play a critical role in verifying the reliability and credibility of property owners, thus enhancing the trustworthiness of transactions.
- Secondary identifier for users: Another area for future exploration is the system's ability to function as a secondary identifier for users. This capability opens numerous verification possibilities.
- Integrated research focus: Future studies should take an integrated approach to explore user adoption factors, security vulnerabilities, and the economic implications of blockchain in real estate. A broader perspective with careful considerations is necessary to advance our framework and its implementation towards a final, market-ready product.

As demonstrated, applying blockchain in real estate provenance opens many new dimensions to explore. These advancements highlight the transformative potential of blockchain as an infrastructural step in real estate e-business.

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Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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