

Property and Pixels: Redefining Real Estate in the Digital Era

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Abstract. This paper addresses the systemic inefficiencies of the traditional real estate system, such as manual processes, intermediary reliance, and lack of transparency, by exploring the integration of blockchain technology. We propose a paradigm shift in real estate transactions management through blockchain's decentralized nature, which enhances transparency, security, and efficiency. Our significant contribution is the development of an RSA-encrypted Non-Fungible Token (NFT) framework tailored for real estate transactions. This framework prioritizes security and privacy by using RSA encryption to protect sensitive transaction data and personal information, ensuring access only to authorized entities with corresponding private keys. We extend this security to image and text-based NFTs, ensuring robust property representation. Additionally, the framework's deployment across multiple Ethereum Virtual Machine (EVM)-supported platforms demonstrates its versatility and adaptability. Our research presents a groundbreaking approach in blockchain-based real estate transactions, offering a novel solution that mitigates risks associated with both traditional and digital methods in the real estate sector.

Keywords: Blockchain · Non-Fungible Tokens (NFTs) · Real Estate Management · RSA Encryption · Social Computing · InterPlanetary File System (IPFS) · Smart Contracts

1 Introduction

The traditional real estate system, while foundational to property ownership and transfer, has long been encumbered by a variety of systemic inefficiencies. At its core, the conventional process is mired in manual documentation, intermediaries, and a lack of transparency that often leads to protracted transaction times and increased susceptibility to fraud [4]. The reliance on paper-based records and in-person verifications not only adds layers of complexity but also creates opportunities for discrepancies and manipulation of critical documents. Such constraints not only impede the fluidity of property transactions but also

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impact the overall dynamism of the real estate market [6]. Moreover, the traditional system's limitations are further exacerbated when it comes to cross-border transactions, where the involvement of multiple intermediaries, each with their own sets of rules and regulations, can significantly escalate costs and complicate due diligence processers [5]. In an increasingly globalized economy, these barriers present substantial challenges for investors and buyers looking to operate in international markets. The opacity of transactions and the centralized nature of record-keeping in such a system can also result in a lack of trust between parties, making the need for innovation in this sector both urgent and clear [21].

The advent of blockchain technology offers a promising solution to these entrenched challenges, presenting a paradigm shift in how real estate transactions can be managed. The decentralized nature of blockchain introduces a level of transparency and security hitherto unattainable, paving the way for a system where transactions are immutable, verifiable, and executed with unparalleled efficiency [13]. The integration of blockchain into real estate has the potential to not only streamline processes but also reduce the risk of fraud, eliminate unnecessary intermediaries, and open up the market to a broader range of participants on a global scale [2].

The intersection of blockchain technology and real estate has catalyzed a paradigm shift in how property transactions are conducted, managed, and recorded [10]. Emergent studies have been pivotal in mapping the contours of this transformation, delineating the benefits and outlining the challenges associated with blockchain implementation in the real estate domain. The pioneering work of [2,16,17], and [8] has collectively underscored the potential for blockchain to revolutionize real estate transactions by enhancing transparency, efficiency, and security, while simultaneously grappling with the impediments posed by inadequate legislative infrastructures and the complex technicalities of blockchain integration. These studies contribute to a nuanced understanding of blockchain's capabilities to facilitate more streamlined, secure, and cost-effective real estate transactions.

In tandem with these technological advancements, the realm of secure transactions and data storage in real estate has been the focus of significant scholarly attention. Innovations proposed by [1,9] have demonstrated the efficacy of integrating blockchain with cutting-edge encryption algorithms to create secure platforms for peer-to-peer real estate transactions. This body of work underpins the creation of a secure, interoperable framework that upholds the confidentiality of personal and financial details, a crucial consideration in the real estate sector. Adding to the corpus of blockchain real estate literature, [20,21], and [11] have introduced systems like 'BlockYards' and blockchain-based authentication schemes that aim to eradicate traditional land registry and contract management system inefficiencies. These systems are designed to ensure the integrity and immutability of asset transactions, fostering a conducive environment for trustworthy and transparent real estate dealings.

As the concept of tokenization and the use of Non-Fungible Tokens (NFTs) in real estate gain traction, studies such as [7,19], and [14] have become increasingly

pertinent. They have laid the groundwork for frameworks that utilize blockchain technology to inject liquidity, transparency, and security into real estate investments and transactions, reshaping the industry to accommodate a more open, efficient, and secure market.

Amidst this backdrop of innovative research, our contribution stands out by addressing the imperative need for security and privacy in blockchain-based real estate platforms. Our study introduces an RSA-encrypted NFT framework for real estate transactions, aiming to bolster anonymity, transaction confidentiality, and interoperability. By leveraging RSA's cryptographic strength, we ensure that such data are securely encrypted, rendering them accessible only to authorized parties who possess the corresponding private keys. This methodology is crucial in mitigating risks such as data breaches and unauthorized access, which are prevalent concerns in digital transactions. Furthermore, our framework extends its security measures to the two most common types of NFTs used in real estate: images and text. By providing a detailed encryption process for both, we cater to the diverse needs of the real estate market, ensuring that all forms of property representation are securely managed and transferred. In addition to enhancing security and privacy, our use of NFTs in representing property titles offers several benefits. Each NFT serves as a unique and tamper-evident digital record of property titles, ensuring the authenticity and provenance of assets in the blockchain ledger. This approach significantly reinforces the trustworthiness and reliability of digital property records, a critical factor in real estate transactions. Moreover, to ascertain the effectiveness and applicability of our RSA-encrypted NFT framework, we conduct a comprehensive deployment across four Ethereum Virtual Machine (EVM)-supported platforms (i.e., BNB, Fantom, Celo, and Polygon). This extensive testing aims to identify the most suitable platform that aligns with our framework's objectives, taking into account factors such as transaction speed, cost-efficiency, and platform stability. By doing so, we provide a practical and versatile solution that can be adapted to various blockchain ecosystems, further emphasizing our framework's flexibility and adaptability.

Concluding our introduction, in the rest of the paper, the following sections of this paper will critically examine related work to position our contribution within the existing body of research; delineate our approach by detailing the RSA-encrypted NFT framework in Sect. 3; rigorously evaluate its performance across varied scenarios in Sect. 4; discuss the potential threats to its validity, and finally, synthesize our findings to draw meaningful conclusions in the last two sections.

2 Related Work

2.1 Blockchain Technology Implementation in Real Estate

In the burgeoning field of blockchain application in real estate, several studies have laid the groundwork for understanding and overcoming the challenges inherent in implementing this technology. The study by [2] delves into the potential for blockchain to enhance public administration, particularly in real estate

registration in Kazakhstan. It underscores the technology's capacity to bolster transparency and efficiency while also serving as a tool to curb corruption and reduce transaction costs. However, the paper brings to light significant impediments such as inadequate legislative frameworks and the technical complexities of integrating blockchain with existing systems. Complementing this analysis, [17] argues for a balanced approach between public and private interests in the realm of real estate registration. The proposed measures aim to augment the reliability of real estate registers and secure property circulation through wider blockchain adoption. This study employs comparative legal research, legal modeling, and economic analysis of law to propose modernization vectors for real estate registration, including the innovative use of virtual and augmented reality technologies for property accounting.

Meanwhile, [16] provides an empirical basis for the discussion, examining the application of blockchain in the real estate sector through the study of existing practices and specific cases. This paper articulates the advantages and potential pitfalls of blockchain, highlighting the efficiency and security it brings to real estate transactions and its role in financing mechanisms. It suggests that blockchain technology streamlines real estate transactions, rendering them faster, more secure, and cost-effective. Lastly, [8] offers a unique perspective from Kosovo, exploring the factors that influence the adoption of blockchain in real estate transactions. Through a quantitative methodology involving a stratified probability sample of buyers and sellers, the study reveals that transparency and cost reduction are the most significant factors driving the intention to adopt blockchain. The paper posits that blockchain can facilitate transparent and errorless interactions in the real estate market, reduce costs by eliminating intermediaries, and increase trust between parties, thereby serving as a deterrent against corruption and money laundering in property investments.

These studies collectively indicate a growing recognition of blockchain's transformative potential in real estate transactions, while also acknowledging the challenges that need to be addressed for its successful implementation. They contribute to a comprehensive understanding of how blockchain technology can revolutionize the real estate sector by making transactions more transparent, secure, and efficient.

2.2 Blockchain for Secure Transactions and Data Storage

The integration of blockchain technology for enhancing security and data storage in real estate transactions has been a focal point of research, as evidenced by several studies that propose innovative solutions to address these challenges. In the work presented by [9], the fusion of blockchain with artificial intelligence is explored to develop a secure platform for peer-to-peer (P2P) real estate transactions. This study ventures into creating an encryption algorithm that is validated through blockchain's consensus process, specifically the practical Byzantine fault tolerance (PBFT) algorithm of Hyperledger, to safeguard the contract verification process. The utilization of virtual machines for blockchain real estate contracts and quantum cryptography for communication are among the methods

applied to automate and test the security features. Additionally, [1] identifies the risk involved in sharing private and financial details within the real estate sector and proposes a blockchain architecture integrated with an optimized attribute-based encryption technique, termed as geometric octal zones distance estimation (GOZDE), to secure real estate information. The paper demonstrates the effectiveness of combining blockchain with the ABE technique to provide a potent solution for storing and transferring sensitive data securely.

Further contributions from [20] introduce 'BlockYards', a blockchain-powered system that seeks to establish a publicly accessible platform for verified real estate transactions on the Ethereum Blockchain. This system aims to address property scams and unauthorized claims by ensuring the integrity and immutability of asset transactions using consensus mechanisms. BlockYards also incorporates Machine Learning decision models to predict the real value of properties, thereby promoting accurate real estate price estimations and transparency in the online property market. The research presented by [21] delves into the authentication threats prevalent in traditional land registry systems and proposes a blockchain-based security scheme to enhance the authenticity and security of real estate land transaction data. By focusing on the shortcomings of centralized systems, the study suggests blockchain as a viable solution to the inherent issues of authentication in land transactions. Also, [11] addresses the risks associated with real estate contracts, especially online, by implementing a blockchain-based system using the zero-knowledge proof algorithm. The system aims to maintain the low cost and high efficiency of online transactions while ensuring the reliability and confidentiality of the contract information. By solving scalability issues with blockchain technology, this system offers a secure online contract management system that prevents fraud throughout the contract lifecycle.

These studies collectively underscore the potential of blockchain technology to revolutionize the security and data storage aspects of real estate transactions. They demonstrate how blockchain can be leveraged to develop secure, efficient, and transparent systems for managing sensitive transaction data in the real estate sector.

2.3 Blockchain and Real Estate Market/Platform Development

The transformative potential of blockchain technology in the real estate sector, specifically through the use of smart contracts, has been a significant point of focus in recent literature. The studies by [5,22], and [13] explore various facets of this integration, from conceptual frameworks to legal challenges and the broader implications for property rights. In the same spirit, The adoption of blockchain for market and platform development in real estate is not just theoretical but increasingly practical, as evidenced by recent research contributions in the field. These studies offer innovative approaches to redefining the real estate market, addressing long-standing challenges such as inefficiency, lack of transparency, and the high cost of transactions.

In the work of [3], blockchain technology is touted as a transformative force in real estate document storage. The study highlights the vulnerabilities of paper-based documentation to forgery and manipulation, especially in high-profile real estate transactions. The paper champions blockchain as a solution that maintains a complete history of real estate transactions and registrations via smart contracts. By digitizing property records, blockchain promises to expedite transaction times from months to mere seconds, heralding significant societal impacts. Building on this foundation, [12] proposes a Real Estate Transaction Trace (RETT) system model that revolutionizes the traditional real estate transaction process in Vietnam. The RETT model facilitates the management and tracking of real estate transactions across all participants, leveraging a blockchain network architecture, distributed ledger, and smart contracts. This system model aims to digitize assets, store decentralized transaction histories, and provide direct transactions between parties, thereby eliminating intermediaries and fostering mutual trust. Also, [18] presents a systematic literature review and thematic content analysis to understand recent blockchain developments and real-world applications in real estate. While the conceptual literature predicts blockchain as a disruptive technology for real estate, empirical applications suggest its incremental adoption in hybrid settings. The paper reveals that blockchain's conceptual benefits are yet to be fully realized empirically but notes the technology's potential to enhance efficiency, reduce transaction times, and increase security and trust, even in smaller-scale applications. Lastly, [15] explores the potential of blockchain in the commercial real estate market, recognizing the liquidity and global access issues that currently limit investor participation. The study concludes that blockchain and smart contracts can resolve classical real estate challenges, proposing a more stable-priced market that benefits tenants, owners, and investors alike.

2.4 Tokenization and NFTs in Real Estate

The topic of tokenization and the use of Non-Fungible Tokens (NFTs) in real estate has been a novel area of exploration, seeking to address the inherent limitations of real estate transactions and ownership records. The studies by [7,19], and [14] have contributed significantly to this emerging field, proposing frameworks that utilize blockchain technology to bring liquidity, transparency, and security to real estate investments and transactions.

[19] introduces a crypto NFT framework specifically tailored for real estate, aiming to tackle the prevalent issues of data availability and veracity. Traditional real estate transactions often suffer from outdated or manipulated data, which can lead to economic disparities. In a similar vein, [7] addresses the issue of liquidity in real estate investments. Real estate assets are typically illiquid compared to stocks, deterring many potential investors. The paper advocates for the tokenization of real estate using blockchain technology, which can transform real estate into a more liquid investment through the creation of security tokens representing fractional ownership. Finaly, [14] envisions a reshaped real estate industry through blockchain adoption. The current real estate industry,

while significant for economic growth, is riddled with complexities and a lack of transparency in transactions. Blockchain technology offers a solution by digitizing property-related information and hosting it on a decentralized database, reducing fraud and inaccuracies. This transformative approach aims to eliminate the potential for deception during sales, rentals, and leases, thereby achieving a digitized and trustworthy environment for all real estate operations.

2.5 Our Contribution

Security and privacy are paramount concerns in blockchain-based real estate platforms, where sensitive data and high-value transactions necessitate robust protection mechanisms. The study by [1] acknowledges the critical importance of preserving user identity and transaction confidentiality.

Our contribution to this landscape of blockchain real estate solutions lies in fortifying the security and privacy foundation laid by prior research. We introduce an RSA-encrypted NFT framework for real estate transactions that not only builds upon the necessity for anonymity and transaction confidentiality but also integrates the dimension of interoperability and transparency. In this version, we deploy the two versions of the NFT - image and text for the encryption process. By employing RSA encryption, our approach ensures that sensitive transaction data and personal information are securely encrypted and accessible only to authorized parties holding the corresponding private keys. Furthermore, the use of NFTs for property representation adds an extra layer of security, as each NFT is unique and tamper-evident within the blockchain, thereby ensuring the authenticity and provenance of property titles.

The combination of RSA encryption and NFTs creates a dual shield against both identity theft and transaction fraud, addressing the urgent need for enhanced security measures in the rapidly evolving real estate sector. Our methodology's deployment in a blockchain-based real estate platform not only promises improved privacy and security but also introduces benefits such as copyright protection and anti-tampering features. The result is a sophisticated, secure, and user-centric platform that significantly reduces the risks associated with traditional and digital real estate transactions.

3 Approach

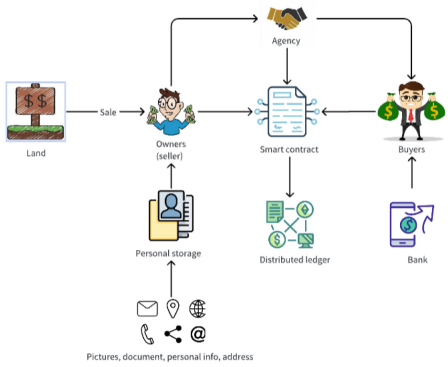
Incorporating the principles of blockchain technology into real estate transaction processes, we introduce an approach that caters to the three main players: the landowner, agency, and buyer. Within this scheme, the agency acts as a trusted entity, orchestrating smart contracts and managing public keys, ensuring a seamless and secure transaction environment. The approach is divided into two intricate phases.

3.1 Phase 1: Blockchain-Based Identification of Prospective Buyers

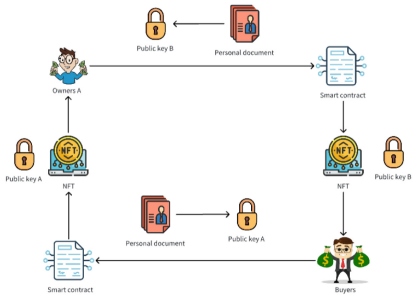
Figure 1a presents our proposed architecture for the first phase real estate transactions by integrating blockchain technology and smart contracts, depicting a shift from the traditional model to a more streamlined and secure approach. The proposed architecture demonstrates a decentralized system where various stakeholders interact through a blockchain-enabled platform, fundamentally transforming the way property sales are conducted.

At the outset of the transaction, we have the land indicating its intrinsic and appreciative value. The owners, denoted as 'Owners A', initiate the sale. Unlike the traditional process, the owners here are equipped with digital tools that empower them to manage their transaction (i.e., generating as an NFT digital asset) with greater autonomy and efficiency. The central node in this architecture is the 'Agency', which, unlike traditional agencies, operates within a blockchain framework. The agency's role is redefined from being a mere intermediary to a facilitator of the smart contract execution. It provides the platform and the necessary blockchain infrastructure to execute the transaction, ensuring compliance, due diligence, and enforceability of the contract terms.

'Buyers B' are the counterparts in the transaction, seeking ownership of the land. In this new model, buyers interact with the blockchain-based system, where they can verify property details, ownership history, and transaction validity in a transparent and immutable manner. The buyer's engagement with the blockchain platform streamlines the process, enabling a faster and more secure transaction. A key component of this architecture is the 'Smart Contract', which encodes the terms of the sale agreed upon by the buyer and the seller. Smart contracts automate the transaction process, executing predefined conditions without the need for intermediary verification. This contract acts as a self-enforcing agreement that triggers actions such as transfer of ownership and release of funds upon satisfaction of contractual terms.



(a) Phase 1: Prospective buyer identification process



(b) Phase 2: RSA-Encrypted NFT Framework for Real Estate Transactions

Fig. 1. RSA&Blockchain-Enhanced Real Estate Transaction Architecture

Underpinning the entire system is the 'Distributed Ledger', a decentralized database that records all transactions across multiple sites, countries, or institutions. All participants have access to the distributed ledger and its immutable record of transactions, ensuring transparency and trust in the system. The ledger records every aspect of the transaction from the initial listing to the final transfer of ownership, including any amendments or disclosures required by law. The 'Personal Storage' represents a secure repository for the sellers, where they can store their personal information, property documents, pictures, and more. This storage is linked to the blockchain, providing a secure way to access and share information as needed for the transaction while maintaining privacy and control over personal data.

The architecture also includes traditional financial institutions like banks, which are now integrated into the blockchain system. Banks facilitate the financial aspect of the transaction, processing payments through secure channels that interface with the blockchain platform. The integration ensures that funds are transferred only upon fulfillment of the smart contract terms, thus safeguarding the interests of all parties involved.

3.2 Phase 2: Facilitating the Transaction Between Owner and Buyer

Figure 1b illustrates the second phase of our proposed approach to secure real estate transactions using a blockchain-based architecture that incorporates Non-Fungible Tokens (NFTs) encrypted with RSA public-key cryptography. This phase represents an advanced progression in the transaction process, harnessing the capabilities of blockchain to enhance security, transparency, and trust between parties involved in the real estate market.

The architecture delineates a flow of information and value facilitated by cryptographic principles and smart contract automation. At the beginning of this process, we see the owners, labeled 'Owners A', who are ready to engage in the sale of their property. They hold the initial key to unlocking the transaction process - their public key, symbolized by a lock with a keyhole. This public key is part of the RSA encryption mechanism that secures the transaction, ensuring that only the intended parties can access the sensitive information involved in the deal.

The owners' first step in this digital transaction is to encrypt their personal documents, which likely include identity verification, proof of property ownership, and legal documents that substantiate their right to sell the property. These documents are encrypted using the public key of the prospective buyer ('Public key B'), guaranteeing that the sensitive information contained within can only be decrypted and viewed by the holder of the corresponding private key, ensuring confidentiality and data protection. Once the personal documents are encrypted and thus secured, they are then tied to a smart contract. This smart contract is a self-executing contract with the terms of the agreement directly written into lines of code. It exists across the blockchain network; it is distributed and replicated on each node, making it immutable and tamper-proof. The smart contract contains logic that dictates the conditions under which the property will

be sold, including verification of payment, transfer of ownership, and release of the encrypted documents to the buyer.

Central to this architecture is the use of NFTs. Here, an NFT is created to represent the property, which is a unique and non-interchangeable unit of data stored on the blockchain that certifies a digital asset to be unique and therefore not interchangeable. The NFT can represent the property's title deed, embodying the ownership rights that will be transferred from the seller to the buyer. The creation of the NFT itself is an action triggered by the smart contract, once all predefined conditions are met.

The NFT, once created, is encrypted using the seller's public key ('Public key A') to ensure that it remains secure and tamper-proof until the transaction conditions are fulfilled. This NFT is then sent to the buyer, but it remains encrypted - and thus, inaccessible - until the buyer fulfills their part of the contract, such as making the payment. The smart contract monitors for the fulfillment of these conditions and, upon their completion, will execute the transfer of the NFT to the buyer's control, simultaneously decrypting the NFT so that the buyer can assume ownership of the property. 'Buyers B' is depicted receiving the NFT, which signifies the completion of the transaction. At this point, the buyer has assurance of the authenticity and uniqueness of their new asset thanks to the blockchain's transparency and the NFT's non-fungibility. The RSA encryption ensures that during this transaction, the integrity and security of the personal documents and property rights were maintained.

This phase of the architecture showcases a sophisticated blend of blockchain technology, RSA encryption, and NFTs to create a seamless, secure real estate transaction process. It not only simplifies the transaction but also introduces a level of security and trust that traditional methods struggle to provide. By leveraging these technologies, we see the potential for a significant reduction in fraud, an increase in transaction speed, and a marked improvement in the accuracy of record-keeping within the real estate domain.

4 Evaluation Scenarios

4.1 Performance Evaluation of RSA-Encrypted NFT Framework

The evaluation of our RSA-encrypted NFT framework for real estate transactions, focusing on two distinct scenarios—a 120 KB image and the text "Hello, RSA encryption!"—offers an in-depth look into the framework's performance across three critical experiments: Generating RSA key, Encrypting, and Decrypting. This performance analysis provides valuable insights into the framework's efficiency and robustness, particularly when handling diverse data types commonly encountered in real estate transactions.

For the image data (Table 1), the RSA key generation process exhibited a consistent performance, with an average time of approximately 101.87 ms and a relatively stable standard deviation of 6.05 ms. This consistency in key generation is crucial, as it lays the foundation for a secure encryption environment. The

Table 1. RSA Key Generation, Encrypting, and Decrypting for Image Data

RSA with image (ms)	1	2	3	4	5	6	7	8	9	10
Generating RSA key	99.142	94.958	100.969	105.679	106.379	110.745	96.81	105.778	106.355	91.907
Encrypting image	77.859	72.325	70.633	80.696	73.735	70.382	74.502	78.371	77.778	77.077
Decrypting image	590.165	617.779	620.544	645.72	666.376	674.631	647.898	585.451	680.482	681.03

encryption of the image data, averaging around 75.34 ms, and a standard deviation of 3.53 ms, further demonstrates the framework's capability to efficiently handle larger and more complex data types. However, the decryption time for the image data was significantly higher, averaging at 641.01 ms. The higher standard deviation of 35.95 ms in this phase indicates a greater variability in processing times, likely attributable to the complexity and size of the image file.

In stark contrast, the text data "Hello, RSA encryption!" was processed much more swiftly, with an average processing time of just 5.50 ms (see Table 2). The standard deviation, although proportionally large relative to the mean time, was minimal in absolute terms at 3.03 ms, suggesting a fairly consistent performance across different instances.

Table 2. RSA Key Generation, Encrypting, and Decrypting for text

RSA with text (ms)	1	2	3	4	5	6	7	8	9	10
Generating RSA key	72.36	99.867	96.377	107.134	82.157	73.38	76.844	100.155	78.44	84.858
Encrypting text	0.162	0.166	0.175	0.157	0.18	0.159	0.137	0.147	0.145	0.151
Decrypting text	1.036	1.049	0.854	0.915	1.143	0.999	0.862	1.182	0.939	1.171

These findings underscore the framework's adaptability and scalability. The substantial disparity in processing times between the image and text data highlights the impact of data size on encryption and decryption efficiency. While the framework demonstrates excellent performance in key generation and text data processing, it also capably handles the more resource-intensive image data encryption and decryption processes. This balance of efficiency and reliability in handling varying data sizes is pivotal for its application in real estate transactions, where both images and textual data play significant roles.

Overall, the RSA-encrypted NFT framework presents a promising solution for securing real estate transactions, showcasing the ability to effectively manage diverse data types with varying complexities. Its performance in these evaluations indicates its potential to transform the landscape of real estate transactions, making them more secure, efficient, and adaptable to the evolving needs of the industry.

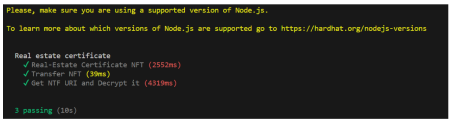
4.2 Land Certificate (i.e., NFT) Journey

As illustrated in Fig. 2, the first step involves the creation of the NFT corresponding to a real-estate certificate. During this phase, a smart contract function is called upon to mint the NFT, encapsulating within it all the relevant

```
it("Real-Estate Certificate NFT", async function () {
  const data = {
    name: "Real estate 1",
    address: "address 1",
    price: 300.000,
    owner: "Owner ID A",
    buyer: "Buyer ID B",
    agency: "agency XYZ",
    time: "12:00:00 GMT+7",
    date: "6th Oct, 2023",
  };
  const options = {
    pinataMetadata: {
      name: "Real estate certificate.json",
    },
    pinataOptions: {
      cidVersion: 0,
    },
  };
```

Fig. 2. Step 1: Real-Estate Certificate NFT

property information and attributes. The minting process is integral, serving as the genesis of the digital certificate that will represent the real estate asset on the blockchain.



(a) Step 2: Hash key generation



(b) Step 3: Uploading NFT to IPFS

Fig. 3. Land certificate (i.e., NFT) Journey in IPFS

In second step, Fig. 3a depicts the subsequent step where a unique hash key is generated. This hash key is fundamental to the NFT's identity, acting as a digital fingerprint that ensures the token's uniqueness and authenticity. The process of hash generation is a cryptographic measure that adds a layer of security, making it computationally infeasible to reverse-engineer or duplicate the NFT.

The journey continues with step three, as shown in Fig. 3b, where the NFT, now associated with a unique hash key, is uploaded to the IPFS[1]. This decentralized storage solution ensures that the NFT's data remains persistent and tamper-proof. By leveraging the IPFS, we ensure that the real estate certificate's digital representation is not confined to a single point of failure and is resilient against data loss or censorship.

Finally, as visualized in Fig. 4, addresses the security concerns related to unauthorized access. In this step, mechanisms are put in place to prevent unauthorized parties from accessing the NFT data stored on IPFS platforms like Pinata. This is achieved through access control measures that restrict data

[1] Pinata platform: https://www.pinata.cloud/.



Fig. 4. Step 4: The unauthorized on IPFS - e.g., Pinata

retrieval to entities possessing the correct authorization credentials, such as private keys or access tokens. For the proof-of-concept, our code for implementation and deployment is presented in our GitHub repositories[2].

4.3 Smart Contract Deployment on the Four EVM-Supported Platforms

Smart Contract Deployment. The landscape of blockchain technology has seen the emergence of various platforms, each with distinct offerings and enhancements. Platforms compatible with the Ethereum Virtual Machine (EVM) stand out for their widespread adoption and unique attributes. These platforms, while maintaining Ethereum's compatibility, distinguish themselves with specialized features and economic frameworks.

In our research, we selected four leading EVM-compatible platforms for the deployment of our smart contract: Binance Smart Chain (BNB Smart Chain), Polygon, Fantom, and Celo. These platforms were chosen based on their prominence and potential within the blockchain environment. The deployment process across these platforms is transparent and can be verified through their respective blockchain explorers. In each platform, e scrutinized three core functionalities (transaction/data creation, mint, and transfer NFT) of the smart contract in real-estate scenarios.

Transaction Fee Analysis. Although the functionalities were consistent across all platforms, the cost implications varied. A key factor in determining a platform's economic suitability is its transaction fee structure. We conducted a detailed comparative analysis of these fees, examining the cost of deploying smart contracts and executing specific functions on each platform. This analysis provides a critical overview of the financial aspects of utilizing these blockchain environments for real estate-related smart contracts.

Among the evaluated EVM-supported platforms shown in Table 3, Fantom emerges as the most suitable for our RSA-encrypted NFT framework when considering the balance between cost-efficiency and functionality. The transaction fees on Fantom for contract creation, NFT minting, and NFT transfers are significantly lower than those on the BNB Smart Chain, Polygon, and Celo, with costs being mere fractions of a dollar. This economical fee structure makes Fantom an

[2] Since the double-blind of the manuscript, we will provide our code when it's public.

Table 3. Transaction fee

	Contract Creation	Create NFT	Transfer NFT
BNB Smart Chain	0.027311 BNB ($8.33)	0.00109162 BNB ($0.33)	0.00056991 BNB ($0.17)
Fantom	0.0095767 FTM ($0.003)	0.000405167 FTM ($0.000127)	0.0002380105 FTM ($0.000075)
Polygon	0.0068405000328344 MATIC ($0.01)	0.000289405001273382 MATIC($0.00)	0.000170007500748033 MATIC ($0.00)
Celo	0.00709722 CELO ($0.004)	0.0002840812 CELO ($0.000)	0.0001554878 CELO ($0.000)

attractive option for deploying smart contracts, particularly in scenarios where multiple transactions and operations are anticipated. Furthermore, the minimal fees associated with NFT creation and transfer on Fantom can facilitate a more accessible and widespread adoption of blockchain technology in the real estate domain.

5 Threats to Validity

The performance evaluation, while comprehensive, points to potential constraints that could influence the framework's applicability in real-world scenarios.

Firstly, the variability in decryption times, especially for image data, may present a threat to the framework's validity. This variability could stem from factors such as computational limitations of the test environment, network latency, or inefficiencies in the encryption algorithm itself when scaling to larger data sets. Such discrepancies could impact the user experience, particularly in real estate transactions where time-sensitive operations are common. Secondly, the framework's reliance on the RSA encryption algorithm, while robust, may not be as efficient when compared to more contemporary cryptographic methods. RSA, being one of the earliest public-key cryptosystems, may not offer the same level of performance as newer algorithms designed with modern computational capabilities and security threats in mind. This aspect suggests a potential limitation in the framework's long-term viability as cryptographic standards evolve.

Furthermore, the deployment of smart contracts across various EVM-supported platforms revealed significant differences in transaction fees, which translate to economic implications for users. While Fantom emerged as the most cost-effective platform, this may not hold true under all conditions, especially as network congestion and demand for blockchain space fluctuate. The economic viability of deploying our framework is thus subject to market dynamics and platform-specific fee structures, which could limit its accessibility for some users. Another limitation pertains to the generalizability of our findings. The platforms selected for this study were chosen based on their prominence within the blockchain ecosystem. However, there are numerous other platforms with different configurations and consensus mechanisms that may offer distinct advantages or drawbacks. The performance and economic feasibility of deploying our framework on these alternative platforms remain untested, which poses a limitation to

the universal applicability of our results. Lastly, as blockchain technology rapidly evolves, there may be unforeseen advancements or shifts in the regulatory landscape that could affect the deployment and functionality of our framework. Legal and compliance issues, particularly in the complex and regionally diverse field of real estate, may present additional hurdles that need to be navigated carefully.

In future work, addressing these threats to validity and limitations will be crucial. This may involve optimizing the encryption process for large datasets, exploring alternative cryptographic solutions, and expanding the scope of deployment platforms for broader testing. Additionally, staying abreast of regulatory changes and market conditions will be vital to ensure the framework remains both compliant and economically viable for widespread adoption.

6 Conclusion

Our study introduces an approach in blockchain applications for real estate as well as an RSA-encrypted NFT framework that addresses critical needs for security, privacy, and interoperability in real estate transactions. By integrating RSA encryption, we ensure the secure encryption of sensitive data, accessible exclusively to entities with the corresponding private keys. This approach not only enhances data protection but also supports the diverse needs of the real estate market through the encryption of both image and text-based NFTs. The use of NFTs in our framework further strengthens the system, offering a secure and transparent method for representing property titles digitally. Our extensive testing across various EVM-supported platforms demonstrates the framework's adaptability and efficiency, highlighting its potential to be a versatile solution in different blockchain ecosystems. This research contributes to the growing body of literature on blockchain technology in real estate and sets a new standard for secure, efficient, and transparent real estate transactions.

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