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The Real Estate Time-Stamping and Registration System Based on Ethereum Blockchain

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Abstract

In recent years, there has been a growing interest in real estate investments that utilize blockchain technology. Traditional real estate investments usually involve third-party intermediaries for verifying and recording real estate informal transactions. This paper proposes a blockchain-based real estate investment model and presents a detailed description of the real estate register authentication aspect of the model. The model uses blockchain technology to create tamper-evident records of real estate transactions and provide secure authentication and verification of real estate informal transactions. Meanwhile, each real estate transaction is recorded in a block, and all transaction records are kept on the blockchain. This means that inventors can access these transaction records and verify their authenticity and validity. The system can also use smart contracts to automate the process of real estate transactions, which further improves transaction efficiency and reduces costs. Further, the model's timestamp and authentication mechanism can eliminate third-party intermediaries and ensure the authenticity and validity of real estate transactions through distributed ledgers and verification mechanisms. Overall, blockchain-based real estate systems offer advantages of security, transparency, efficiency, and cost reduction. With ongoing blockchain advancements, these systems are expected to play a crucial role in future real estate investment transactions.

Keywords: Blockchian technology, Smart contract, Real estate investment, Timestamping and registration system

1 Introduction

Real estate in Australia is one of the most important industries contributing to Australia's social and economic development. It is a big class of assets of the country and the stock market. According to the information (CoreLogic (2022)), a total of approximately 535,000 properties were traded in Australia in the year 2022. In addition to its direct contribution to economic activities through trading, the real estate industry creates jobs, builds communities, and helps investors and families become wealthier. It also contributes to globalization and generates income for governments through taxes and other fees (Gutierrez et al (2022)).

In recent years, the real estate management system has gradually changed from traditional paper-based information storage to a digital record-keeping mechanism. However, the existing system still has many issues and flaws. It involves many agencies and intermediaries and the associated processes are cumbersome, time-consuming and costly. It is also vulnerable to hacking and can lead to information leakage, so the security and accuracy of information are not guaranteed (Wouda et al (2019)).

With the continuous improvement of macro policies and industrial investment in blockchain in various countries around the world, the integrated use of blockchain technology is playing an increasingly important role in the development of industrial innovation. For the real estate industry, the application of blockchain technology can make a breakthrough in the real estate certification and management system. Blockchain smart contracts enable real estate contracts, third-party escrow deeds, and property records to be completed and distributed without the need for a title company or attorney. Blockchain can ensure that the buyer receives the title or deed and the seller receives the money. The blockchain will also record the corresponding public record of title or deed (Thota (2019)).

In recent years, blockchain technology was used in various countries. Swiss urban housing management companies use blockchain technology to record and manage real estate information, ensuring transparency and security of the information (Witzig (2019)). In the United States, blockchain company Propy has developed a blockchain-based real estate trading platform and launched the first batch of real estate NFTs, which can conduct real estate transactions globally (Park (2020)). The government of Singapore is using blockchain technology to manage real estate transactions and improve the transparency and efficiency of transactions (Chow and Tan (2021)). The Georgian government has integrated blockchain technology into land registration, achieving a disruptive transformation of public service delivery systems (Lazuashvili et al (2019)). At the same time, Japanese blockchain company LIFULL HOME'S has also developed a blockchain-based real estate trading platform that can improve the efficiency and transparency of real estate transactions (Rogers (2020)).

In this paper, we will first analyze the shortcomings in the existing real estate investment system in Australia, then propose a new system based on blockchain technology. It will be shown that the new system will involve the establishment of a

blockchain land registration institute, and will create new businesses for the trading of real estate in digital form. The new system will involve the development of a blockchain land registration system and a blockchain-based real estate trading system. In this paper, we will focus on the development of a blockchain-based land registration system. The rest of this paper is presented in six sections. Section 2 describes the existing real estate investment system and its shortcomings. Section 3 presents the proposed blockchain-based approach for real estate investment. Section 4 describes the framework of the proposed real estate time-stamping and registration systems and section 5 elaborates on the implementation of the real estate time-stamping and registration system. Section 6 shows the web pages, functions and operation of the proposed system. Finally, Section 7 summarizes the work of this paper and provides an outlook for future work.

2 Existing real estate investment system and its flaws

Real estate is a physical asset with a high price, and its value and flows are influenced by a variety of factors, including land location, building area, market demand, etc. The real estate industry is an important economic sector, involving housing construction, real estate development, and real estate investment, which has an important impact on the national economy and social development (Shashank and Choudhury (2022)). There are many different forms of existing real estate investment. Some of the common ones are shown in Fig. 1 and briefly described below (Takatsugu (2017)):

(i) Direct purchase of property: This includes the purchase of residential, commercial property, industrial property, etc.
(ii) Real Estate Development: This includes the development of new real estate projects, such as residential, commercial properties, industrial properties, etc.
(iii) Investment through an agent: The property is purchased through a real estate agency or broker, and the agency is responsible for managing and renting out the property.
(iv) Real Estate Leasing: This includes renting out properties, such as residential, commercial, industrial, etc.
(v) Real Estate Investment Trusts (REITs): This is a type of security where investors can invest in real estate by purchasing REITs without having to purchase the property directly.
(vi) Real estate crowdfunding: This is a way to collect funds from multiple investors through an Internet platform to jointly invest in real estate projects.

Traditional forms of real estate investment, such as Form (i), (ii) and (iii), require huge capital, including purchase costs, construction costs and operating costs, which will directly affect the investor's return. Most investors cannot come up with a large amount of capital to cover these costs, so they cannot participate in real estate investments. In addition, these forms of real estate investment are illiquid and often involve the participation of many intermediaries such as agents, lawyers, etc. People are unable to sell a portion of their real estate and have to sell it all. The above

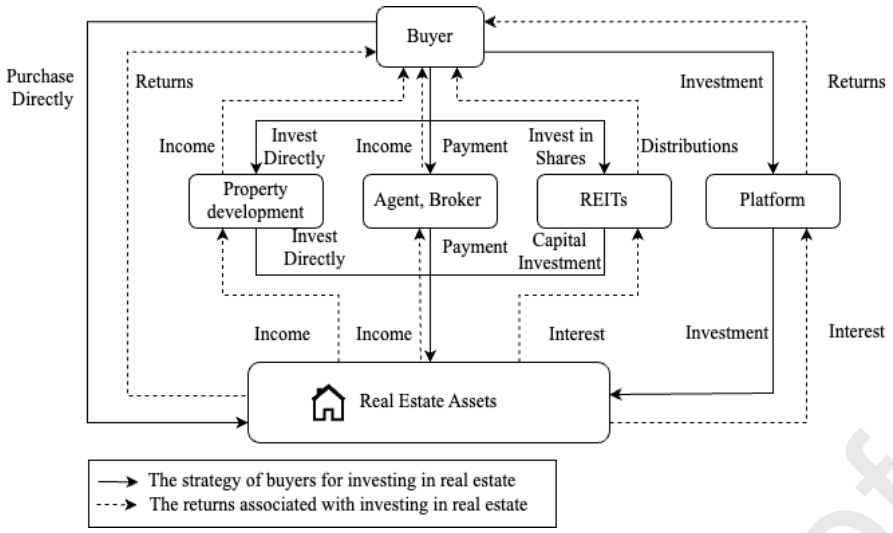

Fig. 1 Existing real estate investment system

investment model makes real estate investment costly, time-consuming, complicated and highly opaque, so this system is not attractive to retail investors. Investors who choose investment form (iv) usually purchase non-self-help properties by taking out a loan and renting them out to receive a rental return. However, this also requires initial capital and requires them to find a suitable tenant themselves. If the property is rented out through a rental agent, a third-party agency fee should be paid. This form of investment still requires a lot of effort and initial capital, so it is only suitable for a small group of investors (Andrew (2022)).

Real Estate Investment Trusts (REITs) (Han et al (2003)), mentioned in form (v), are investment vehicles that allow investors to participate in real estate projects by purchasing shares in the fund. The main advantage of REITs is that they offer liquidity, diversification and stable returns that investors cannot get by investing directly in real estate. By purchasing shares in REITs, investors can diversify their capital across multiple real estate projects, thereby reducing investment risk. At the same time, REITs typically pay stable dividends, which also provide investors with a steady cash flow return. However, REITs also have some disadvantages, such as reliance on management, as the investment results of REITs depend on the decisions of the management team, and investors may suffer losses if the management team does not perform well. In addition, REITs usually need to make capital expenditures to purchase, renovate or maintain their properties. These expenditures may reduce the earnings of the REITs, thereby reducing the returns to investors. Furthermore, investors also need to pay fees such as management fees, operating fees and transaction fees which may also reduce investors' returns.

For the real estate crowdfunding investment method, investors can purchase a share of the project for a smaller amount and enjoy the corresponding returns. The

platform of real estate crowdfunding is usually operated by professional real estate crowdfunding companies or internet finance companies, and its advantage is that it provides investors with small amounts of capital the opportunity to participate in real estate investment, lowering the investment threshold, while providing real estate developers with a diversified source of capital (Montgomery et al (2018)). By diversifying their investments, investors can also reduce their investment risks and receive relatively stable cash flows and capital appreciation returns. However, there are some drawbacks and risks associated with real estate crowdfunding. These include platform risk, namely the reputation and operational capabilities of real estate crowdfunding platforms have a significant impact on the outcome of investors' investments, and investors need to fully investigate the platforms and choose a trusted platform to invest in (Shahrokhi and Parhizgari (2019)). In addition, the success of real estate crowdfunding requires a professional risk management team that can conduct comprehensive risk assessments and management of investment projects to reduce investment risks. Furthermore, investments in real estate crowdfunding are usually long-term and investors may have to wait for a longer period of time before they can exit their investments and receive returns. Overall, real estate crowdfunding is an emerging form of investment, and investors need to understand the relevant investment rules and risk management measures, and carefully assess their investment objectives and risk tolerance. Therefore, this type of investment is not attractive to retail investors.

3 Blockchain-based real estate investment system

3.1 Preliminary

Blockchain technology makes it possible to establish new systems to overcome the various issues in the existing real estate investment system. The new system will include the use of distributed blockchain network for secure and immutable data storage, the application of the time-stamping technique for the record of data, the use of smart contracts for managing, verifying and executing business transactions, the utilization of the encryption system of public and private keys for security, the utilization of cryptocurrency wallets for user digital asset management, and the use of IPFS system for distributed file storage. The key components to be applied in our proposed blockchain-based real estate investment system are briefly introduced below.

Blockchain for distributed data storage

Blockchain is an immutable data list as shown in Fig. 2. It consists of a series of blocks linked together in the order of creation, that is, a series of storage units that record all information exchanged by each block node at a given time linked together in the order of creation. Each block can be identified by its own hash value, and its current hash value is added to the new block as the previous hash value (Ting et al (2018)). Thus, the blocks are linked together in this way in an orderly manner to form a blockchain. In addition, every user in the blockchain system will have the same blockchain ledger record. Once any information in the block is tampered with, the hash value of the corresponding block recording the tampered information will also be changed, and then the ledger will be significantly different from other users'

ledgers. Other users in the system will not be able to identify the wrong ledger, so tampering is invalid. From this, we can see the traceability and invariance of blockchain.

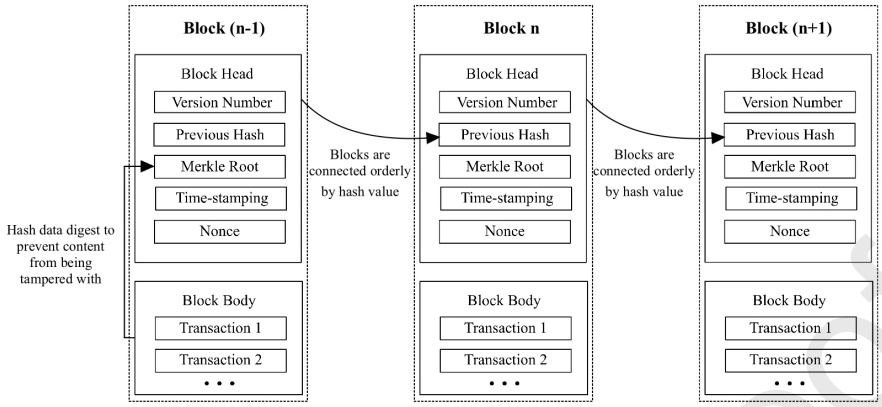

Fig. 2 The structure of the blockchain

Time-stamping record of data

A timestamp shown in Figure 2 is defined as a piece of data that indicates that data has existed in its entirety before a specific time and can be verified. It is generally a character sequence that can completely identify the time of a moment. Its working principle is as follows: the node on the blockchain will hash and encrypt the information in the block to generate an information digest, namely a hash value. This hash value and the time information of the data are then extracted through the relevant server, which will encrypt the information twice and generate a timestamp, and finally return it to the blockchain system. The advantage of the timestamp is that it improves the tamper resistance of the blockchain, because every data is secondly encrypted in the timestamp and has a corresponding time record, and the blocks are sorted in time based on the hash algorithm when they are connected (Estevam et al (2021)). If someone wants to tamper with the data, it is almost impossible to not only consolidate the hash algorithm, but also change the timestamp, and further modify the account books of more than 51% of users in the blockchain network. In short, the timestamp is equivalent to the date of production of the data and acts as a data validation. It not only improves the security of the blockchain, but also puts a time stamp on the information digest as a mark. Hence, the timestamp is a very important anti-counterfeiting function in blockchain technology.

Smart contracts for managing, verifying and exciting transactions

Smart contract is a computer program based on blockchain technology, which is used to manage, verify and execute contract terms. They are automated, transparent, and immutable, and are written in solidity language, instead of being controlled by humans. Smart contracts run on distributed networks, and each node has the same account book to ensure data consistency and security. A smart contract is a way to automatically execute contract terms without human intervention. They can be used to manage various types of contracts, including financial transactions, real estate transactions, asset property rights and other fields. Smart contracts can also ensure the full implementation of contract terms, reduce fraud and errors, and improve transaction efficiency. The execution of smart contracts depends on whether the preset conditions are met. When the conditions are met, the smart contract will automatically execute the contract terms and record the corresponding results on the blockchain to ensure its immutability (Wang et al (2019)). This enables smart contracts to provide a high degree of credibility and security during the execution process.

Cryptocurrency wallet for user asset management

MetaMask wallets, as a crucial conduit facilitating user interactions with Ethereum's decentralized applications (dApps), will be used in this system for users to manage their digital assets. They integrate effortlessly with major browsers to provide an intuitive asset management interface. Beyond simplifying user engagement with the Ethereum network, it champions heightened security and transparency in the digital currency realm through its robust security infrastructure, which includes localized encrypted private key storage and a mnemonic backup function to prevent asset loss due to private key misplacement. Furthermore, its advanced alert system adeptly warns users of potential malicious attempts, thus fostering a secure, efficient, and user-friendly platform that encourages exploration and utilization of the burgeoning digital currency ecosystem.

Public key-private key encryption and digital signatures

The encryption system of public and private keys (RSA asymmetric encryption) will be used to provide security transactions. Each participant in this system has a pair of keys: a public key and a private key. This pair of keys is generated by cryptographic algorithms and is mathematically closely related, but it is almost impossible to deduce the private key from the public key. After the message is encrypted with the receiver's public key, the encrypted message can only be unlocked with the receiver's private key. As long as the receiver's private key is not compromised, no one else will ever know the contents of the message. The private key is also used to generate an RSA digital signature, which is a cryptographic token that can prove the source of the information (Nuta et al (2023)). This technology helps the recipient to confirm that the sender's identity is not forged or fraudulent, and is a legally recognized way of signing digital documents.

When a user wants to send a transaction or message in the blockchain platform, they sign that transaction or message using their private key, generating a unique

digital signature. This signature is then broadcast on the blockchain network along with the original information. The public key is then used to verify the digital signature. The receiver or any other network participant can use the sender's public key to verify the digital signature to ensure that the transaction or message is indeed from the purported sender and has not been tampered with in transit. Since the digital signature is generated using a private key, and only the corresponding public key can verify its validity, this provides a strong authentication and integrity guarantee mechanism for the blockchain (Kara et al (2023)).

IPFS system and INFURA system for distributed file storage

IPFS (InterPlanetary File System) is a decentralized distributed file storage and transfer protocol designed to solve some of the problems of file storage and transfer in the traditional Internet, such as single point of failure, low reliability, and slow speed, etc. IPFS stores files by distributing them across multiple nodes in the network and accessing them through content addressing. rather than through traditional location-based addressing. This allows users to access files through a hash of their contents rather than using URL addresses. INFURA system is an infrastructure provider of Ethernet and IPFS node services, offering developers a fast, secure and reliable way to connect to the Ethernet and IPFS networks. It is a hosted node service that enables developers to access the Ethernet and IPFS networks by providing an API interface without the need to build or maintain the nodes themselves (Chen et al (2017)). In this paper, we combine IPFS system with INFURA system to perform real estate file authentication session for a blockchain-based real estate timestamp and authentication system. The real estate owner can upload the real estate-related files to be authenticated to the INFURA platform, get the hash value of the files and copy the hash value to the system proposed in this paper, and upload the hash value to the blockchain for recording. Investors can copy the hash value of the real estate files and paste it in the IPFS system for file restoration, thus realizing the authentication of the real estate-related files. This strategy can both ease the storage burden of the blockchain and achieve a balance between ensuring evidence traceability and protecting privacy through a multi-signature mechanism (Tian et al (2019)).

3.2 The proposed blockchain-based real estate investment system

Blockchain technology has been used in real estate industries in the United States, Japan, Switzerland and many other countries. However, it has not been used in Australia. Therefore, in this project, we proposed a blockchain-based system for real estate investment in Australia. The framework of this investment model is shown in Fig. 3. In this system, the key participants include real estate owners, investors, blockchain land registration institute and its blockchain real estate registration platform, as well as blockchain-based real estate trading companies and its blockchain-based real estate trading platform.

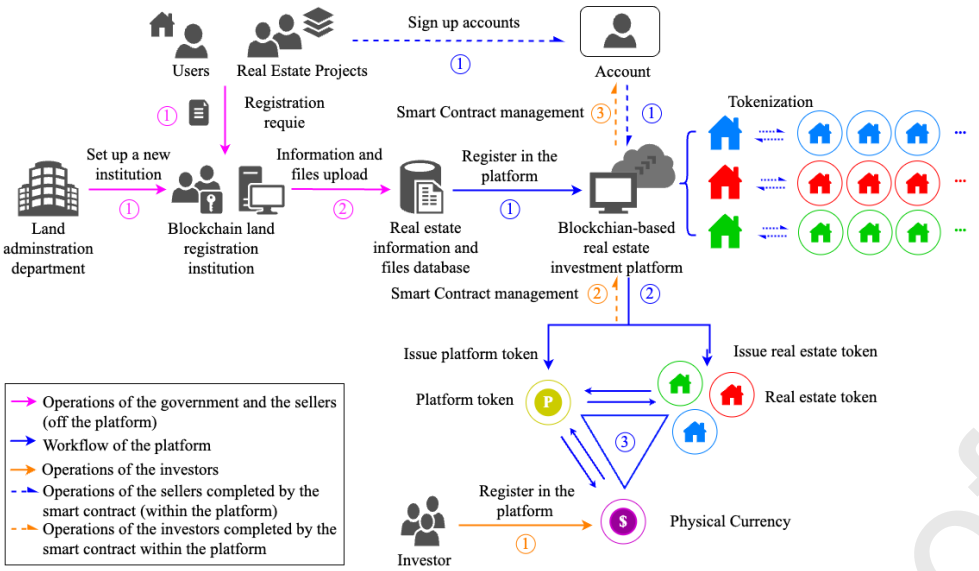

Fig. 3 The blockchain-based real estate investment system

When a user or company wants to upload real estate or real estate related projects to the blockchain platform, it must first go through the authentication and registration process. When a real estate is registered on the blockchain, blockchain technology can then be used to split the real estate asset into smaller parts and allow investors to purchase ownership of these parts through tokenization. Smart contract technology is used to manage real estate investments during the investment process, which allows investors and owners to automate contracts and rules, reducing the risk of human error and fraud. Furthermore, smart contracts could be used to manage rents, loans and property transfers, etc. In addition, blockchain can be used for portfolio management, allowing investors to diversify risk and increase investment return through digital assets. Investors can create their own digital asset portfolios on the blockchain platform, including real estate tokens, stocks, bonds, etc. The advantages of the proposed blockchain-based real estate investment are summarized below (Latifi et al (2019)).

(i) Simplify the intermediate stages of buying and selling real estate and thus reduce the costs of the investigation

The blockchain real estate time-stamping and registration platform can record details such as location, price, and description in the database. Important documents such as property certificates will be authenticated with timestamps and uploaded to the blockchain. In addition, buyers and sellers can develop digital identities, adding information and features to the digital identity to ensure that the data is authentic and reliable and cannot be tampered with. This improvement greatly reduces costs and simplifies the investigation process (Rao et al (2022)).

(ii) Guarantee the authenticity and reliability of data

Blockchain-based real estate ownership systems can make the entire transaction process public, and the platform allows all transaction-related information (such as real estate ownership, address, and description details) to be stored in a database and timestamps could ensure the authenticity of real estate-related documents. Due to the tamper-evident characteristic of the blockchain, ownership of real estate can be guaranteed as long as the real estate information is accurately recorded on the blockchain. This improvement can avoid the risk to property rights and reduce fraud (Veuger (2018)).

(iii) Ensure high information transparency and streamlined management.

Blockchain technology is open source, and the data is open to everyone (except for the private information of the parties to the transaction, which is encrypted), and anyone can access the blockchain data through a private account on the blockchain. As a result, information is highly transparent throughout the system, and the use of blockchain technology not only simplifies the management of the existing real estate as much as possible and reduces management costs, but also greatly reduces the risks that may exist in management (Bhavyansh Sharma and Ranjan (2020)).

(iv) Lower the investment threshold and increase liquidity.

Through blockchain technology, the new real estate investment model can divide real estate assets into smaller pieces and allow investors to purchase ownership of these smaller pieces through tokenization, which can reduce transaction costs and improve transaction efficiency, and also allow investors to buy and sell real estate tokens more quickly and flexibly to better manage their investment portfolios (Veuger (2020)).

(v) Ensure security of data through consensus mechanisms

Blockchain technology ensures the authenticity, integrity, and immutability of data through its unique consensus mechanism, giving it a special place in digital technology innovation. Consensus mechanisms, including proof-of-work (PoW) and proof-of-stake (PoS), are a set of protocols and incentives that allow network nodes to reach an agreement on the blockchain state. PoW relies on solving complex mathematical problems to verify transactions and create new blocks, while PoS selects validators based on the number of tokens held by participants and how long they have been held. In comparison, PoS is not only more economical and environmentally friendly, but also ensures network security through reward and punishment mechanisms (Xie et al (2023)). The transition from PoW to PoS is an important upgrade for the Ethereum network, a POS-based consensus mechanism that not only defines how new blocks are added, but also determines how network participants interact and deal with potential conflicts. As blockchain technology advances, interchain interoperability and sharding technology become cutting-edge research, which respectively allows different blockchains to communicate with each other and improve blockchain scalability (Platt and McBurney

(2023)). In our work, the PoS-based consensus algorithm is used as the security core of the blockchain in our proposed system.

Therefore, due to the characteristics of blockchain such as "immutable", "traceable", "transparent" and "consensus", blockchain technology lays a solid foundation of "trust" and has a wide application prospect in the real estate industry (Burra and Maity (2022)). This article combines blockchain technology to conduct an in-depth study on how to verify real estate information and register it on the blockchain as the first core step of the blockchain-based real estate investment model, and proposes a real estate timestamp and registration system based on the Ethernet blockchain platform, which can solve the shortcomings of traditional existing real estate transactions.

4 The framework of the real estate time-stamping and registration platform

4.1 Framework

The proposed framework of the real estate time stamping and registration platform is shown in Fig. 4. The participants of the system include:

- buyer: the person who wants to buy the real estate,
- seller: the person who wants to sell the real estate he/she owns,
- blockchain land and real estate registration department: the department that registers the land ownership approved for registration in accordance with the approval of the government,
- financial institutions: the institutions that can confirm to buyers whether the real estate they want to buy is encumbered.

Blockchain land and real estate registration mainly includes registration of the following information (Khoa Tan and Nguyen (2022)):

- the basic status of the land, such as land number, map number, location, area, usage, grade, and nature of the ownership,
- name, mailing address, nature of land use unit, and competent department of the land owner or user,
- other information, such as other rights and changes, the basis for registration, and the need to explain the problem.

The process of real estate registration on blockchain includes digital identity verification, property right certification, record on the chain, review and supervision. The key steps and workflow of the registration process are shown in Fig. 5. The details for each key step are given below.

Step 1: The blockchain institution of the land management department establishes a database of user information and a database of real estate information, and uploads all real and reliable land information, real estate owner information and real estate-related information to the blockchain through a smart contract and keeps

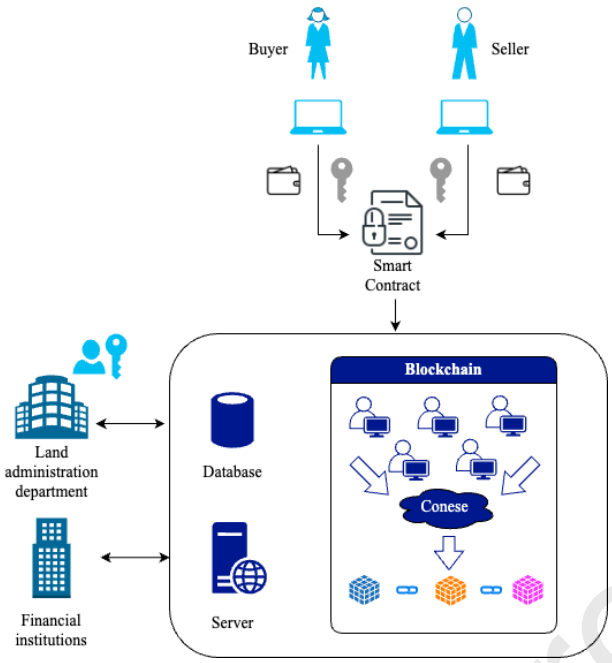

Fig. 4 The framework of the real estate time-stamping and registration platform

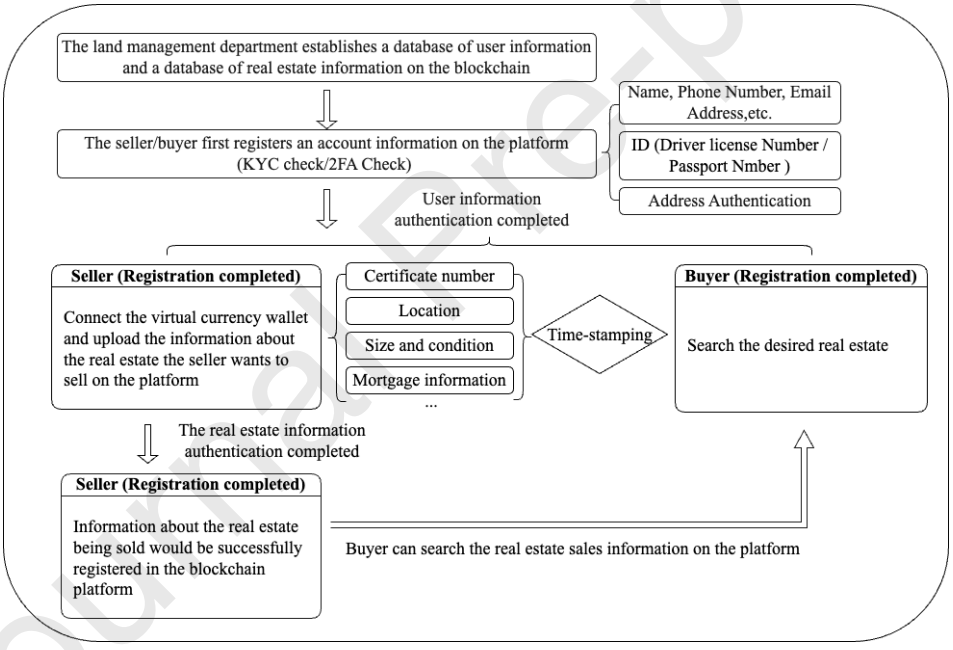

Fig. 5 Platform real estate registration process workflow

them permanently. Real estate owners can apply to the blockchain institution to authenticate their real estate to the blockchain, and the institution will help them register their accounts and upload relevant information through smart contracts. All these operations need to be authorized by the land management department and done by the blockchain registration organization. The uploading of user information will be done through smart contracts, while the uploading of paper or electronic documents of real estate will be done through the combination of the IPFS system and the INFURA system mentioned in section 3.1.

Step 2: Real estate owners, i.e. sellers, can also register their account information on the platform themselves. Sellers first connect their virtual currency wallet to the platform, upload their real name information and complete a KYC check (ID, driver's license, passport). To protect users' assets, the two-factor authentication (2FA) is used in the platform as an additional security measure. When a user attempts to register, in addition to matching the information in the database, the platform sends a one-time verification code to the user's tied email address. The user then must enter this verification code within a specified period of time in order to complete the verification. This ensures that even if other people know the user's login credentials, they will not be able to access the account or conduct transactions without the user's email access. Only after successful 2FA authentication, the uploaded information will be compared one by one with the information in the user's database through the smart contract, and the account can be registered once there is a perfect match.

Step 3: After completing the seller's information authentication, the seller keeps his virtual currency wallet connected and can then upload the real estate information he/she wants to sell on the platform. The real estate information will include:

(i) the basic information about the real estate (such as location, price, conditions of the real estate, etc.).
(ii) the real estate pictures (certified by timestamp).
(iii) the hash value of the real estate files, which is obtained through the INFURA system mentioned before in section 3.1. The uploaded files include the real estate title certificate, the original real estate purchase contract, the land use right certificate, etc.

Step 4: During the real estate information uploading process, the smart contract is triggered and it automatically verifies one by one whether all relevant information uploaded by the seller matches the information held by the land management department (including seller account information, real estate information, etc.). If all information matches successfully, the real estate will be registered and uploaded to the blockchain. However, if any of the information does not match, the authentication of the real estate will fail and the information of the real estate to be sold will not be registered on the blockchain platform.

Step 5: The investors (the buyers) register their account information in the platform according to step 2. If the authentication is successful, the buyers keep their virtual

currency wallet connected and search for the properties they are interested in without worrying about false information and online fraud.

4.2 Design for ensuring transactions security

After designing the complete framework, we must consider some practical factors in view of the unique characteristics of real estate. Real estate, as a kind of high-value assets, its ownership verification is particularly critical. Although transactions can be implemented through P2P trading, without the involvement of a third party, the confirmation and certification of ownership still require government approval and support. This ensures that while pursuing decentralization, we do not lose solid proof of ownership of real-world assets. Therefore, we have designed some functions in the deployment phase of smart contracts to ensure the security of real estate registration authentication and transactions, which involve the following important functions:

Import secure smart contracts from OpenZeppelin Library

OpenZeppelin library is an open-source project that provides developers with a library containing a series of reusable components for building secure smart contracts, and it aims to provide a set of reliable and secure development tools for Ethereum and other blockchains. In the process of building the blockchain platform, in order to prevent the problem of integer overflow and underflow from causing unexpected results or security vulnerabilities, we introduce the SafeMath library, which works by checking whether overflow or underflow will occur before the function performs an operation, and throwing an exception when these conditions are detected, thereby preventing wrong results and improving the security of the system. ReentrancyGuard library is also introduced to prevent reentrant attacks, and the Ownable and Pausable libraries are introduced to restrict certain functions to the contract owner only and to allow the contract owner to suspend the contract if a problem is found.

Create encryption module to protect user privacy

In the platform, real estate related documents and pictures will be encrypted through the IPFS system. Users only need to upload the encrypted hash value results to the platform, without uploading the detailed file to protect the security of the original files. Uploaded files will be stamped with time to protect the ownership of buyers. This approach not only reduces the storage pressure of the blockchain but also balances the traceability and privacy of evidence through multiple signatures. In addition, we have created a blockchain-based access whitelist mechanism (Xu et al (2022)), assigned permissions to the request originator, and introduced a 'msg.sender' global variable to dynamically control access security, when the user sends a request to the smart contract, he/she can only see his/her own information, and query the information record related to him/her to protect the user's privacy.

Use public key-private key encryption system and digital signatures

When using a virtual currency wallet (MetaMask wallet as an example) to interact with Ethereum-based smart contracts, the process involves a public key-private key encryption system and digital signature, ensuring the security and authenticity of

the transaction. First, when a user initiates a transaction through a wallet (such as registering ownership of real estate), the transaction details are first hashed and then the hash is signed using the user's private key to generate a digital signature. This private key is always stored in MetaMask and never leaves the user's device or browser. Next, when a transaction is broadcast to the Ethereum network, other nodes can use the sender's public key to verify that digital signature. If the signature verification is successful, this indicates that the transaction was indeed initiated by the holder of the private key and was not tampered with during the signing process. This process also brings several security guarantees:

(i) Privacy of the private key: The user's private key is always confidential, stored only on the user's device. Without the private key the user cannot generate a valid digital signature, thus ensuring the authenticity of the transaction.

(ii) Unforgeability: Since the digital signature is generated based on the transaction content and private key, it is unique. Any small change to a transaction will result in a completely different signature, preventing malicious tampering.

(iii) Public key verification: Anyone can verify the signature by knowing the sender's public key (available from their Ethereum address), but cannot recreate the signature using the public key.

In this way, the system not only ensures the security and transparency of the transaction, but also maintains the unforgerability of the transaction and the security of the authenticator's identity. By combining preliminary preparation work and security considerations, we will convert the main functions of the real estate platform designed in this paper into smart contracts in preparation for deployment on the blockchain.

5 The implementation of the real estate time-stamping and registration platform

Based on the framework presented in section 4, a time-stamping and blockchain land registration platform has been developed. Fig. 6 shows the overall platform design. It consists of four key components, including the browser, the web server(Front-end), the provider, and the blockchain layers as detailed below.

Browser: The client-side provides users who come to the platform with functions such as connecting to their virtual currency wallets, authenticating and registering, logging in and out, viewing their accounts, and checking the real estate of interest. In order to achieve the goal of a good user experience, we have designed a user interface. Through RPC and backend docking, the platform can achieve a complete smart contract and user UI interaction interface.

Front-end: The two main libraries used are web3.js and ethers.js, which take the input from the user and build the request sent to the smart contract. The front end is the interface and object that interacts with the blockchain, such as calling smart contracts, checking account balances, etc. We write the front-end code to develop the web application, which is an application developed in html and js. The ethers.js library

is embedded in the front-end pages of the platform, and the ethers.js library is used to operate the Metamask wallet and call contracts to interact with the blockchain.

Provider/signer: The provider can read data from the blockchain, it provides a node in order to enable the front-end to connect to the blockchain and interact with the smart contracts in the blockchain. Usually, the signer is needed to upload data.

Blockchain layer: The blockchain contains smart contracts, Ethernet virtual machines and all information stored on the blockchain, among which smart contracts are the most important part of the blockchain. We deploy smart contracts after connecting Remix compiler to the blockchain network and Metamask wallet, then the smart contracts will be deployed on the blockchain by Remix compiler.

In the smart contract deployed at the blockchain layer for the entire platform design proposed in this paper, some key steps have been implemented in detail by the following algorithms.

User Identity Mapping UserID

Everyone who uses the platform needs to complete the 2FA and KYC check as shown in Fig.5. To use the real estate platform, the user needs to launch the virtual currency wallet and enter real information such as his/her name, ID number(passport number or driver license number), and other information. The smart contract compares the information entered by the user with the information recorded in the database through Algorithm 1.

If all the information is consistent, the matching is successful, then, the user will be successfully registered in the platform, and the user information will be registered in the blockchain.

Real Estate Identity Mapping RealEstateID

Each real estate has a unique legal document issued by the government, which contains the property number, owner's information, land map, geographical coordinates, land area, etc. Users who want to authenticate their real estate through the platform need to enter the correct real estate number and owner information. The important information will be compared with the government database through Algorithm 2 in the smart contract.

More information about real estate will also be needed such as legal documents, pictures of the house, etc. Users can time-stamp the documents and upload the hash value to the platform, which can then record the hash value and store the time-stamped documents in IPFS system instead of storing the original documents.

Real Estate Transaction

A real estate transaction method has also been developed that supports direct real estate transactions and completes the transfer of real estate ownership at the same time as the transaction is completed. The user enters the index value i of the real estate and the method helps the user to create a transaction information record

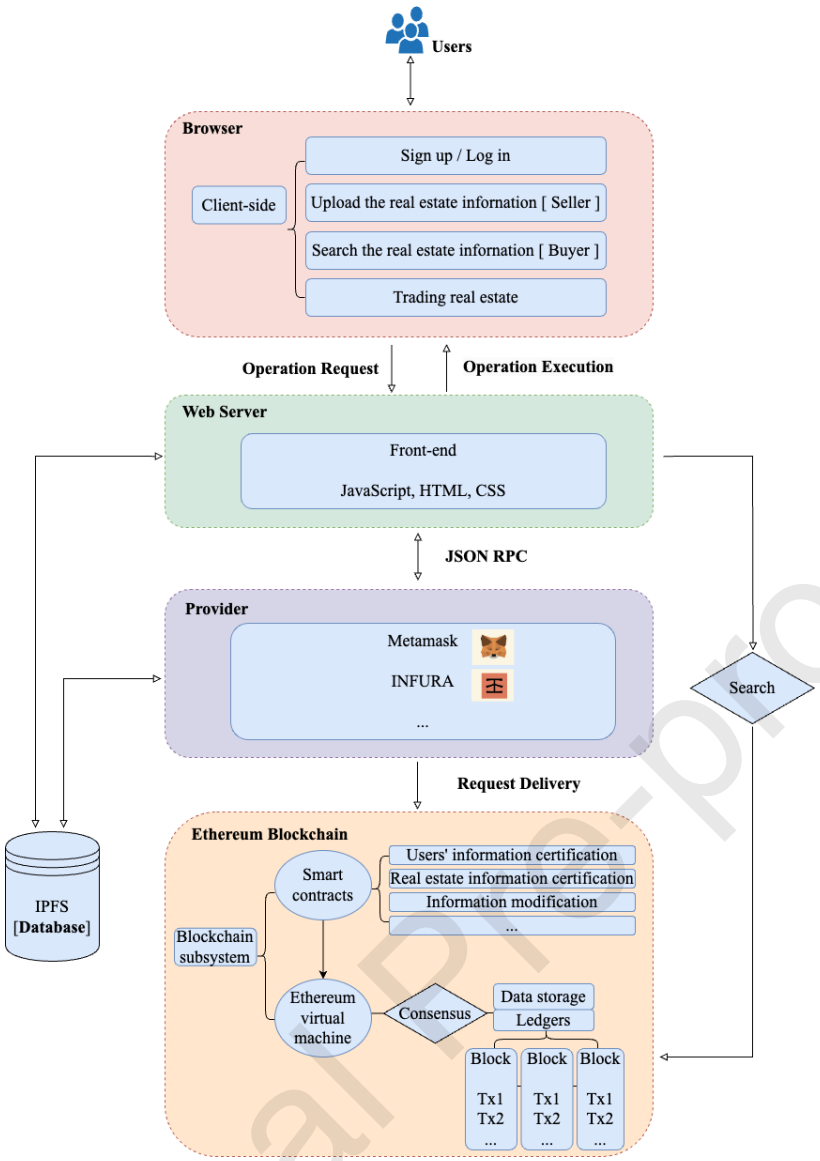

Fig. 6 Overall platform design

containing the information of both parties to the transaction, the real estate information and the block number to which the transaction belongs to facilitate the tracking of real estate transactions. Its algorithm is shown as Algorithm 3.

This method is open, and other investment platforms can call the API of this function and wrap the function to complete their own real estate transaction methods. This method can ensure that after the method is wrapped by an external call, the

Algorithm 1 User Authentication

```
Input: NameofUser (string), UserlD (string)
Output: boolean (indicates success or failure)

Begin
Initialize PROFILE_REF = UserProfileMapping[msg.sender]
if PROFILE_REF.ID is not empty then
    Return error 'This address is already registered'
else
    for each RealUser in GovernmentUser do
        if NameofUser == RealUser.UserName and UserlD == RealUser.ID then
            Add new profile to User array with details:
              UserName = NameofUser
              Who = msg.sender
              ID = UserlD
            Update PROFILE_REF with new user details
            Create a mapping for users to query personal information through wallet addresses
            Return true
        end if
    end for
    Return error 'Authentication failed'
end if
End
```

transaction amount is still determined by the user. This method can verify the seller's house ownership multiple times, and then perform the transfer operation. After the transfer is completed, the smart contract first cancels the ownership record on the platform, and then cancels the ownership record in the government database at the same time. This can ensure that the method will not cause losses to the seller after the method is attacked, such as a fallback attack.

6 Demonstrated examples

In order to better simulate the actual situation, we use the Sepolia Ethereum test network to conduct simulation experiments. The blockchain version is the third generation (3.0) which enables projects to focus on scalability (processing more transactions per second), interoperability (communicating and collaborating with other blockchains), and sustainability (adopting environmentally friendly consensus mechanisms such as proof of equity). The language used for the smart contracts is solidity and the compiler used is Remix(version is pragma solidity 0.8.17), involving 10 nodes. The security of the Sepolia Ethernet test network is underpinned by the Proof-of-Stake (PoS) mechanism.

Algorithm 2 Real Estate Authentication

Input:
RealEstateRegisterNumber, OwnerNameOfLandlord, idNumber, RealEstateAddress, RealEstatePrice, HouseDescripation, HashValue
Output: true (if authentication is successful), false (otherwise)

Begin
Initialize an array HOUSEINFO_USER from RealEstateInfoMapping associated with msg.sender
for each entry VerifyHouse in GovernmentReal **do**
    if VerifyHouse is owned by owner (VerifyHouse.IfOwner == true) **then**
        if RealEstateRegisterNumber == VerifyHouse.RegisterNumber **then**
            if idNumber == VerifyHouse.ID **then**
                if OwnerNameOfLandlord == VerifyHouse.OwnerName **then**
                    // Verify if user information matches government real estate registration database
                    Create a new entry with following details in House array:
                    RegisterNumber: RealEstateRegisterNumber
                    Who: msg.sender
                    OwnerName: OwnerNameOfLandlord
                    ID: idNumber
                    DocHashValue: HashValue
                    Address: RealEstateAddress
                    Price: RealEstatePrice
                    Description: HouseDescripation
                    IfOwner: true
                    Add the newly created entry to HOUSEINFO_USER
                    // Create a mapping for user to view their registered property details
                    Return true **// Notify frontend of successful registration**
                end if
            end if
        end if
    end if
end for
Return false
End

We build a system platform for real estate time-stamping and registration on the Ethereum blockchain network and test the authentication of user information and real estate information to verify the effectiveness of the proposed system. The architecture of the platform is described in detail in Fig. 6. Unlike web 2.0 platforms, our web 3.0-based platforms eliminate the middleman. There is no centralized database that stores the application state, and there is no centralized web server where the back-end logic resides. Web 3.0 platforms use blockchains to build applications on

Algorithm 3 Algorithm for the function TradeRealEstate

Input: Index i, Transaction amount (embedded in msg.value)
Output: Transaction information

Begin
Step 1: Initialization
Retrieve the profile of the caller from 'UserProfileMapping' using 'msg.sender' and store it in 'PROFILE_REF'.
Retrieve all real estate data from 'House' array and store it in 'RealEstateCurrent'.
Retrieve government real estate data list and store it in 'GovernmentReal_REF'.

Step 2: Precondition Checks
if PROFILE_REF.ID is empty **then**
    Return error 'User not registered'
    Exit
end if
if HouseNow[i].isOwner == false **then**
    Return error 'Not owner'
    Exit
end if

Step 3: Updating Seller Platform Records
Retrieve seller's real estate information list from 'RealEstateInfoMapping' and store it in 'HOUSEINFO_USER'.
for (uint j; j<HOUSEINFO_USER.length; j++) **do**
    if 'HOUSEINFO_USER[j]. RegisterNumber' ==
        'RealEstateCurrent[i].RegisterNumber' **then**
        Set 'IfOwner' of the matching record to 'false'.
    end if
end for

Step 4: Transaction Processing and Government Database Update
for (uint $t = 0$; $t <$ GovernmentReal_REF.length; t++) **do**
    if 'GovernmentReal_REF[t].RegisterNumber' ==
        'RealEstateCurrent[i].RegisterNumber' **then**
    if GovernmentReal_REF[t].IfOwner == false **then**
        Return error 'Not owner'
        Exit
        end if

Create a payable address from 'RealEstateCurrent[i].Who' and transfer the transaction amount 'msg.value' to it. After that, update the database.
        RealEstateCurrent[i].IfOwner = false
        GovernmentReal_REF[t].IfOwner = false
        Exit the loop
    end if
end for

Step 5: Create a new house information record and transaction record
if buyer address == PROFILE_REF.Who **then**
    Create a new record in GovernmentReal_REF with all real estate details
end if
TradeRecord.push(Record(...) // **specify the details to be recorded**
Generate mappings for transaction records
End

a decentralized state machine maintained by anonymous nodes scattered across the Internet, and its most prominent advantage is that no single entity can control this decentralized state machine, as this decentralized state machine is maintained jointly by everyone in the network. At the same time, the back-end server is replaced by the written defined application logic contained in the smart contracts deployed on the decentralized state machine.

Fig. 7 The home page and the main functions of the blockchain system platform

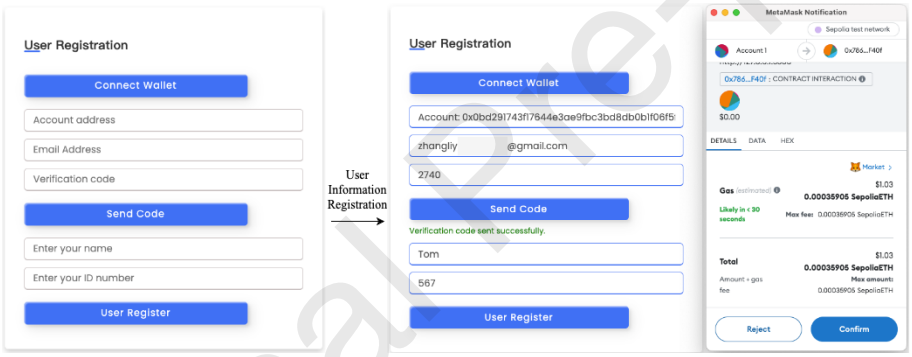

Fig. 8 The users upload the information and sign up the account

Fig. 7 shows the home page and the main functions of the system. The user enters the user registration screen from the home page and a little gas fee is consumed when submitting information as shown in Fig. 8. Buyers and sellers can view their own user information in the user profile screen in Fig. 9 after successful authentication. Sellers can upload real estate information and seller information by consuming some gas fees. If the information uploaded by smart contract authentication matches the information in the database, the real estate will be uploaded to the platform, and buyers

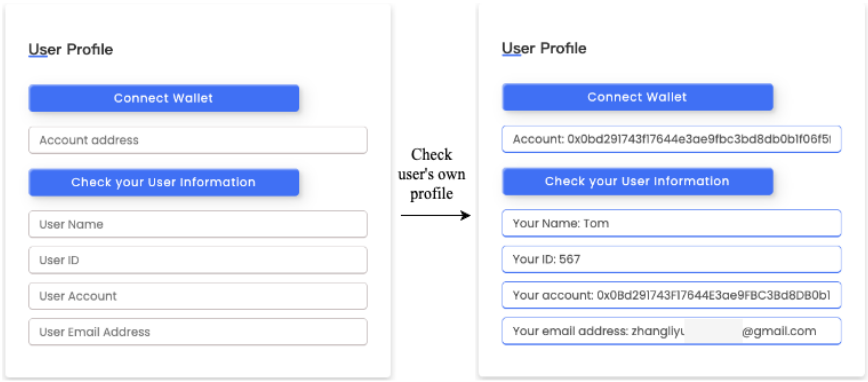

Fig. 9 Users check their own account information

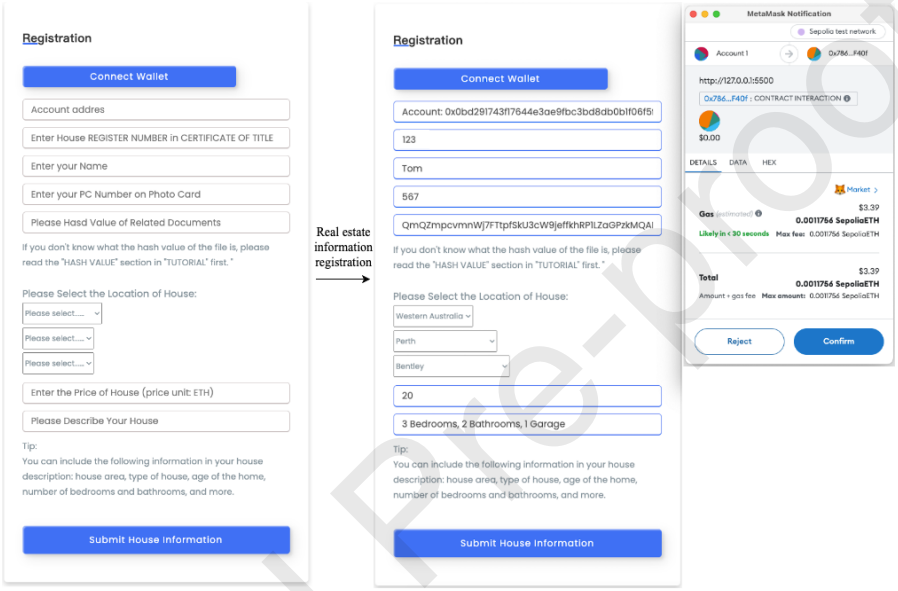

Fig. 10 The sellers upload real estate information to register the real estate

can view all the properties of interest from the search page, as shown in Fig. 10 and Fig. 11. When a buyer wants to buy a property, he/she can enter the index number in the search panel and the price of the property in the transaction panel to complete the transaction. After the transaction is completed, both buyers and sellers can view the transaction information in the "Trade History" panel, as shown in Figure 12.

In the Australian real estate transaction market, real estate investors need to pay a series of fees and taxes such as stamp duty, real estate transfer fees, brokerage fees, registration fees and so on. As different states in Australia have different policies for purchasing real estate, we take Western Australia as an example. In order to

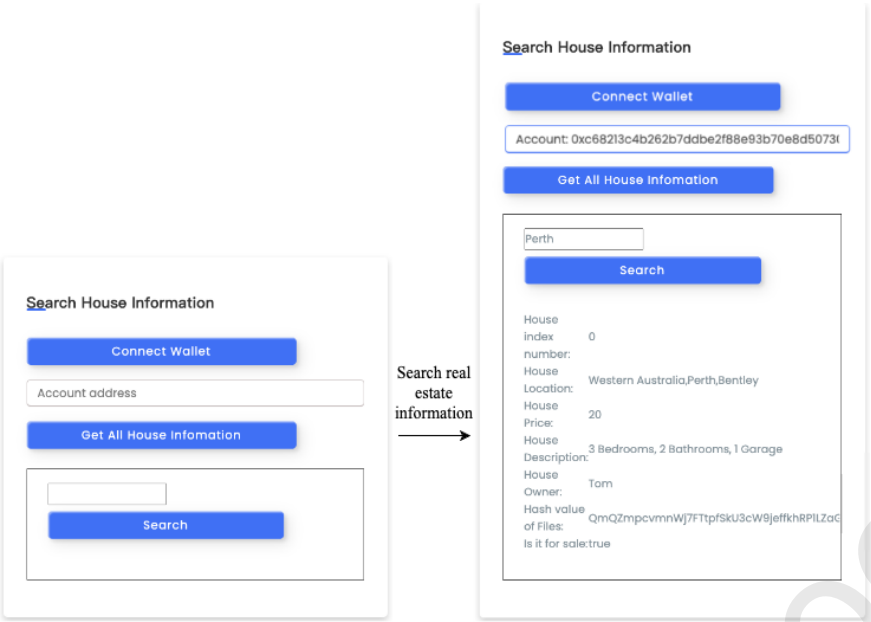

Fig. 11 The buyers search for real estate information they are interested in

Fig. 12 The users search for real estate transaction information

evaluate the cost-effectiveness of the blockchain-based real estate time-stamping and registration platform in comparison with the traditional model, we choose real estate

registration fees and trading fees in different price ranges as key parameters, since these fees are the major real estate trading costs. The price range from $600,000 to $1600,000 was chosen to ensure that most price points in the real estate market are covered, thus providing a comprehensive view.

At the real estate registration stage, the real estate registration fees under the traditional model are shown in Table 1(Exactly (2020)). For real estate transactions in Australia by the traditional model, agent fees may vary by region and agency, but generally range from 1.5% - 2% of the property sale price. These fees may include advertising and marketing expenses, as well as commissions from intermediaries.

Table 1 The real estate registration fee in Western Australia

Your Purchase Price	Registration fee
$0 - $85,000	$178.2
$85,001 - §120,000	$188.2
$120,001 - $200,000	$208.2
$200,001 - $2,000,000	$208.20 + $20 for each $100,000 or part thereof over $200,000
$2,000,001 and above	$568.20 + $20 for every $100,000 or part thereof over $200,000

Based on the price ranges, we simulated each set of data five times on the blockchain platform and derived an average value. This multiple simulation approach aims to reduce any anomalies or errors in a single simulation and ensure that the results obtained are reliable and stable. These averages are then compared to traditional certification cost data. The purpose of this evaluation methodology is to visualize the difference in registration costs and transaction costs between the blockchain-based platform and the traditional approach across a range of prices.

Fig. 13 shows the comparison of real estate registration fees by using blockchain-based real estate platform and traditional model. It is clearly that the cost of users real estate authenticating through the blockchain-based authentication registration platform is much lower than the cost of authenticating real estate through the traditional mode. In addition, it usually takes a few days to register real estate in the traditional mode, but it only takes a few minutes to register the certification through the blockchain platform, and so the time cost will be greatly reduced.

Fig. 14 shows the comparison of real estate transaction fees between the blockchain-based real estate platform and the traditional model. It is obvious that the fees for blockchain transactions do not increase linearly with real estate prices like traditional transactions, where the gas fees for transactions depend on a number of factors, including the complexity of the transaction (for example, a simple money transfer transaction has less gas consumption than a complex smart contract transaction), and the current network congestion. In addition, blockchain technology can enable faster transaction speeds and simplify the real estate transaction process, as it eliminates the need for third parties (such as intermediaries or lawyers) to verify

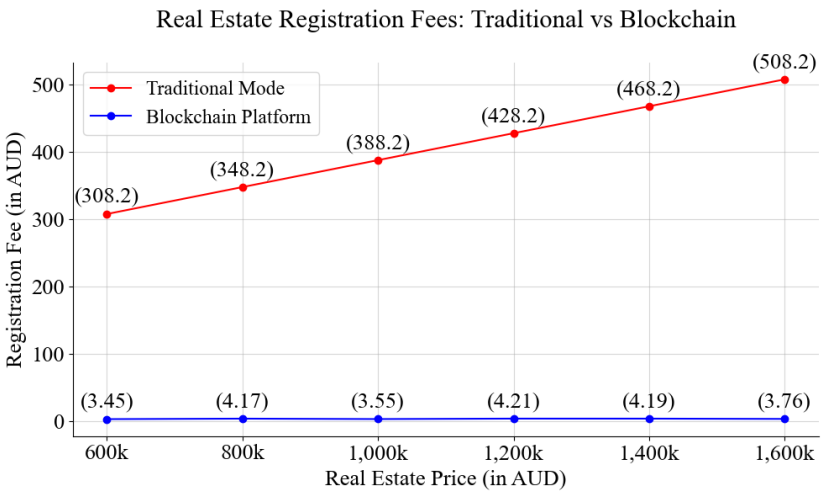

Fig. 13 Comparison of real estate registration fees between blockchain real estate platform and traditional model

transactions, and also reduces complex protocols and protocols involving multiple parties, thus making transactions simpler and more straightforward. Through the comparison of experiments, it is not difficult to realize that blockchain technology can provide more stable and predictable transaction costs for real estate transactions, and provide a better transaction environment for the real estate market.

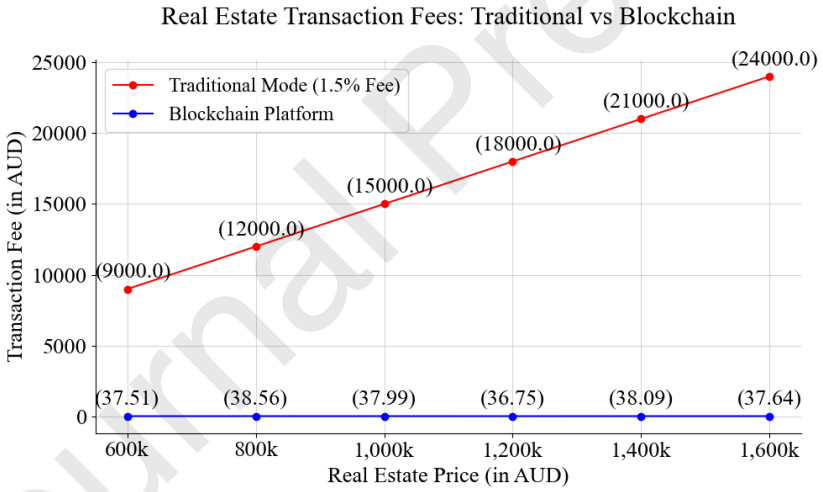

Fig. 14 Comparison of real estate trading fees between blockchain real estate platform and traditional model

By simulating user operations and comparing the cost of the blockchain-based platform with the traditional model, we demonstrated the practicality and effectiveness of our proposed platform. Our platform guarantees the authenticity of the information, simplifies the institutions and sectors involved in traditional real estate, eliminates intermediaries, reduces costs, and increases the transparency of information. Our platform not only records all reliable information, but also simplifies the complex model of traditional real estate registration and authentication, allowing users to use our platform with confidence, time and cost savings. Therefore, our platform can be applied in smart cities so that investors can check real and reliable real estate information without intermediaries.

7 Conclusion

Through our investigation of the traditional real estate registration system, we found that there are many problems in the existing system, such as cumbersome, inefficient, costly, and time-consuming. Combining real estate information registration with blockchain technology can well overcome these disadvantages, because blockchain technology is based on a distributed ledger that stores all information, which can guarantee that data is not tampered with and also can ensure higher transparency and increased reliability and security. Therefore, we propose a real estate time-stamping and registration system based on the Ethereum blockchain to improve the existing real estate registration system, which can guarantee that the privacy of buyers and sellers is not leaked and also ensure the authenticity of real estate information. We design a new network architecture and apply smart contracts to eliminate the participation of third parties to save time and reduce cost for users. Our proposed system can well overcome the weaknesses of the current real estate registration system and provide users with a secure, unchanging, transparent and convenient real estate registration system. The proposed system can be deployed in smart cities for better real estate management. While blockchain-based authentication and registration systems have unique advantages in providing transparency, security, and immutability, they also have some limitations. Here are some of the main limitations:

(i) Technology maturity: although blockchain technology has received a lot of attention and application, it is still a relatively young technology. There may be technical and security challenges that are not yet fully understood or addressed.

(ii) Complexity of key management: users must properly manage their private keys. Once a private key is lost or stolen, the assets associated with it may be permanently lost. So far, the method of retrieving the private key is based on the mnemonic recovery at the time of registration. However, if the mnemonic is also lost, then the asset may not be recovered.

(iii) Legal and regulatory issues: in many countries and regions, the legal status of blockchain technology remains unclear. This can pose challenges for businesses and organizations in practical applications.

(iv) Cybersecurity: while the blockchain itself is considered secure, the applications, wallets, and other interfaces that interact with it can become targets for attacks. This means that an entire ecosystem is only as safe as its weakest link.
(v) Interoperability: different blockchain platforms may use different technologies and standards. This can lead to interoperability issues that complicate cross-chain interactions.
(vi) Dependence on network participants: the security of a blockchain depends in part on the distributed nature of the network. If the majority of the network's computing power or participants are controlled by a small number of entities, this may increase the risk of network attacks. Although the probability of this happening is small, it is still a potential risk that cannot be ignored.

In general, blockchain-based authentication and registration systems undoubtedly offer a unique solution for ensuring the transparency, security and immutability of data. However, just as any other innovative technology that has its maturation process, the system comes with a range of potential challenges and limitations. Before fully adopting and applying this technology, we must weigh its potential benefits and risks, ensuring that their application scenarios match the characteristics and capabilities of blockchain. When we fully understand and develop blockchain technologies, we can truly realize the full potential and value of blockchain technologies.

With the established real estate timed-stamping and registration system, further research and projects is to integrate the fungible token (FT) technology in the blockchain-based trading system and business models, and to extend the technology to other areas including, for example, real estate rental investment and management and digitization of other asset types such as in-ground minerals and agricultural farms.

References

Andrew B (2022) International real estate investment. Real Estate Investment pp 291–329. https://doi.org/https://doi.org/10.1201/9781003140283-15.

Bhavyansh Sharma AM, Ranjan P (2020) Real estate management system based on blockchain. 2020 IEEE 7th Uttar Pradesh Section International Conference on Electrical, Electronics and Computer Engineering (UPCON), 27–29 November 2020

Burra M, Maity S (2022) Characteristics, advances, and challenges in blockchain-enabled cyber-physical systems. Blockchain Technology for Emerging Applications pp 67–89. https://doi.org/https://doi.org/10.1016/b978-0-323-90193-2.00008-9.

Chen Y, Li H, Li K, et al (2017) An improved p2p file system scheme based on ipfs and blockchain. 2017 IEEE International Conference on Big Data(Big Data), 11–14 December 2017

Chow YL, Tan KK (2021) Real estate insights is tokenization of real estate ready for lift off in apac. Journal of Property Investment & Finance 40(3):284–290. https://doi.org/https://doi.org/10.1108/jpif-10-2021-0087.

CoreLogic (2022) Real estate market trends. https://www.corelogic.com/.

Estevam, Gabriel, Lucas M, et al (2021) Accurate and decentralized timestamping using smart contracts on the ethereum blockchain. Information Processing & Management 58(3):102741. https://doi.org/https://doi.org/10.1002/jcaf.22365.

Exactly (2020) How to calculate wa stamp duty. https://exactly.loans/calculate-wa-stamp-duty/

Gutierrez U, Cliff O, Xu GX (2022) Blockchain and smart contracts to secure property transactions in smart cities. Applied Sciences 13(1):66. https://doi.org/https://doi.org/10.3390/app13010066.

Han CS, Erickson J, Wang K (2003) Real Estate Investment Trusts: Structure, Performance, and Investment Opportunities. Oxford University Press, New York

Kara M, Laouid A, Hammoudeh M (2023) An efficient multi-signature scheme for blockchain. Cryptology ePrint Archive

Khoa Tan V, Nguyen T (2022) The real estate transaction trace system model based on ethereum blockchain platform. 2022 14th International Conference on Computer and Automation Engineering (ICCAE), 25–27 March 2022

Latifi S, Zhang YP, Cheng XC (2019) Blockchain-based real estate market: One method for applying blockchain technology in commercial real estate market. 2019 IEEE International Conference on Blockchain (Blockchain), 14–17 May 2019

Lazuashvili N, Norta A, Draheim D (2019) Integration of blockchain technology into a land registration system for immutable traceability: A casestudy of georgia. Business Process Management: Blockchain and Central and Eastern Europe Forum 361:219–233. https://doi.org/https://10.1007/978-3-030-30429-4_15.

Montgomery N, Graham S, Iqbal S (2018) Disruptive potential of real estate crowdfunding in the real estate project finance industry. Property Management 36(5):597–619. https://doi.org/https://doi.org/10.1108/pm-04-2018-0032.

Nuta S, Schuldt JC, Nishide T (2023) Pos blockchain-based forward-secure public key encryption with immutable keys and post-compromise security guarantees. IEICE Transactions on Fundamentals of Electronics, Communications and Computer Sciences 106(3):212–227

Park I (2020) A study on the utilization of real estate blockchain to the real estate transaction - focusing on the propy case of international real estate transaction in the united states -. Journal of the Korea Real Estate Management Review 21:115–152. https://doi.org/https://doi.org/10.37642/jkremr.2020.21.6.

Platt M, McBurney P (2023) Sybil in the haystack: a comprehensive review of blockchain consensus mechanisms in search of strong sybil attack resistance. Algorithms 16(1):34

Rao F, Wang LM, Huo XS, et al (2022) An improved biometric fuzzy signature with timestamp of blockchain technology for electrical equipment maintenance. Energy Engineering 119(6):2621–2636. https://doi.org/https://doi.org/10.32604/ee.2022.020873.

Rogers M (2020) Tokenization of the japanese real estate market. The Definitive Guide to Blockchain for Accounting and Business: Understanding the Revolutionary Technology pp 177–207. https://doi.org/https://doi.org/10.1108/978-1-78973-865-020201010.

Shahrokhi M, Parhizgari AM (2019) Crowdfunding in real estate: Evolutionary and disruptive. Managerial Finance 46(6):785–801. https://doi.org/https://doi.org/10.1108/mf-10-2018-0492.

Shashank J, Choudhury A (2022) Tokenization of real estate assets using blockchain. International Journal of Intelligent Information Technologies 18(3):1–12. https://doi.org/https://doi.org/10.4018/ijiit.309588.

Takatsugu k (2017) Possibility of new real estate registration system by using blockchain. The Japanese Journal of Real Estate Sciences 33(1):72–77. https://doi.org/https://doi.org/10.5736/jares.31.1_72.

Thota S (2019) Blockchain for real estate industry. The Journal of Social Sciences Research 52(1):53–56. https://doi.org/https://doi.org/10.32861/sr.52.53.56.

Tian Z, Li M, Qiu M, et al (2019) Block-def: A secure digital evidence framework using blockchain. Information Sciences 491:151–165

Ting Y, Lin ZW, Tang QL (2018) Blockchain: The introduction and its application in financial accounting. Journal of Corporate Accounting & Finance 29(4):37–47. https://doi.org/https://doi.org/10.1002/jcaf.22365.

Veuger J (2018) Trust in a viable real estate economy with disruption and blockchain. Facilities 36(1/2):103–120. https://doi.org/https://doi.org/10.1108/f-11-2017-0106.

Veuger J (2020) Dutch blockchain, real estate and land registration. Journal of Property, Planning and Environmental Law 12(2):93–108. https://doi.org/https://doi.org/10.1108/jppel-11-2019-0053.

Wang S, Ouyang LW, Yong Y, et al (2019) Blockchain-enabled smart contracts: Architecture, applications, and future trends. IEEE Transactions on Systems, Man, and Cybernetics: Systems 49(11):2266–2277. https://doi.org/https://doi.org/10.1109/tsmc.2019.2895123.

Witzig P (2019) Cutting out the middleman: A case study of blockchain technology induced reconfigurations in the swiss financial services industry. Blockchains, Smart Contracts, Decentralised Autonomous Organisations and the Law pp 18–48. https://doi.org/https://doi.org/10.4337/9781788115131.00008.

Wouda, Pieter H, Opdenakker R (2019) Blockchain technology in commercial real estate transactions. Journal of Property Investment & Finance 37(6):570–579. https://doi.org/https://doi.org/10.1108/jpif-06-2019-0085.

Xie M, Liu J, Chen S, et al (2023) A survey on blockchain consensus mechanism: research overview, current advances and future directions. International Journal of Intelligent Computing and Cybernetics 16(2):314–340

Xu G, Zhang J, Cliff UGO, et al (2022) An efficient blockchain-based privacy-preserving scheme with attribute and homomorphic encryption. International Journal of Intelligent Systems 37(12):10715–10750

Conflict of interest statement

All authors disclosed no relevant relationships.