PaKSoM 2024
DOI: https://doi.org/10.5281/zenodo.14706611

Original Scientific Article

Blockchain-integrated Smart City Services and Real Estate: Creating Synergies for Seamless and Transparent Property Transactions

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Abstract—**Integrating blockchain technology with smart city services poses significant challenges due to the complexity and diversity of the systems involved, particularly in the real estate sector, where solutions often operate in isolation, disconnected from other urban services. This isolation limits the potential benefits of a fully integrated smart city. Blockchain, with its secure, transparent, and decentralized nature, offers an ideal solution for bridging these gaps and creating a unified ecosystem. This study proposes a smart living ecosystem based on blockchain. The proposed ecosystem outlines the technical requirements, governance structures, and stakeholder roles necessary to achieve seamless interoperability across diverse urban services with a focus on real estate. According to a proposed ecosystem, a decentralized application (dApp) is developed, integrating real estate transactions with real-time pollution monitoring data in the smart city. This dApp demonstrates the feasibility of the ecosystem and shows the advantages of incorporating environmental data into property transactions, enabling a more informed and transparent decision-making process in trading with real estate for users**.

Keywords - smart cities, blockchain, smart contracts, real estate trading

I. Introduction

In the urbanization landscape, smart cities have emerged as a key factor for improving life of urban populations. They involve technologies such as the Internet of Things (IoT), artificial intelligence, blockchain, and big data analytics. A fundamental aspect of a smart city is smart living which consists of the development and implementation of smart homes and apartments, intelligent selection of residential locations, and smoothed processes of purchase or rental of properties. Such smart city services change the lifestyle of people within urban environments and allow them to lead their lives with more ease, efficiency, and sustainability. IoT-enabled homes offer security and energy efficiency, allowing users to choose residences based on real-time environmental data, streamlining the property selection process.

However, realizing the full potential of smart living in urban environments requires overcoming significant challenges, particularly in sectors like real estate. Traditional real estate transactions are inefficient and lack transparency, and usually involve multiple intermediaries. These issues can lead to higher costs and delays, complicating the process of finding and securing the right property [1]. New innovative technologies can enhance transparency, efficiency, and trust in property transactions. One such technology that has gained considerable attention is blockchain. In the context of real estate, blockchain offers the ability to streamline transactions by recording all details in a tamper-proof manner, thereby reducing the need for intermediaries, minimizing the risk of fraud, and enhancing trust among all parties involved [2]. By integrating urban services and real estate services into a single platform, new value can be added to all the stakeholders in the real estate sector [3]. Smart city services such as environmental monitoring, transportation management, and energy efficiency generate valuable data that allow for better decision-making when choosing where to live. This integration allows prospective buyers and renters to make more informed decisions when choosing properties.

This study presents an ecosystem that integrates real estate transactions into a broader smart city environment using blockchain technology. The ecosystem addresses challenges related to interoperability, data exchange, and service integration within smart cities. A decentralized application (dApp) is developed as a proof of concept, integrating real estate transactions with real-time pollution monitoring data. This dApp enables users to select properties in areas with low pollution, promoting healthier living environments. It also facilitates property rental and sales transactions over the blockchain, ensuring a transparent and efficient process.

II. Smart Living Services Based on IoT and Blockchain Technologies

Smart cities integrate advanced information technologies by improving efficiency, sustainability, and livability within urban environments. These cities can leverage different services through digital platforms or applications offering real-time monitoring, data-informed decision-making, and resource management capability [4]. Among such services are transportation management, energy efficiency, waste management, and environmental monitoring [5-7]. These services together may contribute to urban systems that can adapt to the well-being of their residents, ensuring less impact on the environment. One such service is environmental monitoring, which has gained increased importance in urban planning and management. The monitoring and analysis of environmental data on air quality, noise, and pollution are some of the crucial things toward proper sustainability of the urban environment and livability [8].

Environmental monitoring enables cities to track performance indicators and address hotspots of pollution or stressors effectively [10], [11]. With effective monitoring, the city could formulate mitigation plans for the noise level reduction with the aim of improving the living conditions of its citizens [4], [12], [13]. Cities can likewise adopt policies promoting energy efficiency and conservation of natural resources based on the effect they have on the environment [14-16]. A recent approach to improve environmental sensing in smart cities is crowdsensing. Crowdsensing takes advantage of the collective potential of citizens, by means of their smartphones [17] and other devices to gather and share real-time environmental measurements [4], [18]. Integrating environmental data in urban management faces a few challenges, such as the accuracy of the data, privacy, and the interoperability of different systems in their study [19]. The quality of sensors used for data acquisition and analysis directly affects the accuracy of environmental data [20].

A. Blockchain Services for Real Estate

Blockchain represents a decentralized and distributed ledger that is used for secure, transparent, and immutable recording of transactions. It uses decentralized consensus mechanisms that reduce intermediaries, minimize fraud, and increase trust among participants. Cryptography is used alongside the storage process, and information recorded in a blockchain is almost impossible to change or tamper with. This makes blockchains particularly valuable in applications where data integrity and security are important [21].

While blockchain technology offers numerous benefits for smart city ecosystems, its environmental impact, particularly due to high energy consumption associated with consensus mechanisms like PoW, is a well-known criticism. One potential solution is the adoption of more energy-efficient consensus mechanisms such as PoS or hybrid models, which drastically reduce energy consumption while maintaining security and decentralization [22]. Incorporating renewable energy sources into blockchain networks, as demonstrated in decentralized energy grids, can further mitigate the carbon footprint of blockchain operations [23]. Solutions like Polygon’s Layer 2 scaling approach highlight how improving scalability can help lower the overall energy consumption of blockchain systems, particularly in large-scale applications [24].

One of the most important features of blockchain technology within smart cities is the provision for smart contracts. Smart contracts represent a special form of self-executing contracts where the terms of the agreement are specifically written in code directly [25]. Those contracts reside on the blockchain and automatically execute once the predefined conditions are met [26], [5]. Smart contracts within a smart city can automate services, from the distribution of energy to public transport management. The distribution of electric power by a smart grid may be regulated through smart contracts, in a way that prices can change in real-time according to demand smart contracts are activated [27], [28]. Integrating blockchain technology with services for smart cities also helps in creating conditions for an effective and sustainable improvement of urban infrastructure efficiency [29-32], which allows property owners to adjust their energy consumption to prevent environmental degradation.

Blockchain technology has recently gained the attention of the real estate industry, where it is used for property transaction processing efficiently and reliably [33]. Traditional property transactions involve a good number of intermediaries, convoluted processes, and quite a considerable amount of paperwork. Using a decentralized ledger ensures that all the details of real estate transactions are immutable and transparent, which removes the need for any intermediaries and minimizes the risks of fraud [34]. Smart contracts enable the operational process in real estate trading, ranging from transfer of ownership, payments, to registration with relevant government bodies. The most promising application for real estate is the tokenization of real estate assets [35]. Tokenization refers to the transfer of a real estate asset into digital tokens, which can then be traded on a platform with the use of blockchain technology. Blockchain real estate platforms provide a transparent secure platform to deal with buyers and sellers without any third parties including real estate agents or brokers and thereby increase trust between participants, while decreasing fraud risk [36-38].

A key challenge for the real-world implementation of blockchain-based real estate transactions lies in the legal and regulatory gaps that currently exist in many jurisdictions. Property transfers traditionally require government-verified title deeds and notarized documentation, none of which are universally recognized through blockchain platforms. In the European Union, for example, traditional intermediaries like notaries and registrars are deeply embedded in the real estate process, and adapting blockchain to these structures would require significant legal reform to ensure that smart contracts can serve as legally binding agreements [39]. While some legislative efforts have begun to address the issue, many countries still lack comprehensive laws that cover the enforceability of smart contracts, especially in cross-border real estate transactions [40]. In Russia, for instance, the permissibility of blockchain transactions depends on the involvement of intermediaries like registrars, further complicating blockchain adoption in real estate [41]. These legal uncertainties pose a significant barrier to the scalability and applicability of blockchain-based systems in the real estate sector, underscoring the need for policymakers to develop clear legal frameworks that ensure the enforceability of smart contracts, protect data privacy, and regulate decentralized transactions. More significantly, smart city data can be tied to the real estate market because much of the value of the property is dependent on the quality of the environment. Properties in locations with a large amount of air and noise pollution will not be so attractive to potential buyers and will reduce the value of the property.

III. SMART LIVING ECOSYSTEM BASED ON BLOCKCHAIN

Normally, real estate services have stayed isolated from other urban systems. While these isolated blockchain solutions can enhance transparency and security within real estate transactions, they remain discrete from the broader ecosystem of smart cities. There is a range of benefits that can come from connecting real estate with urban environments, like increased efficiency, informed decision-making through in-depth environmental data, and improved interoperability among different urban services.

To remedy the current disadvantages of smart living, we suggest a fully integrated ecosystem of smart living real estate services with other services based on blockchain technology (Fig. 1). This ecosystem is designed to link up real estate transactions with environmental monitoring, utility management, urban planning, and many others into one comprehensive, interoperable framework that brings much more benefits than solutions taken in isolation. Our ecosystem permits secure and transparent property transactions that augment the functionalities and effectiveness of the smart city, enabled through more informed choices and more sustainable and connected urban surroundings fostered for its residents and stakeholders. The ecosystem could integrate pollution, transportation, and crime data to enhance decision-making for real estate transactions. Energy consumption data could also be integrated to help users assess the sustainability and efficiency of properties, enabling them to make decisions based on potential long-term cost savings and environmental impact. By incorporating these diverse data streams into the ecosystem, the system could deliver a more comprehensive view of a property's value and its surrounding urban context, thus enhancing the decision-making process for users.

The proposed ecosystem involves a wide range of stakeholders. These stakeholders are residents, real estate developers, agents, notaries, legal advisors, government bodies, IoT service providers, among others. Uniting such a diversified set of actors would be more than a challenge. The challenge lies in ensuring that their systems are compatible and that the interaction among them can be seamless. Each stakeholder is responsible for specific activities and processes including, among others: property development, transaction management, legal verification, and environmental monitoring, which require exact coordination and exchange of information data. For this integration to be possible, members will have to utilize smart contracts, which would make agreements self-executable and eliminate human error, cutting down the need for intermediaries. But for smart contracts to work best, the underlying systems of both participants should be compatible with a blockchain-based framework.

Figure 1. Smart living ecosystem based on blockchain

TABLE I. STAKEHOLDERS, THEIR ROLES AND ACTIVITIES IN SMART LIVING ECOSYSTEM BASED ON BLOCKCHAIN.

Stakeholder	**Activities/Processes**
Residents	Engage in property search, purchase, sale, and rental; manage utility and insurance contracts. **Documents**: Agreements, contracts.
Real Estate Developers	Develop, list, and manage properties; ensure urban compliance. **Documents:** Property details, compliance certificates.
Real Estate Agents	Facilitate transactions; manage listings and processes; provide advice. **Documents**: Listings, agreements.
Notaries/ Legal Advisors	Verify and certify documents; ensure legal compliance. **Documents**: Verified contracts, property titles.
Government Agencies	Oversee compliance, zoning, and urban planning. **Documents**: Zoning permits, compliance reports.
IoT Service Providers	Deploy and manage IoT devices; collect and share environmental and utility data. **Documents**: Data logs, utility reports.
Financial Institutions	Offer mortgages and loans; manage secure payments. **Documents**: Loan agreements, payment records.
Insurance Companies	Provide property insurance; assess risks and claims. **Documents**: Policies, claims reports.
Utility Providers	Supply services (e.g., electricity, water); manage contracts and billing. **Documents**: Utility contracts, billing statements.
Property Management Companies	Manage rental properties; handle maintenance and tenant relations. **Documents**: Lease agreements, maintenance records.
Title Companies	Verify and transfer property ownership; ensure legal clarity. **Documents**: Title deeds, verification reports.
Architects/ Urban Planners	Design buildings and urban layouts; ensure zoning compliance. **Documents**: Design plans, compliance approvals.
Construction Companies	Manage development projects; ensure quality and regulatory compliance. **Documents**: Permits, progress reports, certificates.

This is very important to the health of the ecosystem because incompatible systems induce data silos, delays, and much added complexity in managing transactions.

Achieving interoperability between real estate services and other urban services within a smart city ecosystem requires adherence to specific standards and protocols. One effective approach is the use of a standardized urban data platform that enables integration across various city domains, such as infrastructure, energy, and mobility services. The Open Specifications Framework developed under the mySMARTLife project offers a model for ensuring data and service interoperability, emphasizing open standards for data exchange and service integration [42]. Blockchain can serve as an intermediary to ensure secure, decentralized data management across services, enabling seamless interaction between real estate services and broader smart city applications like IoT-based environmental monitoring [43]. To address scalability across diverse urban environments, the ecosystem could adopt a modular implementation, allowing cities with varying levels of technological infrastructure to integrate components incrementally [44].

Table I shows the information concerning every stakeholder, their activities and documents that they produce.

A. Blockchain-enabled Services in the Ecosystem

The smart living ecosystem streamlines real estate transactions and urban management with blockchain-enabled services, including property listing, transaction management, legal verification, and environmental monitoring. Users can search or post properties on a decentralized platform using filters like location, price, and environmental conditions. Smart contracts handle negotiations and finalize agreements securely, reducing fraud and eliminating intermediaries. Legal verification ensures compliance, while blockchain-integrated environmental data informs property decisions. Financial and insurance services streamline payments, mortgages, and risk mitigation, and blockchain-based title verification guarantees a secure ownership transfer.

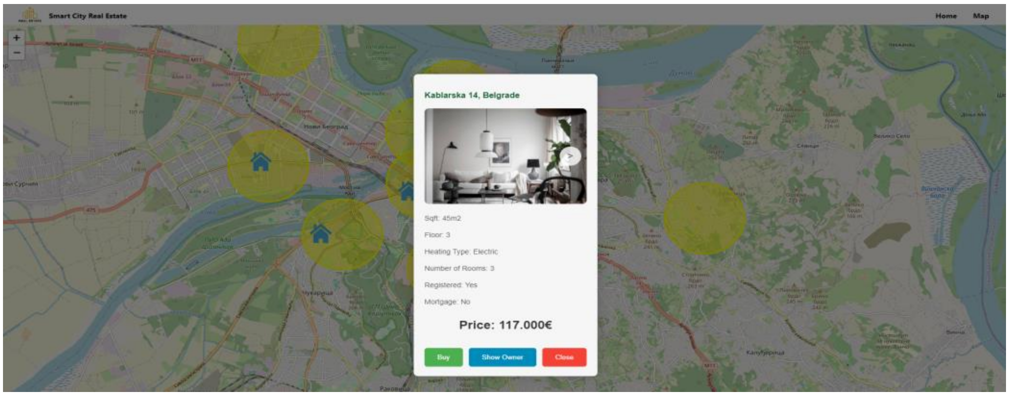

Figure 2. Dapp for real estate trading in smart cities with an interactive map showing the location of the available properties and the pollution levels

For rentals, users start with property listings on a decentralized app (dApp) posted by developers, agents, or residents. After selecting a property, smart contracts handle negotiations and rental agreements, with legal verification ensuring compliance. Environmental monitoring provides real-time data to guide decisions, and services like electricity, water, and internet are automatically transferred upon agreement confirmation. During the rental period, property management handles maintenance and tenant communications, all transparently recorded on the blockchain.

IV. Development of a dApp for Real Estate Trading in Smart Cities

As proof-of-concept dApp was developed to validate the proposed blockchain-based smart living ecosystem. The ecosystem uses Ethereum-based smart contracts for secure transactions and a React front-end for user-friendly interaction (Fig. 2).

The design of the application can be divided into three main modules: The Real Estate Transactions module, the Environmental Data Integration module, and the User Interface module. The transactions in real estate will be managed through smart contracts, which will guarantee that all the terms and conditions will be actualized before finality. Environmental Data Integration is based on real-time pollution data that can be integrated with the blockchain to assist users in including the environment in consideration for property decision-making. The dApp also possesses an interactive map that shows real-time pollution levels at every micro-location in the city, along with property listings retrieved from the blockchain database.

For transaction purposes, the dApp integrates digital wallets, allowing a secure transaction process for Ethereum (ETH). The platform also enables the exchange of any fiat currency to ETH and facilitates transactions between ecosystem participants.

The dApp also underwent extensive functional testing in relation to the transaction processing, correctness of data, system security, and integration with data from IoT sensors. The module for real estate transactions was also tested where the correct operation of smart contracts was ensured. The results of this testing confirmed that the dApp meets all the criteria of a performance objective test, proving to be ready for deployment within a smart city ecosystem.

V. Conclusion

This paper presents the possibilities of integrating blockchain technology with smart city services and real estate transactions within a more extensive smart living ecosystem. The differences in systems, data formats, and varying technological maturity levels present significant obstacles to building a cohesive smart city ecosystem. Real estate services have been slow to merge with other urban services, complicating the creation of a unified platform. To overcome these challenges, we have developed a comprehensive ecosystem aimed at standardizing the integration of real estate services into the smart city framework.

However, this study has certain limitations. The ecosystem and dApp were tested in a controlled environment, and further research is necessary to evaluate their scalability and applicability in various urban contexts. For this application to function effectively in real-world scenarios, it is essential that laws and regulations governing real estate transactions via blockchain are established and adopted.

Future work should focus on addressing these limitations by conducting a feasibility study to assess the practicality of scaling the ecosystem across different urban settings. Moreover, a technology acceptance study should be undertaken to evaluate how stakeholders perceive and are willing to adopt this blockchain-based approach.

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