Implementing UML Models, Principles of Knowledge Representation and Bitcoin Blockchain Technology to Enhance Transparency of Property Payments and Property Registries and Property Transfers Based in the Brazilian Real Estate Registration System

Elton E. Sasaki[1], Daniel Grossmann[2], Egon Walter Wildauer[3]

[1]Universidade Federal do Paraná
Curitiba, Brazil.

[2]Technische Hochschule Ingolstadt
Ingolstadt, Germany

[3] Universidade Federal do Paraná
Curitiba, Brazil.

eigi@ufpr.br, daniel.grossmann@thi.de, egon@ufpr.br.

Abstract. *Objective: This paper proposes a Solution Concept based on Bitcoin Blockchain technology to aid in solving the problem of transparency in the Brazilian Real Estate Registry System by registering Property Payments, Property Registries (Ownership), and Property Transfers on the Bitcoin Blockchain. Methods: This paper develops the Solution Concept using Unified Modeling Language (UML) diagrams, Principles of Knowledge Representation and it uses the Testnet3 and Signet Networks of the Bitcoin Blockchain to implement the Solution Concept using the Bitcoin Core's full node and wallet, and the Bitcoin Ordinal Software Utility. Results: Through the Solution Concept, it is verified that there would be more certainty and*

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[1] Pursuing his PhD in Information Management at the Universidade Federal do Paraná, Curitiba, Brazil. He received an MS in Information Management from the Universidade Federal do Paraná, and BA in Interdisciplinary Studies from the University of California – Riverside, Riverside, USA

[2] Vice President for Knowledge and Technology Transfer at Technische Hochschule Ingolstadt, Ingolstadt, Germany. He received his PhD in Automation Technology from Technische Universität München (TU München), Munich, Germany. He received his BSc in Mechanical Engineering from TU München.

[3] Researcher and Professor in the Information Management and Organization Management, Leadership and Decision Making Postgraduate Programs at the Universidade Federal do Paraná (UFPR), Curitiba, Brazil. He received his PhD in Forest Engineering from UFPR and BSc in Informatics from UFPR.

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security in the Brazilian Real Estate Registry System when Property Payments are made in bitcoin. Additionally, it is verified that provenance and digital thread of Property Registries would be assured if they were registered on the Bitcoin Blockchain. Lastly, the Bitcoin Blockchain Testnet3 Network also endures the same scalability issues as the Bitcoin Blockchain Mainnet Network, with delayed confirmation times of payment, Property Registry, and Property Transfer transactions*. Conclusions: The Bitcoin Blockchain adds transparency to the Brazilian Real Estate Registry System because Property Payments, Property Registry (Ownership), and Property Transfers registered on the Bitcoin Blockchain are public, traceable, and immutable (Bitcoin.org, n.d.-c).* Although the Bitcoin Blockchain Network endures with scalability issues, it was verified that this is due to Bitcoin Blockchain's public network design that prioritizes decentralization and security over scalability within the realm of the Blockchain Trilemma (Nakai et al., 2024, p. 80560).

1. Introduction

This paper proposes a Solution Concept to aid in solving the problem of transparency in the Brazilian Real Estate Registry System by registering Property Purchase Payments, Property Registries and Property Transfers on the Bitcoin Blockchain.

It justifies implementing this solution based on Bitcoin Blockchain technology to increase transparency in the Brazilian Real Estate Registry System because "transparency is the key factor that influences the adoption of blockchain technology in the real estate transactions system" according to research conducted by Hoxha & Sadiku (2019, p. 696) in Kosovo. For this reason, the Bitcoin Blockchain technology can aid in solving the problem of transparency in real estate financial transactions since Bitcoin was primarily created to register financial transactions. Additionally, the Bitcoin Blockchain technology can aid in solving the problem of transparency in real estate records by storing Property Registries and Property Transfers on the Bitcoin Blockchain.

Contextually, there are several government measures instituted by Law 14.382 (Dispõe sobre o Sistema Eletrônico dos Registros Públicos, 2022) in Brazil that were scheduled to be implemented by January 31st, 2023 to increase transparency in services of notary and registry offices. The Law 14.382 aims to:

> modernize and unify notary offices systems across the country and allow registrations and consultations via the internet". […] The Serp [Sistema Eletrônico dos Registros Públicos] must be implemented by January 31st, 2023. From that date onwards, certificates will be extracted by reprographic or electronic means, that is, registration officers will be exempt from printing certificates (civil or titles). Electronic certificates must be made using technology that allows the user to print them and identify their authenticity,

according to the criteria of the National Council of Justice (CNJ). The system should allow remote assistance to users of public records via the internet; the reception and sending of documents and titles; the issuance of certificates; the provision of information in electronic format and the electronic visualization of acts transcribed, registered, or annotated in the registry offices. According to the government, the Serp should "debureaucratize" access to documents, which are currently scattered across different registry offices, and reduce costs. Through the system, it should be possible to access several documents electronically, in one place. (Agência Senado, 2022).

2. Literature Review

This literature review aims to present the topics that form the basis of this research paper.

2.1. Bitcoin Blockchain Technology

The emergence of blockchain and cryptocurrencies is the result of decades of research in distributed systems and cryptography (Antonopoulos, 2010, p. 219), which resulted in the creation of Bitcoin: "A purely peer-to-peer version of electronic cash would allow online payments to be sent directly from one party to another without going through a financial institution" (Nakamoto, 2008, p. 1). The blockchain is a public, traceable, and immutable data structure (Bitcoin.org, n.d.-c) that records and timestamps Bitcoin transactions which are accessible to anyone with an internet connection. This technology introduced decentralized trust in the banking and payment system (Antonopoulos, 2010, p. 3, 15).

Traditionally, trust is centralized on the authority of a Central Bank. In Bitcoin, on the other hand, there is no central authority; instead, it is replaced by consensus algorithms established among peer-to-peer computers in the network (Diniz, 2018, p. 51). Each peer-to-peer member in the network shares a copy of a ledger containing the history of all Bitcoin transactions, called blockchain. According to Antonopoulos (2017, p. 195):

> each block within the blockchain is identified by a hash, generated using the SHA256 cryptographic hash algorithm on the header of the block. Each block also references a previous block, known as the parent block, through the "previous block hash" field in the block header. In other words, each block contains the hash of its parent inside its own header. The sequence of hashes linking each block to its parent creates a chain going back all the way to the first block ever created, known as the genesis block (Figure 1). (Antonopoulos, 2017, p. 195).

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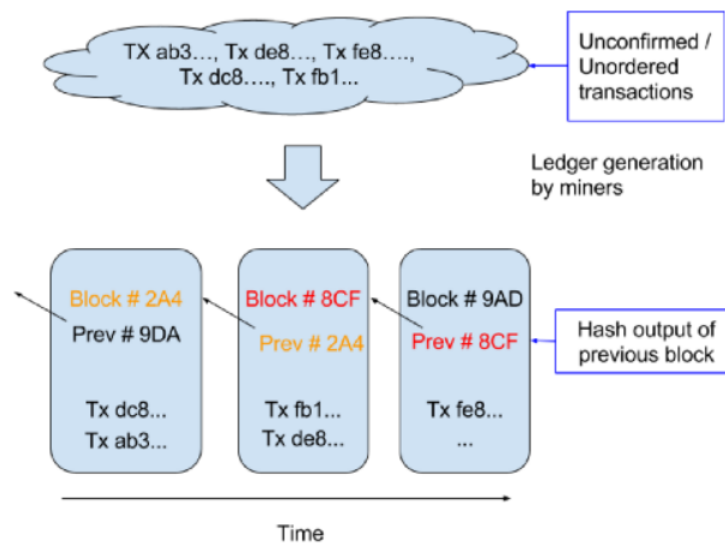
Figure 1. Generation of blockchain from unordered transactions

Note. From *Blockchain Technology: Beyond Bitcoin*, by Crosby et al., 2023, *Applied Innovation, 2*(71), p. 11 (https://scet.berkeley.edu/wp-content/uploads/AIR-2016-Blockchain.pdf).

Bitcoin transactions are defined "as a chain of digital signatures. Each owner transfers the coin to the next by digitally signing a hash of the previous transaction and the public key of the next owner and adding these to the end of the coin. A payee can verify the signatures to verify the chain of ownership" (Nakamoto, 2008, p. 2) (Figure 2).

Additionally, the Bitcoin Blockchain technology also allows recording and timestamping other data formats. In November 2021, Bitcoin activated a major upgrade called Taproot. This upgrade increases Bitcoin transactions to "4MB rather than about 1.8MB" (Trustnodes, 2023), allowing media such as "images, videos, PDFs, etc'" (Eshghi, 2024) to be stored on the blockchain. Thus, this increase of up to 4MB in transaction storage allowed the implementation of Non-fungible Tokens (NFTs) through a protocol called Ordinal Theory on the Bitcoin Blockchain.
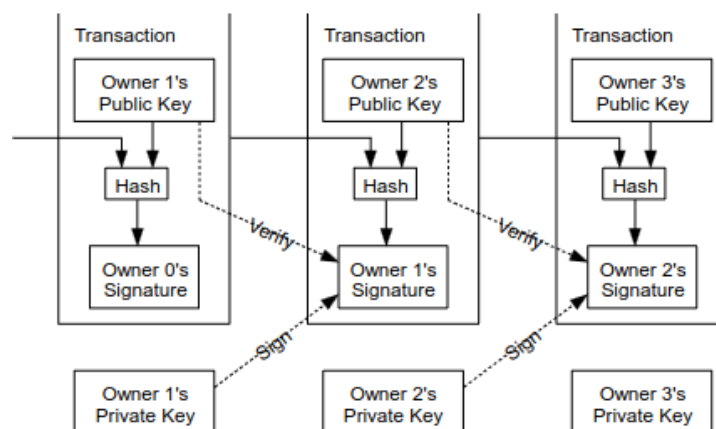
Figure 2. Chain of digital signatures

Note. From *Bitcoin: a Peer-to-Peer electronic cash system*, by Nakamoto, S., 2008, *Satoshi Nakamoto Institute*, p. 2 (https://nakamotoinstitute.org/library/bitcoin/).

"An NFT, or non-fungible token, is a unique, digital object certified on a blockchain or distributed ledger" (Ross et al., 2021, p. 2262), that can be "owned and transacted by individuals as well as consignment to third party brokers/wallets/auctioneers ('operators'). NFTs can represent ownership over digital or physical assets" (Entriken et al., 2018). Non-fungible Tokens (NFTs) "can represent digital or real-world items like artwork and real estate" (Sharma, 2024). As a result, an NFT and its representative object are both linked together (Serrano, 2022).

The Ordinal Theory made NFTs possible on Bitcoin by allowing data to be registered on the smallest unit of a bitcoin (BTC), called satoshi or sat, which was termed in honor of the anonymous Bitcoin creator Satoshi Nakamoto. Every bitcoin is composed of 100,000,000 (100 million) sats. If one satoshi is converted to Bitcoin, 1 sat (or satoshi) equates to 0.00000001 BTC, i.e., 100 millionth of a BTC. (Kaur, 2023).

The total supply of bitcoins is 21,000,000, which, theoretically, would allow 2,100,000,000,000,000 (2.1 quadrillion) sats to be registered with data on the Bitcoin Blockchain. As of October 21th, 2024, the bitcoin supply was 19,769,436 bitcoins (Blockchain.com, 2024a), i.e., 1,976,987,600,000,000 (approximately 1.976 quadrillion) satoshis. The bitcoin supply is expected to increase every 10 minutes on average as every miner that solves a cryptographic riddle (Köhler & Pizzol, 2019, p. 13598) is rewarded with 3.125 bitcoins, which would add 312.500.000 (312,5 million) more satoshis in circulation, every 10 minutes in average.

The Ordinal Theory is concerned with imbuing individual identities to satoshis by assigning them serial numbers that are indexed in ordinal sequence. Every satoshi is numbered in an ordinal sequence (starting at 0) in the order in which every satoshi was mined and created. The fixed identifier on every satoshi enables the development of Bitcoin applications that can store data on an individual satoshi. It also enables the transfer of an individual satoshi that contains data stored on it by sending it to another wallet. (Ordinal Theory Handbook, n.d.-a; Rodarmor, 2022).

2.2. Blockchain Trilemma

The Bitcoin Blockchain design prioritizes security and decentralization over scalability within the realm of the Blockchain Trilemma (Figure 3). Vitalik "Buterin's [Blockchain Trilemma] concept stipulates that a blockchain network can, at best, achieve two out of the following three essential properties: decentralization, scalability, and security" (Nakai et al., 2024, p. 80560).
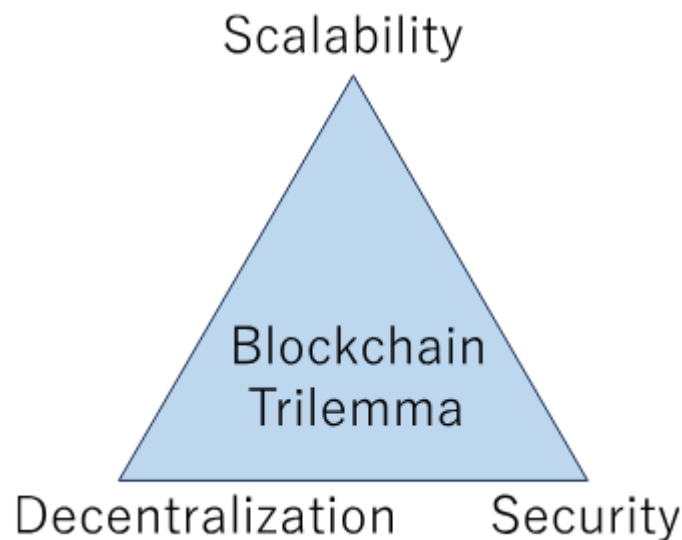
Figure 3. Blockchain trilemma (Nakai et al., 2024, p. 80560)

The definitions of each Blockchain Trilemma property are:

- **Scalability**: "The maximum throughput and latency of a network are the most decisive indicators for scalability for users who do not actively participate in the network. Therefore, the maximum throughput (how many transactions per second a network can handle), the block time, and time to finality are selected to measure the scalability of a network" (Werth et al., 2023, p. 150).

- **Decentralization**: "is at the core of blockchain technology, but also a bottleneck regarding scalability and security. It describes the transfer of control and decision-making rights from a central authority to a distributed network. A characteristic of decentralization in blockchains is the distrust between its participants, which is desired and required for it to work correctly" (Werth et al., 2023, p. 147).

- **Security:**

  > In cybersecurity, the CIA acronym stands for confidentiality, integrity, and availability. Confidentiality involves the task of keeping particular information secret. This is done in blockchain platforms in the form of encrypted addresses. Users can interact with the system using public key hashes without revealing their real identity. However, this only guarantees pseudonymity as the ledgers are public and transactions can be traced. Once a public address is compromised and the owner of an address is known, blockchain platforms no longer provide confidentiality. Integrity refers to data's consistency, authenticity, and accuracy. It also states that data must not be tampered with, which is achieved through the immutability of the blockchains. Availability means that the blockchain state is always available and readable. (Werth et al., 2023, p. 147-148).

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2.3. Real Estate Registry System in Brazil

The Real Estate Registry System is composed of Real Estate Registry Offices. Each Real Estate Registry Office "has an 'area of activity' delimited by law, called real estate circumscription, and the user is obliged to use the registry office responsible for the location of the property" (Registro de Imóveis, n.d.).

Registry Offices are managed privately by natural persons, who are delegated by the Brazilian Public Authority. A natural person becomes a Registry Officer by being selected through public tender in which the natural person takes an exam to exercise notary and registry activities. The exam is comprised of five stages: exam with objective questions; written exam; practical exam; oral exam; proof of qualification requirements for granting registry delegations and examination of titles for notary positions. (Constituição, 1988, Cartório no Brasil, n.d.).

"Brazil adopted the 'title and mode' [registry and] notary system to organize property registration. This is made up of two stages: The first consists of the obligation between the parties [through a Public Deed] and the second in the effective transfer of the property to the buyer, through registration of the title at the Real Estate Registry Office" (Gomes, 2022).

Therefore, in the Brazilian Real Estate Registry System, a Public Deed of Sale and Purchase (Escritura Pública de Compra e Venda) is required before a property can be registered. The Registry Office analyses if the Public Deed of Sale and Purchase fulfills all qualification requirements of the law. Once the Public Deed of Sale and Purchase is qualified, the Registry Office registers the Public Deed of Sale and Purchase. (Burtet et al., 2021, p. 156). Regarding the Real Estate Registry System, Loureiro (2004, p. 250) affirms that:

> The real estate registry, in addition to serving as registration of real estate property, enabling any interested party to know of all mutations, alterations, and extinctions relating to properties, serving as a 'mirror and indicator of the contracts that take place, with relation to the real estate property, and in this role is dependent on celebrated contracts; and your mission is to bring them to publicity, to facilitate the means of getting to know them right away'. The basic function of the property registry is to constitute the faithful repository of the real estate property and the legal transactions inherent to it, in the country, observing the territorial limitations established by judicial organization laws. (Loureiro, 2004, p. 250).

The signing of the Public Deed of Sale and Purchase and its registration in the Registry Office is among the last steps in the process of buying a property. An article entitled "6 Steps When Buying a Property" by Souza (2022) describes the process of buying a property in Brazil. This process is illustrated in Figure 4, and each of the processes is detailed below.

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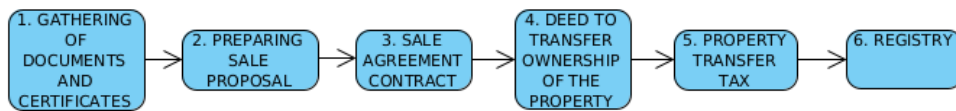
igure 4. Steps to buying a property in Brazil F

1) Gathering of Documents and Certificates

"The analysis of documents and certificates is essential to guarantee the security of legal business, avoiding losses. Through this step, it will be possible to discover any debts that accompany the property [...]. Furthermore, it will be possible to check whether the person selling is the real owner of the property and whether there are no encumbrances on the property's registration that compromise it, such as mortgage, seizure, or even enjoyment of property rights". (Souza, 2022).

2) Preparing Sale Proposal

"It is important to bind the seller because if the proposal is accepted by him, he[/she] must sell the property under the agreed terms. The proposal must be clear and objective, in addition to containing essential information such as details about the property for sale and the details of the parties, the value and method of payment, ownership, and all important items of the transaction". (Souza, 2022).

3) Sale Agreement Contract

"Everything about the negotiation will be agreed upon, such as value, payment methods, details of the property and parties, documents, possible objects that will remain in the property, penalties, guarantees, and other essential items for carrying out the transaction, formalizing the commitment of sale contract". (Souza, 2022).

4) Deed to Transfer Ownership of the Property

"[…] the [public] deed [of sale and purchase] must be granted by the seller to the buyer when the property is purchased [by the buyer] with its own financial resources, apt of being registered in the appropriate registry office" (Souza, 2022).

The Public Deed of Sale and Purchase is signed between both Property Owner and Property Buyer at a Notary Public Office once the following steps have been completed:

- the gathering of documents and certificates have been analyzed and approved by a notary public clerk;

- confirmation of Property Payment by obtaining proof of payment from the Property Buyer and confirmation of payment receipt from the Property Owner.

5) Property Transfer Tax (ITBI)

"The buyer will be required to pay the Real Estate Transfer Tax (ITBI) [Inter-Vivos Property Transfer Tax - Imposto sobre a Transmissão Inter Vivos] to the Municipality where the property is located" (Souza, 2022).

6) Registry

"There is the saying "those who do not register are not owners". The Registration [of the Public Deed of Sale and Purchase in a Real Estate Registry Office] serves to complete and make the purchase of the property effective. It is through this that the buyer becomes the formal and legal owner of the property". (Souza, 2022).

2.4. Related Works

Since "the end of 2020" (Souza et al., 2024, p. 4), Blockchain technology has been used in the Brazilian Notary System through e-Notariado, which is a digital certificate platform that provides "a set of services dedicated to meeting the needs of modernizing notarial activity" (Colégio Notarial do Brasil, n.d.). The e-Notariado platform is composed of two technologies: a Cloud Backup solution for data storage, and a Blockchain solution called Notarchain (Colégio Notarial do Brasil, n.d.), that implements IBM's (International Business Machine) Hyperledger Fabric Blockchain Technology (Brito, 2022, p. 43) to provide its services.

Notarchain is "the blockchain of notaries [in Brazil]. Notarchain is a blockchain network exclusively for notaries, where each notary is one of the supporting nodes of this security and data exchange system. In the network, the strong encryption that ensures the validity of an electronic document is shared among the participants so that fraud does not occur at either end. In other words, it will be possible to detect if any of the documents are fraudulently altered" (Colégio Notarial do Brasil, n.d.). Some of the acts available through Notarchain within the e-Notariado's services are Public Power of Attorney, Public Deed, Public Deed of Real Estate Purchase, Divorce, Living Will, Prenuptial Agreement, etc (E-Notariado, n.d.).

Additionally, according to the article entitled "Top 12 NFT Real Estate Companies To Follow" by Mileva (2023), there are several companies that "use blockchain technology to allow investors to buy and sell property tokens [as NFTs]". According to Mileva (2023), the NFT real estate company, called Propy (Propy, 2023), provides its services "by recording the real estate transactions on the blockchain, the buyer gets access to the property's legal documents that signify ownership within a span of minutes" (Mileva, 2022). Additionally, Mileva (2023) states that the NFT real estate

company, called RealT (RealT,2023), "offers cost-effective and simplified investments by eliminating the need for paper deeds. With the use of the Ethereum blockchain, you can fractionally invest in real-world properties through their NFTs called RealTokens" (Mileva, 2022).

Lastly, Mileva (2023) states that the NFT real estate company, called Vesta Equity (Vesta Equity, 2023), allows both property owners and investors "to directly connect with each other through the company's tools and marketplace. When a property is tokenized and negotiations and agreements are finalized on the percentage of the property, the investor gets full residential rights fully retained through the platform. Aside from not having any monthly payments, the investor also partakes in the property's appreciation" (Mileva, 2022).

3. Methodology

The Solution Concept uses Unified Modeling Language (UML) diagrams to "specify, visualize and document" (Object Management Group, 2005) a method based on Bitcoin Blockchain technology to aid in solving the problem of transparency in the Brazilian Real Estate Registry System. It uses three UML diagrams to design a Brazilian Real Estate Registry System based on Blockchain technology that:

- Use case diagram (Section 3.1)

- State Diagram (Section 3.2)

- Deployment Diagram (Section 3.3)

Additionally, the Solution Concept applies the principles of Knowledge Representation (Section 3.4) on Property Registries and Property Transfers that are registered on the Bitcoin Blockchain to aid in building a machine-readable domain that is accessible to the public to increase transparency in the Brazilian Real Estate Registry System.

Additionally, the Solution Concept implements principles of Knowledge Representation on Property Registries that are recorded on the Bitcoin Blockchain. This is intended to

The Solution Concept delimits itself within the following scope of operations:

- it is concerned only with the Real Estate Registry System, which is step 6 – REGISTRY in Figure 4 of the process of buying a property in Brazil described in Section "2.4. Related Works". It is taken into consideration that steps 1 through 5 in Figure 4 have already been properly completed.

- it only contemplates direct property purchases without real estate broker intermediaries between Property Buyers and Property Owners (Hryczyk, 2024).

- it also only contemplates one-time full upfront payments on property purchases between Property Buyers and Property Owners.

3.1. Use Case Diagram

A Use Case Diagram provides an external view to describe a system and its interactions with the exterior world and represents a high-level view of how a system functions upon receiving a user request (Furlan, 1998, p. 169).

The Use Case Diagram illustrated in Figure **5** performs three use case operations:
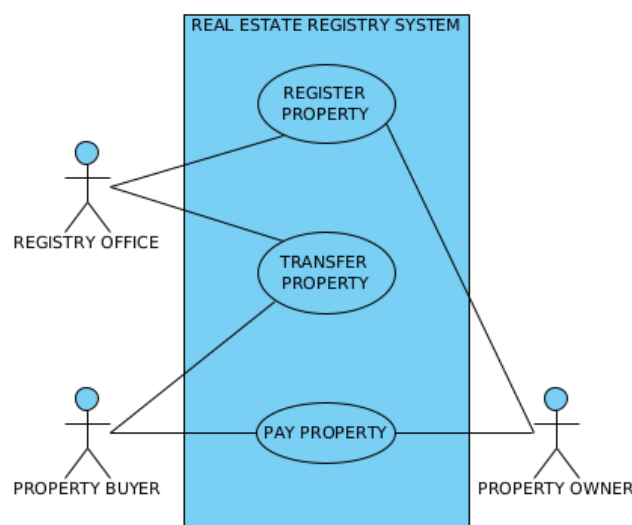
Figure 5. Use case diagram of Brazilian real estate registry system based on blockchain technology

Register Property Use Case

The REGISTER PROPERTY operation represents a registration of a new property or registration of a property that has already been registered on the traditional Brazilian Real Estate Registry System and needs to be registered on the Bitcoin Blockchain.

Pay Property Use Case

The PROPERTY BUYER (Figure **5**) performs the PAY PROPERTY operation, by sending payment to the PROPERTY OWNER.

Transfer Property Use Case

The TRANSFER PROPERTY operation represents the transfer of a property from the PROPERTY OWNER to the PROPERTY BUYER. The REGISTRY OFFICE registers the Property Transfer by linking the Property Transfer to the Property Registry.

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3.2. State Diagram

According to Furlan (1998, p. 205), a state diagram verifies events and transitions of states that occur in a system in chronological order.

There are three state events in the State Diagram in Figure **6**:
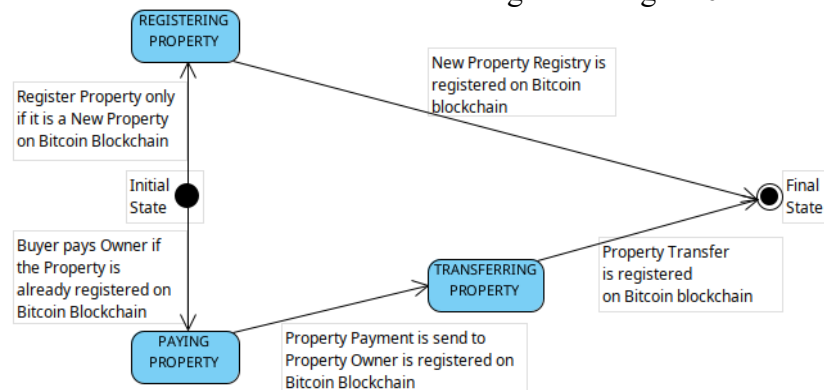
Figure 6. State diagram of Brazilian real estate registry system based on blockchain technology

Registering Property State

In state event REGISTERING PROPERTY in Figure **6**, the REGISTRY OFFICE registers a Property Registry on the Bitcoin Blockchain. This state event only occurs if it is a new property or a property that has already been registered on the traditional Brazilian Real Estate Registry System and needs to be registered on the Bitcoin Blockchain.

Paying Property State

In the state event PAYING PROPERTY in Figure **6**, the PROPERTY BUYER sends a Bitcoin payment from his/her wallet address to the PROPERTY OWNER's wallet address.

Transferring Property State

In state event TRANSFERRING PROPERTY in Figure **6**, the REGISTRY OFFICE transfers property ownership from the PROPERTY OWNER to the PROPERTY BUYER. This is accomplished by registering (storing) the Property Transfer as a "child" of a "parent" Property Registry registered (stored) in "State Event 1 REGISTERING PROPERTY". The "Parent-Child" functionality is detailed in Section "4**.**1. Implementation of the Solution Concept".

3.3. Deployment Diagram

The deployment Diagram in Figure **7** models the physical architecture of a Real Estate Registry System based on Bitcoin Blockchain. It shows "relationships between the

software and hardware components in the system and the physical distribution of the processing" (IBM Documentation, 2023).

The deployment diagram is composed of a Linux Server node, Artifacts, and a Frontend node.
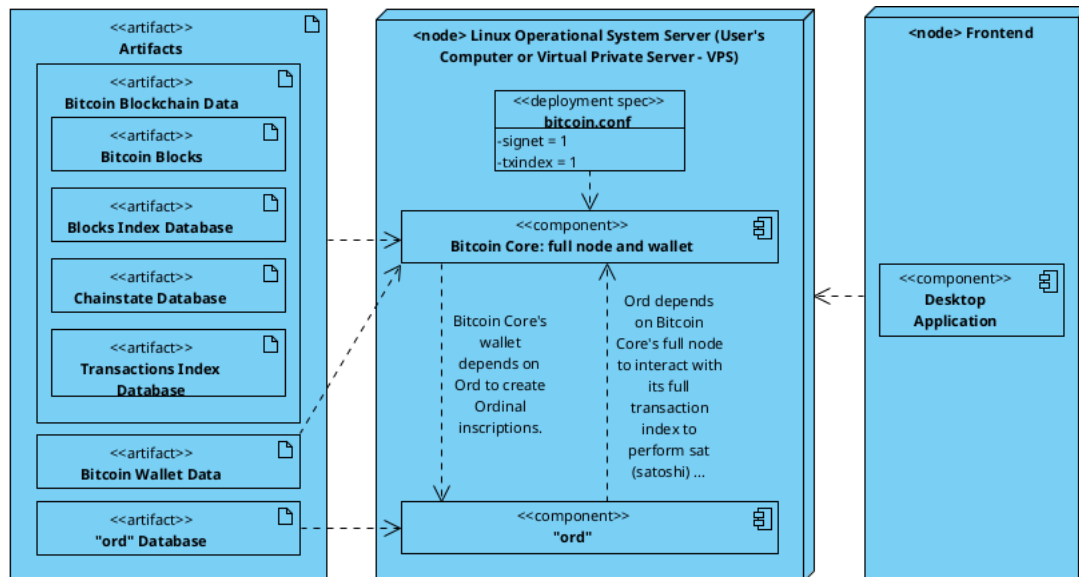

Figure 7. Deployment diagram of Brazilian real estate registry system based on blockchain technology

3.3.1. Linux Server Node

The Linux Server node in the deployment diagram (Figure 7) consists of a "Linux Operational System Server". There are two components installed on the "Linux Operational System Server" node: Bitcoin Core and "ord" (Ordinal Software Utility). The Bitcoin Core and "ord" are interdependent upon one another. Additionally, the deployment diagram also has a deployment specification file called "bitcoin.conf" that is required, so that Bitcoin Core can work alongside "ord" (Ordinal Theory Handbook, n.d.-c).

Bitcoin Core is an open-source software (Bitcoin.org, n.d.-b). It is maintained by a team of community developers that consists of a Bitcoin wallet and a "full node" that validates blocks on the Bitcoin blockchain (Bitcoin.org, n.d.-a).

The Bitcoin Core "full node" is a secure "full client [sever] in the sense that it downloads [and runs] a complete [updated] copy of the Blockchain for transaction verification" (Van der Horst et al., 2023, p. 22388).

The Bitcoin Core wallet "can refer to either a wallet program or a wallet file. […] Wallet programs create public keys to receive satoshis and use the corresponding private keys to spend those satoshis. Wallet files store private keys and (optionally)

other information related to transactions for the wallet program". (Bitcoin Developer, n.d., Introductions section, para. 1).

The Bitcoin Core wallet depends on an Ordinal Software Utility called "ord" because the it "cannot create inscriptions [store data] and does not perform sat control" (Ordinal Theory Handbook, n.d.-c).

The "ord" (Ordinal Software Utility) implements the Ordinal Theory to allow individual satoshis (sats) to be stored with arbitrary digital content. Interdependently, the "ord" Software Utility needs to work alongside Bitcoin Core. This allows "ord" to access the entire transaction index of Bitcoin Core "full node", so that "ord" can perform sat (satoshi) control by maintaining its own inscription [data storage] index database. (Ordinal Theory Handbook, n.d.-a; Ordinal Theory Handbook, n.d.-b; Ordinal Theory Handbook, n.d.-c).

The deployment specification file "bitcoin.conf" (Figure **7**) contains configuration settings for the Bitcoin Core "full node". It has two parameters: "txindex" and "signet". Parameter "txindex", sets Bitcoin Core "full node" to store a copy of Bitcoin Core's transaction index on the "Linux Operational System Server".

3.3.2. Artifacts

Artifacts in the deployment diagram (Figure **7**) consist of Bitcoin Blockchain Data, Bitcoin Wallet Data, and "ord" Database.

The Bitcoin Blockchain Data is a physical implementation of the Bitcoin Core "full node" that is represented by several pieces of data (IBM Documentation, 2023): Bitcoin Blocks, Blocks Index Database, Chainstate Database, and Transactions Index Database.

Bitcoin Blocks (in $HOME/.bitcoin/blocks) "contain raw block data received by a bitcoin core node. […] these blk.dat files basically store 'the blockchain'" (Walker, 2024). They are "needed for rescanning missing transactions in a wallet, reorganizing to a different part of the chain, and serving the block data to other nodes that are synchronizing" (Bitcoin Wiki, 2020, Overview section, para. 2).

Blocks Index, Chainstate, and Transactions Index databases are built from the Bitcoin Blocks data. Validation and operations become impracticably slow without them (Bitcoin Wiki, 2020).

The Blocks Index Database (in $HOME/.bitcoin/blocks/index) "contains metadata about all known blocks, and where to find them on disk. Without this, finding a block would be very slow" (Bitcoin Wiki, 2020, Overview section, para. 3).

The Chainstate Database (in $HOME/.bitcoin/chainstate) "maintains information about the resulting state of validation as a result of the currently best-known chain" (Gr0kchain, 2019). It is "a compact representation of all currently unspent transaction outputs and some metadata about the transactions they are from. The data

here is necessary for validating new incoming blocks and transactions" (Bitcoin Wiki, 2020, Overview section, para. 4).

Transactions Index Database stores a copy of the transaction index database (in $HOME/.bitcoin/indexes). It is an optional setting in Bitcoin Core, but it is required by the "ord" Software Utility, so it can access Bitcoin Core's transaction index and rest interface to perform sat (satoshi) control by maintaining its own data storage index database. (Gr0kchain, 2019; Ordinal Theory Handbook, n.d.-c).

By maintaining "an index of all transactions. This means a complete copy of the blockchain that allows you to programmatically retrieve any transaction by ID" (Antonopoulos, 2017, p. 41).

The Bitcoin Wallet Data is a physical implementation of the Bitcoin Core wallet represented by a file called "wallet.dat" (in $HOME/.bitcoin/wallets) which contains private key information, scripts corresponding to addresses, metadata, and wallet transactions (Bitcoin Wiki, 2023).

The "ord" Database (in $HOME/.local/share/ord) is a physical implementation of the "ord" Software Utility. Bitcoin Core wallet is represented by a file called "wallet.dat" (in $HOME/.bitcoin/wallets).

3.3.3. Frontend Node

The Frontend node in the deployment diagram (Figure **7**) represented by a "Frontend" can consist of a Desktop Application.

3.4. Knowledge Representation

Knowledge Representation (KR) is an application of ontology within the knowledge domain of computer science (Almeida, 2013, p. 1682). "In computer science, ontologies are understood as devices that bring a machine-readable conceptual structure to a domain of interest" (Oellinger & Wennerberg, 2006). Moreover, in computer science, ontology "is a formal, explicit specification of shared a conceptualization" (Gómez-Pérez, 2004, p. 44). In KR, "ontology supports a machine-readable representation of the context aimed at automatic reasoning" (Almeida, 2013, p. 1682). Additionally, "an ontology is a kind of controlled vocabulary in that it specifies the set of predicates that can be used to make statements (i.e., representations) about a resource" (Almeida, 2013, p. 1690).

In the Solution Concept, KR is applied when Property Transfers are registered on the Bitcoin Blockchain in JSON (JavaScript Object Notation) file format using the concept of IRIs (Internationalized Resource Identifiers) from JSON-LD (JavaScript Object Notation – Linked Data) to identify relationships between "child(ren)" Property Transfer(s) and a "parent" Property Registry. JSON-LD is a structured data, recommended by Google, for "providing information about a page and classifying the page content" (Google Developers, n.d.). It is "a JSON-based format to serialize Linked

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Data […] in Web-based programming environments, to build interoperable Web services, and to store Linked Data in JSON-based storage engines" (W3C, 2020).

The concept of IRIs is used to make RDF (Resource Description Framework) statements "for describing and exchanging metadata, which enables standardized exchange of data based on relationships" (TechTarget Network, 2022). IRIs "are fundamental to Linked Data as that is how most nodes and properties are identified" (W3C, 2020).

In the Solution Concept, a Property Transfer is registered in JSON file format on the Bitcoin Blockchain containing the following IRI key-value:

- **@parent**: key to identify the inscription ID of a "parent" Property Registry. Every Property Transfer contains a **@parent** value identified with the inscription ID of its "parent" Property Registry that was registered on the Bitcoin Blockchain.

4. Results and Discussions

In the traditional Brazilian Real Estate Registry System, there is uncertainty and insecurity when a Property Buyer makes a one-time full upfront payment (as delimited in Section "3. Methodology") to the Property Owner during the process of Property Purchase because the Notary Public Office requires the Buyer to have transferred the one-time full upfront payment to the Property Owner's bank account before both, the Buyer and the Owner, are allowed to sign the Public Deed of Sale and Purchase (Escritura Pública de Compra e Venda). This is required because only the Property Buyer and the Property Owner have access to the payment information registered on their bank accounts. For this reason, the Property Buyer is required to present proof of the one-time full upfront payment to the Notary Public Office before both, the Property Buyer and the Property Owner, are allowed to sign the Public Deed of Sale and Purchase.

This practice of requiring the Property Buyer to have transferred the one-time full upfront payment to the Property Owner's bank account may put the Property Buyer at risk of falling for a "Double Sale Scam" or "False Owner Scam". The "Double Sale Scam" occurs when the Property Owner sells the property to more than one Property Buyer before the Public Deed of Purchase is taken to the Real Estate Registry Office for the definitive transfer of the property to a Property Buyer. (Neto, 2022, Golpe Imobiliário, n.d.).

The "False Owner Scam" occurs through a scammer who "taking advantage of the lack of knowledge and information about how the purchase and sale process works, the individual presents himself as the seller and owner of the property. […] He [the scammer] presents documents and contracts with the sole intention of creating an illusion, but none of them have any legal validity. In his naivety, the person [Property

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Buyer] makes a down payment or deposit [or one-time full upfront payment], and the scammer simply disappears with the money" (Neto, 2022).

On the other hand, as proposed in this paper's Solution Concept, if a Property Buyer sends a payment in Bitcoin to a Property Owner, the Bitcoin payment can be verified on the Bitcoin Blockchain. Since the Notary Public Office can verify Property Payments on the Bitcoin Blockchain, it would no longer require proof of Property Payment from the Property Buyer. As a result, the Property Buyer and Property Owner would be allowed to sign the Public Deed of Sale and Purchase at the Notary Public Office before the Property Buyer is required to make a one-time full payment in Bitcoin to the Property Owner. Consequently, the Property Buyer would only be required to send the one-time full payment in Bitcoin to the Property Owner after having taken the signed Public Deed of Sale and Purchase to the Real Estate Registry Office. This prevents the Property Buyer from falling for a "Double Sale Scam" or "False Owner Scam" because the Real Estate Registry Office would only register the definitive transfer of the property to the Property Buyer after it verifies that the Property Buyer has sent the one-time full payment to the Property Owner on the Bitcoin Blockchain.

Regarding registries of property ownership and transfer, this paper's Solution Concept uses the Bitcoin Blockchain to provide provenance, and digital thread of registries. Provenance is provided through "the history of the ownership" (Provenance, n.d.) of a Real Estate property registered on the Bitcoin Blockchain. Moreover, considering the concept of digital thread from China (2023), the digital thread of a Property Registry is provided through the digital representation of its lifecycle, from registration of a new property to transferring it to a Property Buyer, resulting in a complete and transparent view of the Property Registry history. Provenance and digital thread of Property Registries are made possible through the "Parent-Child" functionality (Section "3.2.3. Transfer property operation") of the Ordinal Theory Protocol (Section "2.1. Bitcoin Blockchain Technology") by registering Property Transfers as "children" of a "parent" Property Registry on the Bitcoin blockchain. Additionally, the concept of "Parent-Child" functionality of the Ordinal Theory Protocol is also applied by implementing principles of Knowledge Representation (KR) when a Property Transfer is registered in JSON file format on the Bitcoin Blockchain containing a @parent IRI (Internationalized Resource Identifiers) key-value (Section "3.4. Knowledge Representation").

4.1. Implementation of the Solution Concept

An implementation of the Solution Concept based on Bitcoin Blockchain technology executes operations (Register Property, Pay Property, and Transfer Property) considering the use case, state, and deployment diagrams described in Section "3. Methodology". The Solution Concept operations are implemented in chronological order as described in Section "3.2. State Diagram" as presented in the following Sections 4.1.1., 4.1.2. and 4.1.3.

The Solution Concept used was tested on the Testnet3 and Signet Networks of the Bitcoin Blockchain. The Testnet3 Network "is an alternative Bitcoin block chain to be used for testing. Testnet3 coins are separate and distinct from actual bitcoins, and are never supposed to have any value. This allows application developers or bitcoin testers to experiment, without having to use real bitcoins or worrying about breaking the main bitcoin [block]chain" (Bitcoin Wiki, 2024). The Signet Network "is another testing network similar to Testnet3 but with enhanced coordination and stability. Unlike traditional Testnets, Signet blocks must be signed by a designated authority, ensuring stability and reliability in the testing process" (Xverse, 2025).

On the Testnet3 Network bitcoins have no real value, the bitcoins can be "obtained via online services called faucets. Secondly, the mining difficulty is also set to a lower value than Mainnet, making the blockchain grow faster" (Franzoni et al., 2020, p. 4). Although, it would be expected that obtaining timestamps of confirmed transactions on Testnet3 would be faster than on Mainnet, implementation of the Solution Concept endured scalability issues related to delayed confirmation of payment and registry transactions on the Bitcoin Blockchain Testnet3 Network. Also, the Ordinals Explorer for the Testnet3 Network, which allows searching and browsing inscriptions on an internet web browser has been disabled. For this reason, the Solution Concept was implemented on the Signet Network of the Bitcoin Blockchain, which has "stable network behavior [which] is crucial for accurate testing outcomes" (Xverse, 2025) and has an Ordinals Explorer for the Signet Network enabled for internet web browsers.

4.1.1. Register property operation

In the REGISTER PROPERTY OPERATION, the REGISTRY OFFICE registers a Property Registry in JSON file format (Figure **8**) on the Bitcoin Blockchain, considering that it is a new property or a property that has already been registered on the traditional Brazilian Real Estate Registry System and needs to be registered on the Bitcoin Blockchain (as described in Section "3. Methodology").

```json
{
    "type": "Property Registry",
    "property_info": {
        "property_id": 594039054,
        "address": "Rua Rio Grande do Sul - Nova Ubiratã, MT, 78888-000, Brasil",
        "area_square_meters": 32
    },
    "owner_info": {
        "name": "Joao Bamberger",
        "national_id": "159.098.908-55",
        "owner_wallet_address": "mxpoTHpkyGcaEMsqsYL9BE3kttdXZsmreu"
    }
}
```

Figure 8. Property registry in JSON file format

The Property Registry (Figure **8**) contains three information objects:

- "**type**": informs that the type of registry is "Property Registry"
- "**property_info**": details information about the Property
- "**owner_info**": details information about the PROPERTY OWNER

Implementation of this operation results in the Property Registry (Figure **8**) being registered (stored) by the REGISTRY OFFICE on the Bitcoin Blockchain Signet Network[4].

4.1.2. Pay property operation

In the PAYING PROPERTY OPERATION, the PROPERTY BUYER sends a Bitcoin payment from his/her wallet address to the PROPERTY OWNER's wallet address (as described in Section "3. Methodology"). For this paper's Solution Concept, it is assumed that the Property Payment in the amount of 0.00001 sBTC has been agreed between the Property Buyer and the Property Owner, through a fictional Public Deed of Sale and Purchase signed between both parties.

Implementation of the PAYING PROPERTY OPERATION results in the PROPERTY BUYER sending a one-time full upfront payment in Bitcoin in the amount of 0.00001 sBTC to the PROPERTY OWNER on the Bitcoin Blockchain Signet Network[5].

4.1.3. Transfer property operation

The TRANSFERRING PROPERTY OPERATION transfers property ownership from the PROPERTY OWNER to the PROPERTY BUYER (as described in Section "3. Methodology"). In this operation, the REGISTRY OFFICE registers (stores) the Property Transfer (Figure **9**), as a "child" of the Property Registry registered (stored) in "State Event 1 REGISTERING PROPERTY", in JSON file format.

To make the Property Transfer a "child" of the Property Registry, the "parent" Property Registry has to be registered in the REGISTRY OFFICE's Bitcoin wallet

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[4]The Property Registry registered (stored) on the Bitcoin Blockchain Signet can be accessed at the following link:
https://signet.ordinals.com/inscription/b5a40f2687eed4cc4c4a1aa960dad4411bcfa78cb67ae8363424ac7b82b290afi0

[5]The Property Payment transaction registered on the Bitcoin Blockchain Signet Network can be accessed at the following link:
https://mempool.space/signet/tx/9c81b2c2d3fca9e87074bdd43ba59309646db73acde0e9d71723cd4e42596993

(Ordinal Theory Handbook, n.d.-c). Since the REGISTRY OFFICE controls the wallet that contains the Property Registry, it can create as many "children" of a Property Registry, trustlessly establishing the provenance of the Property Transfers registered on the Bitcoin Blockchain, as proof of having been created by the REGISTRY OFFICE. (Ordinal Theory Handbook, n.d.-b).

The REGISTRY OFFICE only performs the Property Transfer registry upon confirmation that a Bitcoin payment in the amount agreed between both, the PROPERTY OWNER and PROPERTY BUYER, has been sent from the PROPERTY BUYER's Bitcoin wallet address to the PROPERTY OWNER's Bitcoin wallet address.

The Property Transfer (Figure **9**) contains five information objects:

- "**type**": informs that the type of registry is "Property Transfer"

- "**property_info**": details information about the Property

- "**owner_info**": details information about the PROPERTY OWNER

- "**buyer_info**": details information about the PROPERTY BUYER

- "**payment_info**": details information about the Payment sent from the PROPERTY BUYER to the PROPERTY OWNER.

```json
{
    "type": "Property Transfer",
    "property_info": {
        "@parent": "1fec293637664e3009bd2b1a6cd1eea41e0cc8295c8189fa4e81a1f5c743a90fi0",
        "property_id": 594039054,
        "blockchain_block_number": 235800,
        "inscription_timestamp": "2025-02-17 17:47:47 UTC",
        "address": "Rua Rio Grande do Sul - Nova Ubiratã, MT, 78888-000, Brasil",
        "area_square_meters": 32
    },
    "owner_info": {
        "name": "Joao Bamberger",
        "id": "159.098.908-55",
        "owner_wallet_address": "mxpoTHpkyGcaEMsqsYL9BE3kttdXZsmreu"
    },
    "buyer_info": {
        "name": "Maria Fürth",
        "id": "876.324.678-09",
        "buyer_wallet_address": "mxExcqAAuRZWW6vhSCBwV9B7EuxjadPhS4"
    },
    "paymentInfo": {
        "transaction_id": "d9d77d8a580253424fc8dee89da79e0b7022c4e9f8fed7f6db355ac84355df39",
        "payment_amount": 0.00001,
        "blockchain_block_number": 235802,
        "timestamp": "2025-02-17 14:52:39 UTC"
    }
}
```

Figure 9. Property transfer in JSON file format

Implementation of the TRANSFERRING PROPERTY OPERATION results in the Property Transfer (Figure **9**) being registered (stored) by the REGISTRY OFFICE on the Bitcoin Blockchain Signet Network[6]. This allows for verifying provenance on the Ordinals Explorer (link of Footnote 3) that the Property Transfer is a "child" of the "parent" Property Registry. It can also be verified on the Ordinals Explorer (link of Footnote 4) that the Property Registry is the "parent" of the "child" Property Transfer.

Additionally, principles of Knowledge Representation can be applied since the Property Transfer was registered on the Bitcoin Blockchain in JSON file format containing the IRI @parent value "b5a40f2687eed4cc4c4a1aa960dad4411bcfa78cb67ae8363424ac7b82b290afi0" (Figure **9**). This @parent value, which references the Property Registry inscription ID (Figure **7**), allows for making the following RDF statements (TechTarget Network, 2022) as illustrated in Figure **3**:
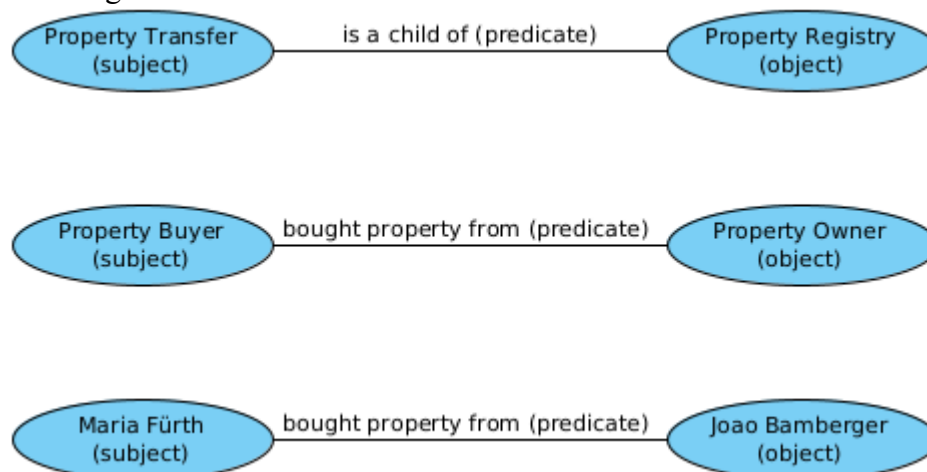

Figure 10. RDF (Resource Description Framework) statements

4.2. Limitations and Challenges of the Solution Concept

Regarding limitations and challenges, the implementation of the Solution Concept endured scalability issues related to delayed confirmation of payment and registry transactions on the Bitcoin Blockchain Testnet3 Network. The Testnet3 Network is set to confirm transactions faster than the Mainnet Network (Franzoni et al., 2020, p. 4); therefore, it would be expected that the Testnet3 Network would confirm transactions faster than the Mainnet Network. However, regardless of whether utilizing the Bitcoin Blockchain on Mainnet Network or Testnet3 Network delayed confirmation of transactions is very common nowadays, which may be caused by high traffic or

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[6]The Property Transfer registered (stored) on the Bitcoin Blockchain Signet can be accessed at the following link:
https://signet.ordinals.com/inscription/f1c787ac671b00328e3fec0ce51cf5a9bb53391f06decaa27a5159bfc90ff40ci0

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transactions sent with low fees (Blockstream, n.d.). Because of the delayed confirmation of transactions endured on the Testnet3 Network, payment, and registry transactions on the Solution Concept were implemented on the Bitcoin Signet Network.

There was no data available regarding the Average Confirmation Time of transactions on the Testnet3 and Signet Networks since they are intended for use by "application developers or bitcoin testers to experiment, without having to use real bitcoins or worrying about breaking the main bitcoin [block]chain" (Bitcoin Wiki, 2024). However, on the Mainnet Network, there is data provided by Blockchain.com, which is a Bitcoin "Blockchain Explorer that enabled anyone to not only examine transactions and study the blockchain" (Blockchain.com, 2024b).

To comprehend Bitcoin Blockchain's delayed confirmation, three charts provided by Blockchain.com were analyzed: Average Confirmation Time, Average Number of Transactions per Block
, and Transaction Rate. Additionally, a comparison with the Notarchain Blockchain is formulated within the realm of the Blockchain Trilemma (Section 2.2), to comprehend Bitcoin Blockchain's delayed Transaction per Second (TPS) Rate.

In respect to the Average Confirmation Time chart, during the 30 days from October 14th, 2024 to November 12th, 2024, the Average Confirmation Time "for a transaction with miner fees to be included in a mined block and added to the public ledger" (Blockchain.com, 2024f), was 85 minutes (Figure **9**). This is almost 8.5x (eight and five-tenths times) longer than the Average Confirmation Time of 10 minutes (KÖHLER; PIZZOL, 2019, p. 13598) that the Mainnet Network is expected to perform since it was launched in January 2009. The long Average Confirmation Time of 85 minutes (Figure **9**) was caused because "there is only a certain amount of space in each block, so it will take a longer time for your transaction to be confirmed when it is competing with others to be added" (Blockstream, n.d.).

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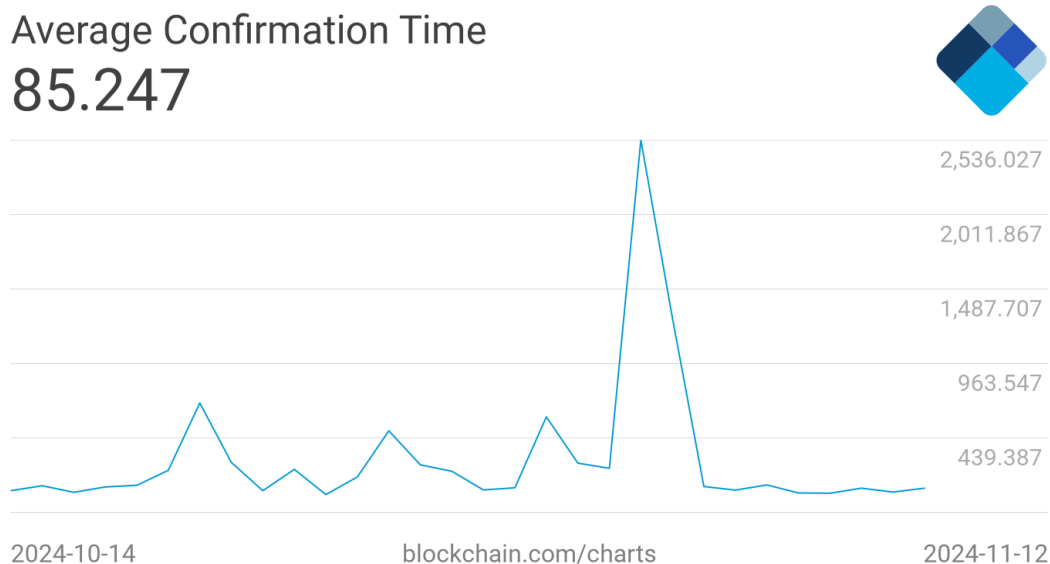
**Figure 11. Average confirmation time from October 14th, 2024 to November 12th, 2024 (Blockchain.com, 2024d)**

As for the Average Number of Transactions per Block chart, during the 30 days from October 14th, 2024 to November 12th, 2024, the Average Number of Transactions per Block was only 3,450 transactions (Figure **12**). Since the Bitcoin Blockchain is being used not only to send bitcoins from one wallet to another but also to store data on the Bitcoin Blockchain through the Ordinal Theory Protocol, this is contributing "to clog the [Mainnet] network, raising confirmation time and costs for regular Bitcoin transactions" (Vardai, 2023). Likewise, the popularity of the Ordinal Protocol may also increase the use by "application developers or bitcoin testers to experiment" (Bitcoin Wiki, 2024) on the Testnet3 Network, which may also explain why transaction confirmation time is delayed on the Testnet3 Network.

Average Number Of Transactions Per Block
3,450

5,074
4,643
4,213
3,783
3,353

2024-10-14   blockchain.com/charts   2024-11-12
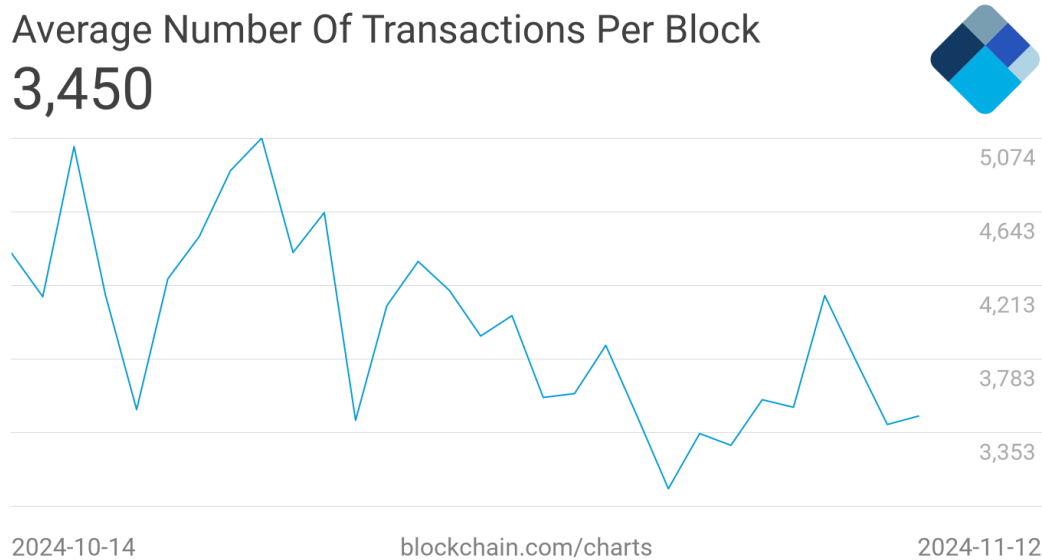
Figure 12. Average number of transactions per block from October 14th, 2024 to November 12th, 2024 (Blockchain.com, 2024c)

Concerning the Transaction Rate chart, the Bitcoin Blockchain is compared with the Notarchain Blockchain (Section "2.4. Related Works") in terms of the number of Transactions per Second (TPS). During the 30 days from October 14th, 2024 to November 13th, 2024, Bitcoin's Transaction Rate of 6.87 TPS (Figure **13**), was 320 times slower than Notarchain's 2.2k TPS (Nakaike et al., 2020, p. 1).

Regarding the realm of the Blockchain Trilemma (Section 2.2), by comparing the Bitcoin Blockchain with the Notarchain Blockchain, Bitcoin Blockchain's slower Transaction Rate of 6.87 TPS is due to its public network design that prioritizes decentralization and security over scalability. On the other hand, Notarchain Blockchain's higher Transaction Rate of 2.2k TPS is due to its private network design that prioritizes security and scalability over decentralization.
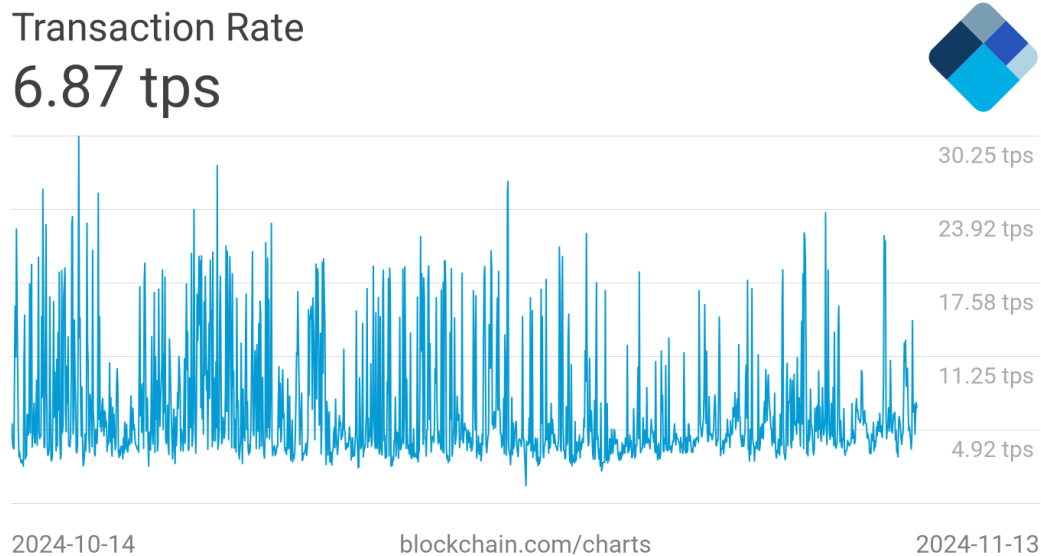
Figure 13. Transaction Rate from October 14ᵗʰ, 2024 to November 13ᵗʰ, 2024 (Blockchain.com, 2024e)

5. Conclusion

This paper's Solution Concept develops a method to aid in solving the problem of transparency in the Brazilian Real Estate Registry System by registering Property Payments, Property Registries (Ownership), and Property Transfers on the public, traceable, and immutable Bitcoin Blockchain (Bitcoin.org, n.d.-c). Considering the realm of the Blockchain Trilemma (Section 2.2), the limitations and challenges related to delayed confirmation of payment and registry transactions on the Bitcoin Blockchain are justified by its public network design that prioritizes decentralization and security over scalability. To make the Property Transfer a "child" of the Property Registry, the "parent" Property Registry has to be registered in the REGISTRY OFFICE's Bitcoin wallet (Ordinal Theory Handbook, n.d.-c). Since the REGISTRY OFFICE controls the wallet that contains the Property Registry, it can create as many "children" of Property Transfers, trustlessly establishing the provenance of the Property Transfers registered on the Bitcoin Blockchain, as proof of having been created by the REGISTRY OFFICE. (Ordinal Theory Handbook, n.d.-b). Additionally, the Property Transfers registered on the Bitcoin Blockchain implement principles of Knowledge Representation (KR) which allows for making the RDF (Resource Description Framework) statements (Figure **12**).

References

Agência Senado. (2022). Sancionada com vetos lei sobre modernização de cartórios. Retrieved October 30, 2024, from

https://www12.senado.leg.br/noticias/materias/2022/06/28/sancionada-com-vetos-lei-sobre-modernizacao-de-cartorios

Almeida, M. B. (2013). Revisiting ontologies: A necessary clarification. Journal of the American Society for Information Science and Technology, 64(8), 1682–1693. https://doi.org/10.1002/asi.22861. Retrieved February 12, 2025, from https://mba.eci.ufmg.br/downloads/pos/RevisitingOntologies-Almeida.pdf

Antonopoulos , A. M. (2010). Mastering Bitcoin: Unlocking Digital Crypto-Currencies.

Antonopoulos , A. M. (2017). Mastering Bitcoin: Programming the Open Blockchain.

Bitcoin.org. (n.d.-a). Bitcoin Core. Retrieved November 01, 2023, from https://bitcoin.org/en/bitcoin-core/

Bitcoin.org. (n.d.-b). Download Bitcoin Core. Retrieved November 04, 2023, from https://bitcoin.org/en/download

Bitcoin.org. (n.d.-c). Protect your privacy. Retrieved August 01, 2024, from https://bitcoin.org/en/protect-your-privacy

Bitcoin Developer. (n.d.) Wallets. Retrieved December 29, 2023, from https://developer.bitcoin.org/devguide/wallets.html

Bitcoin Wiki. (2020, June 27). Bitcoin Core 0.11 (ch 2): Data Storage. Retrieved August 02, 2024, from https://en.bitcoin.it/w/index.php?title=Bitcoin_Core_0.11_(ch_2):_Data_Storage&oldid=68025

Bitcoin Wiki. (2024, October 16). Testnet. Retrieved October 20, 2024, from https://en.bitcoin.it/wiki/Testnet

Bitcoin Wiki. (2023, February 06). Wallet. Retrieved August 02, 2024, from https://en.bitcoin.it/w/index.php?title=Wallet&oldid=69620

Blockchain.com. (2024a). Total Circulating Bitcoin. Retrieved October 23, 2024, from https://www.blockchain.com/explorer/charts/total-bitcoins

Blockchain.com. (2024b). About. Retrieved November 01, 2024, from https://www.blockchain.com/de/about

Blockchain.com. (2024c). Average Number Of Transactions Per Block Chart. Retrieved November 13, 2024, from https://api.blockchain.info/charts/preview/n-transactions-per-block.png?timespan=30days&h=810&w=1440

Blockchain.com. (2024d). Average Confirmation Time Chart. Retrieved November 13, 2024, from https://api.blockchain.info/charts/preview/avg-confirmation-time.png?timespan=30days&h=810&w=1440

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Blockchain.com. (2024e). Transaction Rate Chart. Retrieved November 13, 2024, from https://api.blockchain.info/charts/preview/transactions-per-second.png?timespan=30days&h=810&w=1440

Blockchain.com. (2024f). Average Confirmation Time. Retrieved November 18, 2024, from https://www.blockchain.com/explorer/charts/avg-confirmation-time

Blockstream. (n.d.). Why is my transaction taking so long to be confirmed and why are fees so high? Retrieved November 16, 2024, from https://help.blockstream.com/hc/en-us/articles/4407567899801-Why-is-my-transaction-taking-so-long-to-be-confirmed-and-why-are-fees-so-high

Brito, V. A. (2022). Validade jurídica dos atos notariais registrados em blockchain. Retrieved November 16, 2024, from https://biblioteca.sophia.com.br/terminalri/2764/VisualizadorPdf?codigoArquivo=11030&tipoMidia=0

Colégio Notarial do Brasil. (n.d.). E-notariado, Backup em Nuvem e Notarchain: a revolução digital nos tabelionatos. Retrieved November 16, 2024, from https://www.notariado.org.br/wp-content/uploads/2019/09/RevistaFuturoemTransformacao.pdf

Dispõe sobre o Sistema Eletrônico dos Registros Públicos (Serp). (2022, June 27). "Lei Nº 14.382". Diário Oficial da União, 2022. Retrieved October 30, 2024, from https://www.in.gov.br/en/web/dou/-/lei-n-14.382-de-27-de-junho-de-2022-410727955

Burtet, T., Trindade, M. G. N., & Vecchio, F. B. (2021). Considerações Quanto à Possibilidade da Tokenização da Propriedade Imobiliária e dos Negócios Imobiliários no Brasil: Ficção ou Realidade? Revista de Direito Notarial, 3(2), 143-171. ISSN (electronic): 2675-9101. Retrieved August 12, 2024, from http://rdn.cnbsp.org.br/index.php/direitonotarial/article/view/40/30

Cartório no Brasil. (n.d.). Concurso para cartório: o que é e como funciona? Retrieved October 16, 2024, from https://cartorionobrasil.com.br/artigos/concurso-para-cartorio-o-que-e-e-como-funciona/

China, C. R. (2023, June 29). Digital twin vs. digital thread: Two complementary ways to digitally replicate assets. IBM Blog. Retrieved June 12, 2024, from https://www.ibm.com/blog/digital-thread-vs-digital-twin/

Constituição da República Federativa do Brasil de 1988. (1998). Brasília. Retrieved August 01, 2024, from http://www.planalto.gov.br/ccivil_03/constituicao/constituicao.htm

Crosby, M., Pattanayak, P., Verma, S., & Kalyanaraman, V. (2023, July 10). Blockchain Technology: Beyond Bitcoin. Applied Innovation, 2(71). Retrieved May

AKR *Advances on Knowledge Representation Journal*

28, 2024, from https://scet.berkeley.edu/wp-content/uploads/AIR-2016-Blockchain.pdf

Diniz, E. H. (2018). O blockchain veio para ficar. GV Executivo (Impresso)/GV Executivo, 17(3), 51. Retrieved May 02, 2024, from https://periodicos.fgv.br/gvexecutivo/article/view/75760/72608

E-Notariado. (n.d.). Retrieved November 16, 2024, from https://www.notariado.org.br/e-notariado/

Entriken, W., Shirley, D., Evans, J, & Sachs, N. (2018). ERC-721: Non-Fungible Token Standard. Ethereum Improvement Proposals. Retrieved September 24, 2023, from https://eips.ethereum.org/EIPS/eip-721

Eshghi, B. (2024). Top 5 Differences Between Ordinal Inscriptions vs NFTs in 2023. AIMultiple: High Tech Use Cases & Tools to Grow Your Business. Retrieved August 12, 2024, from https://research.aimultiple.com/ordinal-inscriptions-vs-nfts/

Franzoni, F., Abellan, I., & Daza, V. (2020). Leveraging Bitcoin Testnet for bidirectional Botnet command and control systems. In *Lecture notes in computer science* (pp. 3–19). https://doi.org/10.1007/978-3-030-51280-4_1

Furlan, J. D. (1998). Modelagem de Objetos Através da UML Unified Modeling Language. Makron Books.

Golpe Imobiliário. (n.d.). In Unio Imóveis. Retrieved October 19, 2024, from https://www.unioimoveis.com.br/golpe-imobiliario

Gomes, J. V. G. (2022). Como fazer Registro de Imóvel no Brasil - Sistema Registral. Retrieved October 15, 2024, from https://www.jusbrasil.com.br/artigos/como-fazer-registro-de-imovel-no-brasil/1742752727

Gómez-Pérez, A., Fernández-López, M., & Corcho, O. (2004). Ontological Engineering. In *Advanced information and knowledge processing*. https://doi.org/10.1007/b97353. Retrieved February 12, 2025, from https://oa.upm.es/5456/1/CL09.pdf

Gr0kchain. (2019). Understanding the data behind Bitcoin Core. Bitcoin Developer Network. Retrieved December 31, 2023, from https://bitcoindev.network/understanding-the-data/

Google Developers. (n.d.). Introduction to structured data markup in Google Search. Retrieved February 16, 2025, from https://developers.google.com/search/docs/appearance/structured-data/intro-structured-data

Hoxha, V., & Sadiku, S. (2019). Study of factors influencing the decision to adopt the blockchain technology in real estate transactions in Kosovo. Property Management, 37(5), 684–700. https://doi.org/10.1108/pm-01-2019-0002

AKR *Advances on Knowledge Representation Journal*

Hryczyk, F. A. (2024). No Brokerage for Home Buyers: Exploring a Cost-Efficient approach. Retrieved January 30, 2024, from https://www.linkedin.com/pulse/brokerage-home-buyers-exploring-cost-efficient-qumgc

IBM Documentation. (2023). Rational Software Architect 9.7.0. Retrieved March 31, 2024, from https://www.ibm.com/docs/en/rational-soft-arch/9.7.0?topic=diagrams-deployment

Kaur, Guneet. (2023). Bitcoin vs. satoshi: Key differences explained. Retrieved October 13, 2024. from https://cointelegraph.com/learn/bitcoin-vs-satoshi-key-differences-explained

Köhler, S., & Pizzol, M. (2019). Life Cycle Assessment of Bitcoin Mining. Environmental Science & Technology, vol. 53, p. 13598-13606, 2019. Retrieved November 4, 2024, from https://pubs.acs.org/doi/epdf/10.1021/acs.est.9b05687?ref=article_openPDF

Loureiro, L. G. (2004). Direitos reais : à luz do Código Civil e do direito registral. Editora Método.

Mileva, Geri. (2022, June 13) Top 12 NFT Real Estate Companies To Follow. Influencer Marketing Hub. Retrieved January 21, 2023 from https://influencermarketinghub.com/nft-real-estate-companies/#toc-8

Nakai, T., Sakurai, A., Hironaka, S., & Shudo, K. (2024). A formulation of the trilemma in proof of work blockchain. *IEEE Access*, *12*, 80559–80578. https://doi.org/10.1109/access.2024.3410025. Retrieved November 16, 2024, from https://repository.kulib.kyoto-u.ac.jp/dspace/bitstream/2433/289516/1/ACCESS.2024.3410025.pdf

Nakaike, T., Zhang, Q., Ueda, Y., Inagaki, T., & Ohara, M. (2020). Hyperledger Fabric Performance Characterization and Optimization Using GoLevelDB Benchmark. *2020 IEEE International Conference on Blockchain and Cryptocurrency (ICBC)*, 1–9. https://doi.org/10.1109/icbc48266.2020.9169454. Retrieved November 18, 2024, from https://www.researchgate.net/publication/343709352_Hyperledger_Fabric_Performance_Characterization_and_Optimization_Using_GoLevelDB_Benchmark

Nakamoto, S. (2008). Bitcoin: a Peer-to-Peer electronic cash system. Satoshi Nakamoto Institute. Retrieved May 03, 2024, from https://nakamotoinstitute.org/library/bitcoin/

Neto, O. (2022). Golpe na Compra de Imóvel: 4 cuidados simples para se prevenir. Oliveira Neto. Retrieved May 11, 2024, from https://www.oliveiranetoimob.com.br/compra-e-venda-de-imovel/como-nao-cair-em-golpe-na-compra-de-imovel/

AKR *Advances on Knowledge Representation Journal*

Object Management Group. (2005). What is UML. Retrieved March 11, 2024, from https://www.uml.org/what-is-uml.htm

Oellinger, T., & Wennerberg, P. O. (2006). Ontology based modeling and visualization of social networks for the web. INFORMATIK 2006 – Informatik für Menschen – Band 2, Beiträge der 36. Jahrestagung der Gesellschaft für Informatik e.V. (GI). Bonn: Gesellschaft für Informatik e.V.. PISSN: 1617-5468. ISBN: 978-3-88579-188-1. pp. 489-497. Regular Research Papers. Dresden. Retrieved February 12, 2025, from https://cs.emis.de/LNI/Proceedings/Proceedings94/GI-Proceedings-94-65.pdf

Ordinal Theory Handbook. (n.d.-a). Introduction. Retrieved April 07, 2024, from https://docs.ordinals.com/#introduction

Ordinal Theory Handbook. (n.d.-b). Provenance. Retrieved April 07, 2024, from https://docs.ordinals.com/inscriptions/provenance.html

Ordinal Theory Handbook. (n.d.-c). Ordinal Theory Handbook: Wallet. Retrieved April 07, 2024, from https://docs.ordinals.com/guides/wallet.html

Provenance. (n.d.). In *Dictionary.Cambridge.org dictionary*. Retrieved March 21, 2024, from https://dictionary.cambridge.org/dictionary/english/provenance

Propy. (n.d.). Buy and sell homes - faster, easier and more securely. Retrieved October 30, 2024, from https://propy.com/browse/

RealT. (n.d.). Fractional and frictionless real estate investing. Retrieved October 30, 2024, from https://realt.co/

Registro de Imóveis. (n.d.). In *Corregedoria-Geral da Justiça – Foro Extrajudicial*. Retrieved October 15, 2024, from https://extrajudicial.tjpr.jus.br/registro-imoveis

Rodarmor, C. (2022). Ordinal Numbers. GitHub. Retrieved September 18, 2023, from https://github.com/casey/ord/blob/master/bip.mediawiki

Ross, D., Cretu, E., & Lemieux, V. (2021). NFTs: Tulip Mania or Digital Renaissance? 2021 IEEE International Conference on Big Data (Big Data). https://doi.org/10.1109/bigdata52589.2021.9671707

Serrano, W. (2022). Real Estate Tokenisation via Non Fungible Tokens. ICBCT '22: Proceedings of the 2022 4th International Conference on Blockchain Technology. https://doi.org/10.1145/3532640.3532651

Sharma, R. (2024). Non-Fungible Token (NFT): What it means and how it works. Investopedia. Retrieved August 01, 2024, from https://www.investopedia.com/non-fungible-tokens-nft-5115211

Souza, G. (2022). 6 passos na compra de um imóvel. In *Jusbrasil*. Retrieved April 28, 2024, from https://www.jusbrasil.com.br/artigos/6-passos-na-compra-de-um-imovel/1597205975

AKR *Advances on Knowledge Representation Journal*

Souza, G. C., Oliveira, L. F. & Sena, V. C. (2024). Analysis of the Feasibility of the Wide Use of Blockchain Technology in Notary Offices in Brazil. Engetec em Revista, 1(9), https://doi.org/10.5281/zenodo.13367843. Retrieved November 16, 2023, from http://revista.fateczl.edu.br/index.php/engetec_revista/article/view/214/213

TechTarget Network. (2022). Resource Description Framework (RDF). Retrieved February 14, 2025, from https://www.techtarget.com/searchapparchitecture/definition/Resource-Description-Framework-RDF

Trustnodes. (2023). Taproot Based Bitcoin NFTs Spark Controversy. Retrieved May 05, 2023, from https://www.trustnodes.com/2023/01/30/taproot-based-bitcoin-nfts-spark-controversy

Van Der Horst, L., Choo, K. R., & Le-Khac, N. (2017). Process memory investigation of the Bitcoin clients Electrum and Bitcoin Core. IEEE Access, 5, 22385–22398. https://doi.org/10.1109/access.2017.2759766. Retrieved November 05, 2023, from https://ieeexplore.ieee.org/document/8058429

Vardai, Z. (2023). Ordinals inscriptions slow down but Bitcoin congestion lingers. Retrieved November 03, 2024, from https://forkast.news/ordinals-inscriptions-slow-bitcoin-congestion-lingers/

Vesta Equity. (n.d.). Global home equity marketplace. Retrieved October 30, 2024, from https://vestaequity.net

Xverse. (2025). Understanding the Basics of Bitcoin Networks. Retrieved February 21, 2025, from https://support.xverse.app/hc/en-us/articles/8713145788941-Understanding-the-Basics-of-Bitcoin-Networks#h_01J5T6ZAX1JZX7PDQ88RCE9MY1

W3C. (2020). JSON-LD 1.1 - A JSON-based Serialization for Linked Data. Retrieved February 14, 2025, from https://www.w3.org/TR/json-ld11/#iris

Werth, J., Berenjestanaki, M., Barzegar, H., Ioini, N. E., & Pahl, C. (2023). A Review of Blockchain Platforms Based on the Scalability, Security and Decentralization Trilemma. *Proceedings of the 25th International Conference on Enterprise Information Systems*, *1*, 146–155. ISBN: 978-989-758-648-4; ISSN: 2184-4992. https://doi.org/10.5220/0011837200003467. Retrieved November 05, 2024, from https://pdfs.semanticscholar.org/eeb1/21061555e383b2fe0b3a9a36c41bf5dcee14.pdf

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