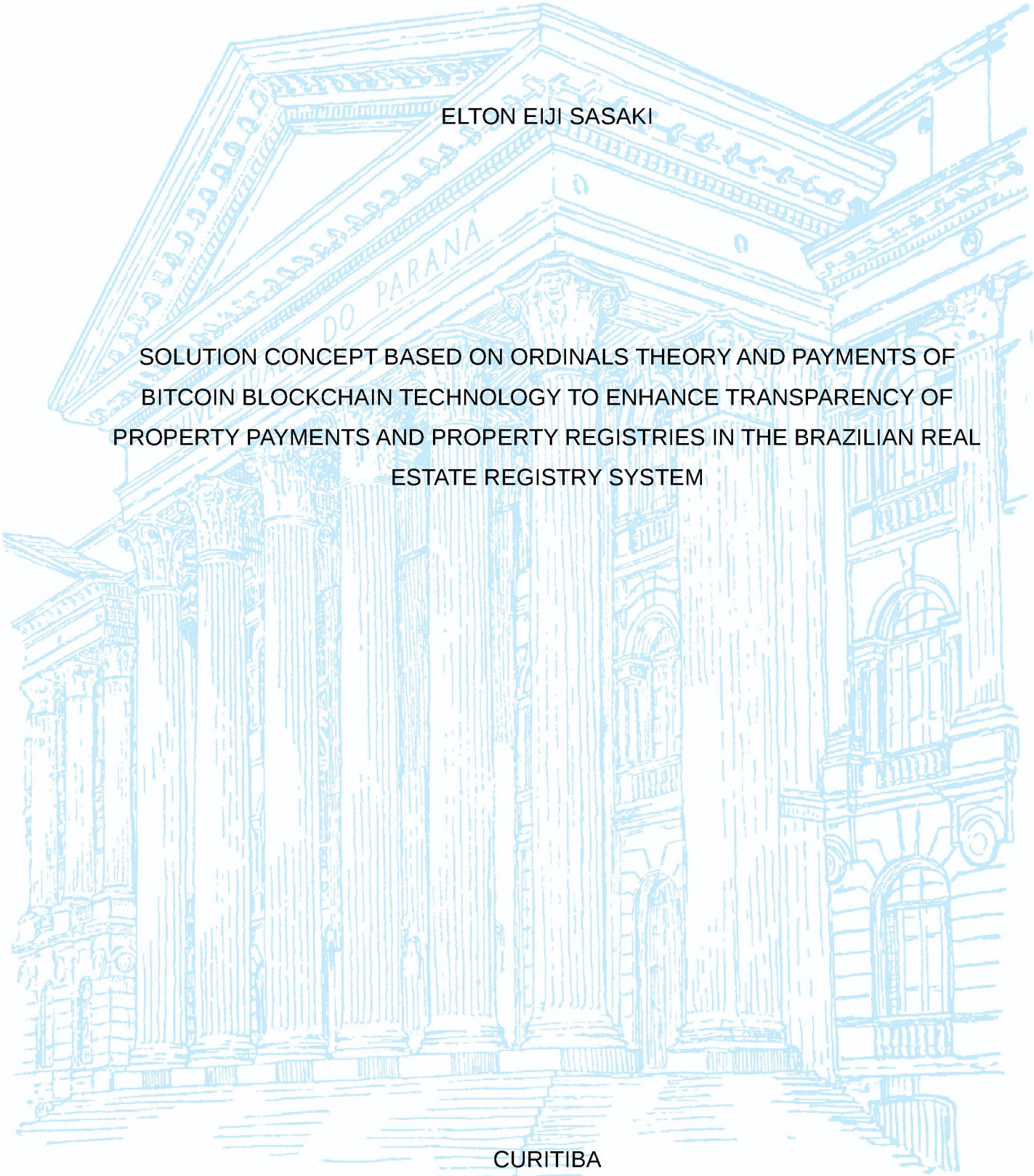
UNIVERSIDADE FEDERAL DO PARANÁ

ELTON EIJI SASAKI



SOLUTION CONCEPT BASED ON ORDINALS THEORY AND PAYMENTS OF BITCOIN BLOCKCHAIN TECHNOLOGY TO ENHANCE TRANSPARENCY OF PROPERTY PAYMENTS AND PROPERTY REGISTRIES IN THE BRAZILIAN REAL ESTATE REGISTRY SYSTEM

CURITIBA

2025

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Tese apresentada ao Curso de Pós-Graduação em Gestão da Informação, Setor de Ciências Sociais Aplicadas, da Universidade Federal do Paraná, como requisito parcial à obtenção do título de Doutor em Gestão da Informação.

Orientador: Prof. Dr. Egon Walter Wildauer

Coorientador: Prof. Dr. José Simão de Paula Pinto

Coorientador na Alemanha durante Programa de Doutorado-Sanduíche no Exterior (PDSE) da CAPES: Pror. Dr. Daniel Grossmann

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TERMO DE APROVAÇÃO

Os membros da Banca Examinadora designada pelo Colegiado do Programa de Pós-Graduação GESTÃO DA INFORMAÇÃO da Universidade Federal do Paraná foram convocados para realizar a arguição da tese de Doutorado de **ELTON EIJI SASAKI**, intitulada: **SOLUTION CONCEPT BASED ON ORDINALS THEORY AND PAYMENTS OF BITCOIN BLOCKCHAIN TECHNOLOGY TO ENHANCE TRANSPARENCY OF PROPERTY PAYMENTS AND PROPERTY REGISTRIES IN THE BRAZILIAN REAL ESTATE REGISTRY SYSTEM**, sob orientação do Prof. Dr. EGON WALTER WILDAUER, que após terem inquirido o aluno e realizada a avaliação do trabalho, são de parecer pela sua APROVAÇÃO no rito de defesa.
A outorga do título de doutor está sujeita à homologação pelo colegiado, ao atendimento de todas as indicações e correções solicitadas pela banca e ao pleno atendimento das demandas regimentais do Programa de Pós-Graduação.

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04/04/2025 13:40:32.0
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Presidente da Banca Examinadora

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RESUMO[1]

Objetivo: Este projeto de pesquisa propõe um Conceito de Solução baseado em *Bitcoin Blockchain* para auxiliar na solução do problema de transparência no Sistema de Registro de Imóveis Brasileiro, fornecendo um método para assinatura e registro de Escrituras Públicas de Compra e Venda, e registro de Pagamentos de Compra e Venda de Imóveis, Registros de Propriedade de Imóveis e Registros de Transferência de Propriedade de Imóveis no *Bitcoin Blockchain*. Métodos: Este projeto de pesquisa implementa o Conceito de Solução usando diagramas de *Unified Modeling Language* (UML) para especificação de requisitos para desenvolver uma Aplicação Desktop na linguagem de programação Java. A Aplicação Desktop serve como uma GUI (Graphical User Interface) que interage com a Rede do *Bitcoin Blockchain*, o *software* da carteira *bitcoin* e *full node* do *Bitcoin Core* e o *software utilitário* do *Bitcoin Ordinal*. Resultados: Por meio do Conceito de Solução, verifica-se que haveria mais confiança e segurança no Sistema de Registro de Imóveis Brasileiro se os Pagamentos de Compra e Venda de Imóveis fossem realizados em *bitcoin*. Além disso, verifica-se que a procedência e o *digital thread* dos Registros de Propriedade de Imóveis seriam assegurados se fossem registrados no *Bitcoin Blockchain*. Por fim, a Rede *Testnet3* do *Bitcoin Blockchain* também arca com os mesmos problemas de escalabilidade da Rede *Mainnet* do *Bitcoin Blockchain*, com atraso no tempo de confirmação de transações de pagamentos e transações de Registro de Propriedade e Transferência de Imóveis. Conclusões: O *Bitcoin Blockchain* adiciona transparência ao Sistema Brasileiro de Registro de Imóveis porque os Pagamentos de Compra e Venda de Imóveis, Registros de Propriedade de Imóveis e Registros de Transferência de Propriedade de Imóveis registrados no *Bitcoin Blockchain* são públicos, rastreáveis e imutáveis (Bitcoin.org, 2024d). Embora a Rede do *Bitcoin Blockchain* tenha problemas de escalabilidade, foi verificado que isso se deve ao design de rede pública do *Bitcoin Blockchain* que prioriza a

[1]SECTION “RESUMO” contains text with translation to Portuguese from SECTION “Abstract” of the published article at the following reference: SASAKI, E. E., GROSSMANN, D., WILDAUER, E. W. **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.** Advances on Knowledge Representation, vol. 1, no. 1, p. 137-168, 2025. DOI: 10.5281/zenodo.15041980. Available in: https://periodicos.ufmg.br/index.php/advances-kr/article/view/53994/47843.

descentralização e a segurança em detrimento da escalabilidade dentro do domínio do *Blockchain Trilemma* (Nakai et al., 2024, p. 80560).

Palavras-chave: Blockchain 1. Teoria de Ordinal 2. Pagamentos em *Bitcoin* 3. Sistema de registro de imóveis brasileiro 4.

ABSTRACT[2]

Objective: This research project proposes a Solution Concept based on Bitcoin Blockchain to aid in solving the problem of transparency in the Brazilian Real Estate Registry System by providing a method for signing and registering Public Deeds of Sale and Purchase, and registering Property Payments, Property Registries (Ownership) and Property Transfer Registries on the Bitcoin Blockchain. Methods: This research project implements the Solution Concept using Unified Modeling Language (UML) diagrams to specify requirements to develop a Desktop Application in Java programming language. The Desktop Application serves as a GUI (Graphical User Interface) that interacts with the Bitcoin Blockchain Network, Bitcoin Core's full node and wallet softwares, and the Bitcoin Ordinal software utility. Results: Through the Solution Concept, it is verified that there would be more certainty and 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 and Property Registry transactions. Conclusions: The Bitcoin Blockchain adds transparency to the Brazilian Real Estate Registry System because Property Payments, Property Registries (Ownership), and Property Transfers registered on the Bitcoin Blockchain are public, traceable, and immutable (Bitcoin.org, 2024d). 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).

Keywords: Blockchain 1. Ordinal theory 2. Bitcoin payments 3. Brazilian Real Estate Registry System 4.

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[2]SECTION "ABSTRACT" contains text from SECTION "Abstract" of the published article at the following reference: SASAKI, E. E., GROSSMANN, D., WILDAUER, E. W. **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.** Advances on Knowledge Representation, vol. 1, no. 1, p. 137-168, 2025. DOI: 10.5281/zenodo.15041980. Available in: https://periodicos.ufmg.br/index.php/advances-kr/article/view/53994/47843.

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LIST OF ABBREVIATIONS AND ACRONYMS

API	- Application Programming Interface
dApp	- Decentralized Application
CAPES	- Coordenação de Aperfeiçoamento de Pessoal de Nível Superior
EVM	- Ethereum Virtual Machine
GUI	- Graphical User Interface
HFB	- Hyperledger Fabric Blockchain
ICP-Brasil	- Brazilian Public-Key Infrastructure
KR	- Knowledge Representation
IPFS	- InterPlanetary File System
JSON	- JavaScript Object Notation
MVC	- Model-View-Controller
NFT	- Non-fungible Token
RPC	- Remote Procedure Call
URI	- Uniform Resource Identifier

SUMMARY

PREFACE

Parts of this doctorate dissertation has been published. For the flow of the doctorate dissertation, changes were made to the text of the published article that were incorporated in this doctorate dissertation.

Published article:

SASAKI, E. E., GROSSMANN, D., WILDAUER, E. W. **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.** Advances on Knowledge Representation, vol. 1, no. 1, p. 137-168, 2025. DOI: 10.5281/zenodo.15041980. Available in: https://periodicos.ufmg.br/index.php/advances-kr/article/view/53994/47843.

- SECTION “RESUMO” is an extended version from SECTION “Abstract” of the published article.
- SECTION “ABSTRACT” is an extended version from SECTION “Abstract” of the published article.
- SECTION “1 INTRODUCTION” contains text from SECTION “2.1. Bitcoin Blockchain Technology” of the published article.
- SECTION “1.1 PROBLEM” contains text from SECTION “1. Introduction” of the published article.
- SECTION “1.2 CONTEXT ” contains text from SECTION “1. Introduction” of the published article.
- SECTION “1.3 JUSTIFICATION” contains text from SECTION “1. Introduction” of the published article.
- SECTION “2.5 BITCOIN INSCRIPTIONS/NON-FUNGIBLE-TOKENS (NFTs)” contains text from SECTION “2.1. Bitcoin Blockchain Technology” of the published article.
- SECTION “2.6 BLOCKCHAIN TRILEMMA” contains text from SECTION “2.2. Blockchain Trilemma” of the published article.

- SECTION “2.7 REAL ESTATE REGISTRY SYSTEM IN BRAZIL” contains text from entire SECTION “2.3. Real Estate Registry System in Brazil” of the published article.
- SECTION “2.8 RELATED WORKS” contains text from SECTION “2.4. Related Works” of the published article.
- SECTION “2.9 UNIFIED MODELING LANGUAGE (UML), MODEL–VIEW–CONTROLLER (MVC) DESIGN PATTERN, AND KNOWLEDGE REPRESENTATION (KR)” contains text from SECTION “3. Methodology” of the published article.
- SECTION “2.10 KNOWLEDGE REPRESENTATION (KR)” contains text from SECTION “3.4. Knowledge Representation” of the published article.
- SECTION “3.2 DELIMITATION” contains text from SECTION “3. Methodology” of the published article.
- SECTION “3.3 SOLUTION CONCEPT REQUIREMENTS” contains text from SECTION “3. Methodology” of the published article.
- SECTION “3.3.6 Application of Knowledge Representation (KR)” contains text from SECTION “3.4. Knowledge Representation” of the published article.
- SECTION “3.4 SOLUTION CONCEPT DEVELOPMENT” contains text from SECTION “4.1. Implementation of the Solution Concept” of the published article.
- SECTION “4.1 SCALABILITY: LIMITATIONS AND CHALLENGES OF THE SOLUTION CONCEPT” contains text from SECTION “4.2. Limitations and Challenges of the Solution Concept” of the published article.

  SECTION “5 CONCLUSIONS” contains text from SECTION “5. Conclusion” of the published article.

1 INTRODUCTION[3]

The emergence of blockchain and cryptocurrencies are 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). This technology introduced decentralized trust in banking and payment system (Antonopoulos, 2014, 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, which is a data structure that mainly records and timestamps Bitcoin transactions.

Moreover, the Bitcoin Blockchain also allows recording and timestamping different data formats. This allows for the provision of notarization services by obtaining a “cryptographic hash, or ‘fingerprint’, that is unique for each file. This hash […] of the whole structure containing the files’ fingerprints is recorded into the blockchain” (Acronis, 2025a). This service is provided by Blocknotary (Blocknotary, 2025), Stampd (Stampd, 2025b), Acronis (Acronis, 2025a).

Additionally, 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, 2023) to be stored on the blockchain. Thus, this increase of up to 4MB in storage has enabled Non-fungible Tokens (NFTs) to be implemented on Bitcoin since its blockchain can now “contain media” (Dalton, 2023).

“An NFT, or non-fungible token, is a unique, digital object certified on a blockchain or distributed ledger” (Ross; Cretu; Lemieux, 2021, p. 2262), that can be “owned and transacted by individuals as well as consignment to third party brokers/wallets/auctioneers

[3]SECTION “1 INTRODUCTION” contains text from SECTION “2.1. Bitcoin Blockchain Technology” of the published article at the following reference: SASAKI, E. E., GROSSMANN, D., WILDAUER, E. W. **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.** Advances on Knowledge Representation, vol. 1, no. 1, p. 137-168, 2025. DOI: 10.5281/zenodo.15041980. Available in: https://periodicos.ufmg.br/index.php/advances-kr/article/view/53994/47843.

('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).[4]

The creation of NFTs began in June 2017 (Marcobello, 2022) with the CryptoArt movement led by the CryptoPunks collectable characters that inspired the development of an NFT standard, called ERC-721, on Ethereum blockchain, which powers most NFT projects (CryptoPunks, 2022).

Besides using NFTs for "digital art and collectibles" (CryptoPunks, 2022), different service sectors are using NFTs. In the gaming industry, NFTs:

> "have offered a way for content owners to further fan engagement with particular games, in the same way that 'skins' and various offerings for in-game avatars offered additional engagement for their fans. With NFTs, there's an added dimension of ownership in a piece of property. They're buying some sense of, 'I get to be a part of this game, and I get to own a piece of property that's related to the game.' So, from a content-owner perspective, NFTs are furthering the content owners' reach within the community that they already have, and also providing the ability to expand into a new audience that might not otherwise have engaged with a game, because there is the new concept of, 'Look, I get to actually participate in and own a piece of this game.' So NFTs offer a new way for fans to engage and interact with the games" (Sullivan, 2022).

In the supply chain industry, "NFTs are used to represent the digital twin of the medical device. This digital twin captures the medical device attributes and its relevant metadata during its life cycle from production, manufacturing, distribution and movement, to current use and ownership" (Gebreab et al., 2022, p. 126394). In the real estate industry, NFT is used to represent "a physical real state asset where both entities, physical and digital, are linked together" (Serrano, 2022).

[4]SASAKI, E. E., GROSSMANN, D., WILDAUER, E. W. **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.** Advances on Knowledge Representation, vol. 1, no. 1, p. 137-168, 2025. DOI: 10.5281/zenodo.15041980. Available in: https://periodicos.ufmg.br/index.php/advances-kr/article/view/53994/47843.

1.1 PROBLEM[5]

This research project aims to present a Solution Concept to aid in solving the problem of transparency, uncertainty, and insecurity in the Brazilian Real Estate Registry System by providing a method for signing and registering Public Deeds of Sale and Purchase, and registering Property Purchase Payments, Property Registries and Property Transfers on the Bitcoin Blockchain. Furthermore, this research project concerns itself in building a Solution Concept for the Real Estate Registry System delegated by the Brazilian Federal State level.

The Brazilian Real Estate Registry System currently uses e-Notariado's digital certificate platform which is composed of two technologies: a Cloud Backup solution for data storage, and Notarchain Blockchain solution (Colégio Notarial do Brasil, 2025). The Solution Concept presents Blockchain utilities not provided by the e-Notariado's Notarchain Blockchain, such as storing documents, signing Public Deeds of Sale and Purchase, and paying for properties on-chain, i.e., "activities, data, or transactions that occur directly within a blockchain network" (Legge, 2023). On e-Notariado's platform, document hashes (Martini, 2020) are registered on the Notarchain Blockchain, and the content of documents is stored on a Cloud Backup solution (Colégio Notarial do Brasil, 2025).

1.2 CONTEXT[6]

A Political, Economical, Social, Technological, Legal, and Environmental (PESTLE) analysis on the Brazilian Real Estate Registry System points out the growing need to use NFTs to provide real estate services.

[5]SECTION "1.1 PROBLEM" contains text from SECTION "1. Introduction" of the published article at the following reference: SASAKI, E. E., GROSSMANN, D., WILDAUER, E. W. **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.** Advances on Knowledge Representation, vol. 1, no. 1, p. 137-168, 2025. DOI: 10.5281/zenodo.15041980. Available in: https://periodicos.ufmg.br/index.php/advances-kr/article/view/53994/47843.

[6]SECTION "1.2 CONTEXT " contains text from SECTION "1. Introduction" of the published article at the following reference: SASAKI, E. E., GROSSMANN, D., WILDAUER, E. W. **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.** Advances on Knowledge Representation, vol. 1, no. 1, p. 137-168, 2025. DOI: 10.5281/zenodo.15041980. Available in: https://periodicos.ufmg.br/index.php/advances-kr/article/view/53994/47843.

In regard to the economic context of NFTs and real estate markets, both have high market cap values. The most popular use cases for cryptocurrencies are NFTs (Non-Fungible Tokens), DeFi (Decentralized Finance) and GameFi (Video Gaming Finance). These three popular use cases, NFTs, DeFi and GameFi, represent digital assets supported by blockchain technology in the form of cryptocurrencies and tokens (Bouraga, 2021).

In December 27th, 2022, the total market cap of NFTs was USD$ 10.7 Billion (Coingecko, 2022c). In comparison with other popular use cases for cryptocurrencies, in December 27th, 2022, the market cap of DeFi was USD$ 35.4 Billion (Coingecko, 2022a) and the market cap of GameFi was USD$ 6.5 Billion (Coingecko, 2022b). Currenlty, two years later, in December 7th, 2024, the total market cap of NFTs, DeFi, and GameFi is USD$ 40 Billion (Coingecko, 2022c), USD$ 142.3 Billion (Coingecko, 2022a), and USD$ 34,1 Billion (Coingecko, 2022b), respectively.

According to Tostevin (2021), real estate “property is the world’s biggest store of wealth” (Tostevin, 2021). “The value of all the world’s real estate reached $326.5 trillion in 2020, a 5% increase on 2019 levels and a record high. Growth was driven by residential which is by far the largest real estate sector, accounting for 79% of all global real estate value. It saw its value increase by 8% over the year, to some $258.5 trillion” (Tostevin, 2021). By 2024, “the Real Estate market worldwide is expected to reach a staggering value of US$634.90tn” (Statista, 2024).

As for the political and legal context, 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 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 criteria of the National Council of Justice (CNJ). The system should allow remote assistance to users of public records via 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).

In addition, NTFs' use in real estate markets could be subject to laws and regulations in Brazil. According to Comissão de Valores Mobiliários (CVM), which is the United States' Securities and Exchange Commission (SEC) equivalent in Brazil, there is not a specific regulation on NFTs according to a document published on October 11th, 2022, called PARECER DE ORIENTAÇÃO CVM nº 40 (Comissão de Valores Mobiliários, 2022), but the document states that crypto assets such as NFTs may be subject to laws and regulations applicable to services in which NFTs are being used. In real estate markets, selling real estate properties as NFTs may be liable to capital gains tax in Brazil. Moreover, buying real estate properties with cryptocurrencies may also be liable to capital gains tax in Brazil.

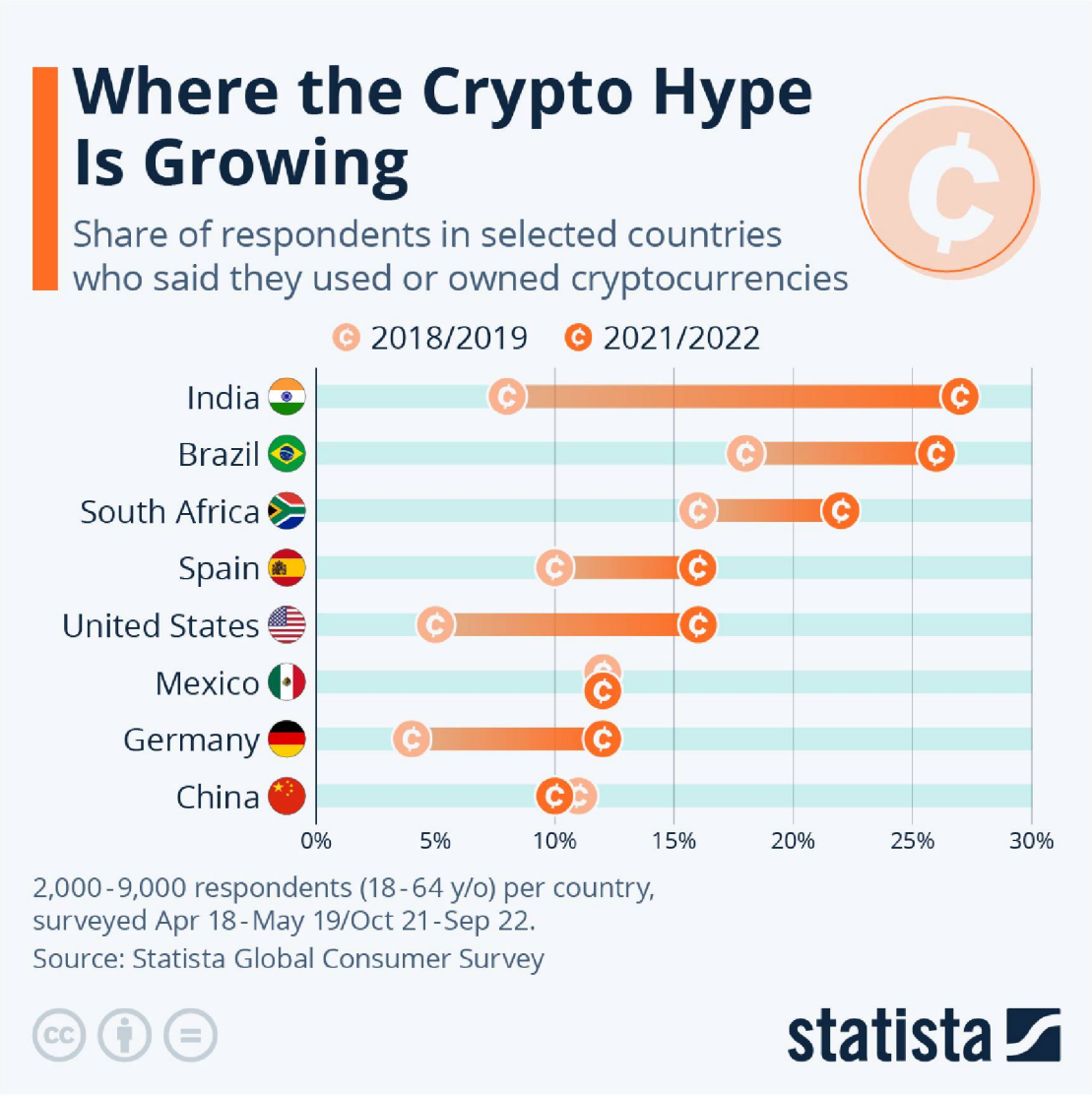
With respect to the social, technological, and environmental context of NFTs and real estate markets, according to Vick (2022), in the article entitled "How NFTs Are Creating Social Value", "the NFT space allows small communities to form based on the convergence of art, technology and purpose" (Vick, 2022), which as a result, "the emergence of NFTs and decentralized communities has also led to a new way of thinking about social responsibility and sustainability" (Vick, 2022). Moreover, NFT-based blockchain technologies simplifies "property sales by eliminating intermediaries and reducing dependence on complex paperwork" (Dobruský, 2022). Even though NFTs were purposely created to represent digital art and collectibles (CryptoPunks, 2022), NFT Real Estate can facilitate community access to property ownership.

Moreover, there have been an increase of internet access and cryptocurrency adoption in Brazil. According to a research conducted in 2024 by Cetic.br (Centro Regional de Estudos para o Desenvolvimento da Sociedade da Informação - Regional Center of Studies for the Development of the Information Society), 86% of individuals aged 10 or older have accessed the internet in Brazil (CGI.br, 2024). According to a research conducted in 2021, there has been an increase on internet access by individuals aged 10 or older in Brazil. In 2021, 81% of individuals aged 10 or older (148 million individuals) accessed the internet in Brazil, which is a 7% increase in comparison 2019 (Silva, 2022; CETIC.br, 2022).

Additionally, according to a national research conducted in partnership with IBGE (Instituto Brasileiro de Geografia e Estatistica - Brazilian Institute of Geography and Statistics) and the Ministry of Communications of Brazil, in 2021, 90% of Brazilian households had internet access, which corresponds to 65.6 million households, an

increase of more than 5.8 million in comparison to 2019 (Casa Civil, 2022). This research also informs that, in 2021, 155.2 million people aged 10 or older owed a cell phone, which accounts to 84,4% of the Brazilian population, an increase of 3% in comparison to 2019 (81.4%) (R7, 2022).

FIGURE 1 – WHERE THE CRYPTO HYPE IS GROWING



SOURCE: STATISTA GLOBAL CONSUMER SURVEY (2023).

Brazil is among the countries, along with India, Unite States and Germany “where the number of crypto users and owners increased significantly between 2018/19 and 2021/22” (Armstrong, 2022) (FIGURE 1). Regarding cryptocurrency adoption, Brazil was ranked 7th out of 146 countries in 2022, 14th in 2021 and 13th in 2020 according to Statista (2023).

1.3 JUSTIFICATION[7]

This research project is in line with the Information Management Postgraduate Programme of the Universidade Federal do Paraná in its Information and Technology area of research that studies “the development of methods, techniques and tools with a view to transforming data and information as an input for the development and improvement of technological processes and products” (Universidade Federal Do Paraná, 2025).

It justifies implementing this solution (as described in SECTION “1.1 PROBLEM”) based on Bitcoin Blockchain technology to increase transparency and decrease uncertainty and insecurity in the Brazilian Real Estate Registry System. “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, since the launch of NFTs through the Ordinal Theory on the Bitcoin Blockchain in January 2023 (Rodarmor, 2023a), the Bitcoin Blockchain technology can aid in solving the problem of transparency in real estate records by storing Public Deeds of Sale and Purchase and Property Registries on the Bitcoin Blockchain through Ordinal Theory.

Moreover, uncertainty and insecurity may be eliminated in the Brazilian Real Estate Registry System by sending and verifying bitcoin payments on the Bitcoin Blockchain and signing Public Deeds of Sale and Purchase using a method that combines Bitcoin multi-signature transactions and Ordinal Theory.

Finally, the primary motivation for the creation of Bitcoin was to record and timestamp financial transactions, Bitcoin technology also aids in solving the problem of transparency in real estate records’ storage. Currently, storage of Public Deeds of Sale and Purchase (Escrituras Públicas de Compra e Venda) and Property Registries are maintained in private storage servers and/or third party cloud storage servers, which are

[7]SECTION “1.3 JUSTIFICATION” contains text from SECTION “1. Introduction” of the published article at the following reference: SASAKI, E. E., GROSSMANN, D., WILDAUER, E. W. **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.** Advances on Knowledge Representation, vol. 1, no. 1, p. 137-168, 2025. DOI: 10.5281/zenodo.15041980. Available in: https://periodicos.ufmg.br/index.php/advances-kr/article/view/53994/47843.

“dependent upon the continuing existence of the webhost. A consequence is the loss of neutrality and decentralization inherent to the blockchain ethos, since these platforms come under the control of the elite few” (Ross; Cretu; Lemieux, 2021, p. 2264). To solve this issue, this research project uses the Bitcoin Blockchain to permanently store real estate property records. This is made possible by paying a “one-time, up-front fee” (Amber Group, 2021) in bitcoin to Nodes, that are responsible for permanently storing data on the Bitcoin Blockchain.

1.4 OBJECTIVES

The objectives of this research project are divided in general and specific objectives.

1.4.1 General Objectives

This research project develops a Solution Concept based on Bitcoin Blockchain to aid in solving the problem of transparency, uncertainty and insecurity in the Brazilian Real Estate Registry System by providing a method for signing and registering Public Deeds of Sale, and Purchase and registering Property Payments, Property Registries (Ownership) and Property Transfer Registries on the Bitcoin Blockchain. Furthermore, this research project concerns itself in building a Solution Concept for the Real Estate Registry System delegated by the Brazilian Federal State level.

1.4.2 Specific Objectives

a) Identify how the Bitcoin Blockchain technology, specifically the Bitcoin Core software and the Ordinal Software Utility (SECTION “3.3.1.1 Linux Server Node”), can aid in solving the problem of transparency, uncertainty, and insecurity in the Brazilian Real Estate Registry System.
b) Develop a proof of the Solution Concept (SECTION “3.4 SOLUTION CONCEPT DEVELOPMENT”) through an application using the Java programming language and technology based on the identified system requirements of SECTION “3.3

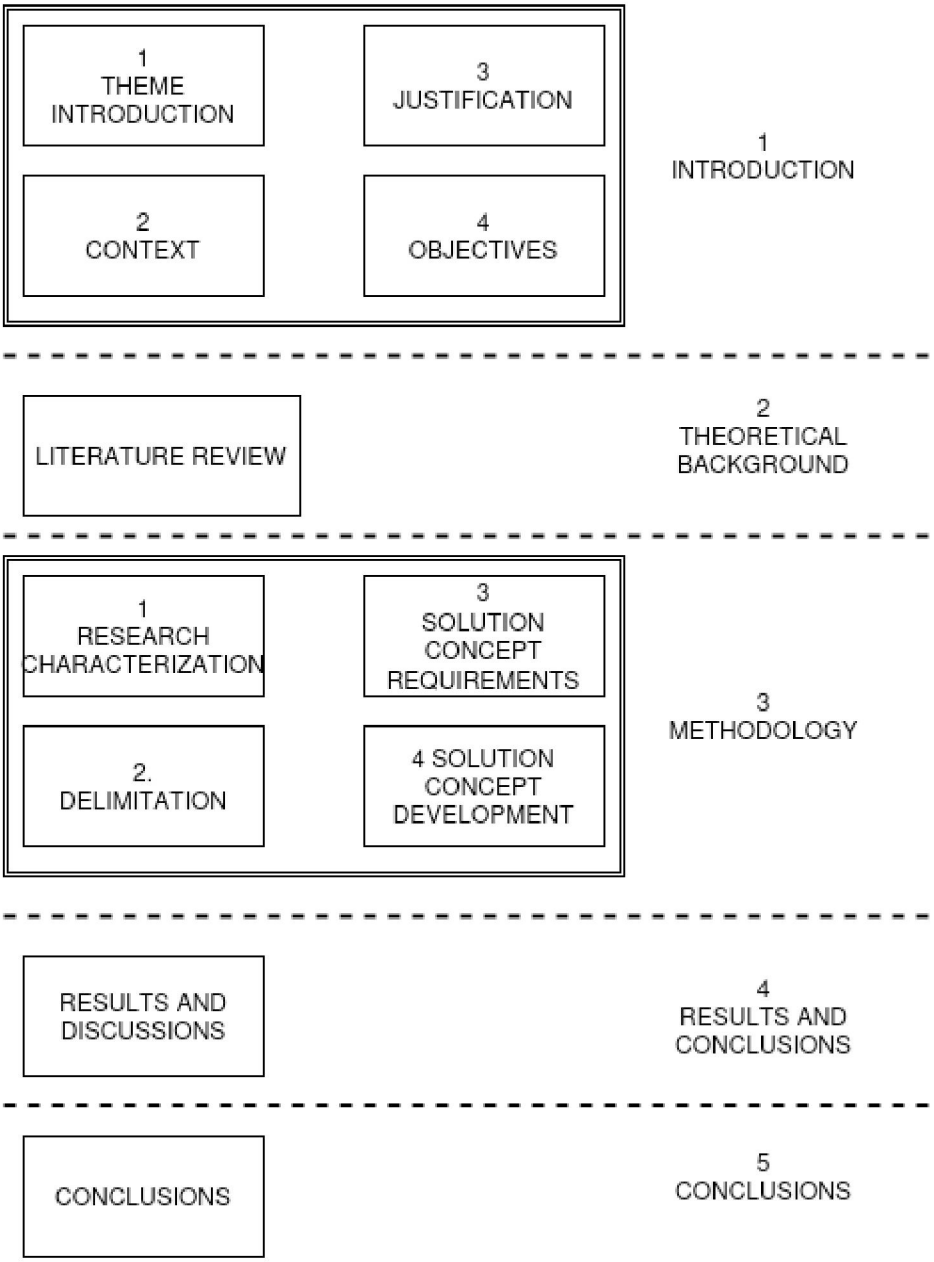
SOLUTION CONCEPT REQUIREMENTS" to construct a Real Estate Registry System based on Bitcoin Blockchain.

c) Compare the Solution Concept (SECTION "4 RESULTS AND DISCUSSIONS") with other systems considering three comparison parameters: NFT system, payment/timestamp system, and registry system.

1.5 THESIS STRUCTURE

This thesis is structured in five chapters (FIGURE 2). Chapter 1 presents this project's introduction, justification, and objectives (general and specific). Chapter 2 begins with the introduction of bitcoin blockchain, and its operation as "an electronic payment system based on cryptographic proof" (Nakamoto, 2008, p. 1). It is followed with the introduction of Ethereum blockchain, and its smart contract capabilities that allows for issuance of NFT assets. Finally, it defines the "the broken link problem", an issue that makes NFT objects unrenderable, unrecoverable and considered lost. Chapter 3 presents the research characterization, research geographical delimitation, Solution Concept requirements, and Solution Concept development. Chapter 4 presents results and discussions regarding achieving the general and specific objectives proposed in this research project. Chapter 5 presents conclusions regarding this research project.

FIGURE 2 – STRUCTURE OF DISSERTATION PROJECT



SOURCE: AUTHOR (2025).

2 LITERATURE REVIEW

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

2.1 BITCOIN BLOCKCHAIN TECHNOLOGY[8]

In 2008, with the publication of the Bitcoin white paper and implementation of Bitcoin prototype, a decentralized currency was created based on cryptography. It allows two or more parties to exchange financial transactions without intermediaries, such as banks or money transfer services. Since transactions are validated by participants in a peer-to-peer network, it eliminates centralized control and reduces transaction costs. (Karame; Androulaki, 2016, p. 1).

Bitcoin is a distributed timestamp server created to record transactions of a digital cash system (Saito; Yamada, 2016, p. 168). Antonopoulos (2010, p. 163) defines blockchain as a data structure that is organized in “an ordered back-linked list of blocks of transactions”. He adds that

> the blockchain is often visualized as a vertical stack, with blocks layered on top of each other and the first block ever serving as the foundation of the stack. The visualization of blocks stacked on top of each other results in the use of terms like ‘height’ to refer to the distance from the first block, and ‘top’ or ‘tip’ to refer to the most recently added block” (Antonopoulos, 2010, p. 163).

Every computer server that participates in the distributed peer-to-peer network is a node. Nodes are computers participating in the peer-to-peer network, where each node shares a copy of a data timestamp server, known as blockchain (Antonopoulos, 2010, p. xviii).

2.1.1 Multisig Smart Contracts on Bitcoin Blockchain

[8]Additional Literarure Review regargind BITCOIN BLOCKCHAIN TECHNOLOGY can be found in SECTION “2.1 BITCOIN CRYPTOCURRENCY” of the thesis by this same author at the following reference: SASAKI, E. E. **Use of Blockchain Timestamping and Digital Certificates Based on ICP-BRASIL Standards to Provide Authenticity of Documents.** Advisor: Egon Walter Wildauer. 2020. Thesis (Master’s in Information Management) – Universidade Federal do Paraná. Curitiba, 2020. Available in: https://acervodigital.ufpr.br/handle/1884/68798?show=full.

According to Singh et al. (2020) smart contracts are codifyied self-executing contract agrements that are stored on a blockchain. “Smart contracts can facilitate safe and trusted business activities by providing automated transactions without the supervision of an external financial system such as banks, courts, or notaries. These transactions are traceable, transparent, and irreversible” (Singh, 2020).

Furthermore, “smart contracts refer to binding contracts between two or more parties and are enforced in a decentralized manner by the blockchain without the need for a centralized enforcer” (Karame; Androulaki, 2016, p. 172). Smart contracts can “be used to control the ownership of properties. These properties might be tangible (e.g., houses, automobiles) or intangible (e.g., shares, access rights)” (Nofer, M. *et al*., 2017, p. 185).

The Bitcoin Blockchain allows for constrained usage of smart contracts because of its “limited set of variables, transaction types, and data storage [that] seemed to limit the types of applications that could run on top, as second layer solutions” (Antonopoulos; Wood, 2018, p. 18).

One smart contract that exists on the Bitcoin Blockchain is called Multi-signature (Multisig), which “refers to requiring multiple keys to authorize a Bitcoin transaction, rather than a single signature from one key” (Bitcoin Wiki, 2024b). “A multisignature is a methodology that allows more than one person to jointly create a digital signature. […] A multisignature transaction is a Bitcoin transaction that has been sent to a multisignature address, thus requiring the signatures of certain people from the multisignature group to reuse the funds. […] In a multisignature, "m" signatures out of a group of "n" are required to form the signature, where ‘m ≤ n’.” (Blockchain Commons, 2022b). Multisignature transactions are used to construct smart contracts in order to achieve the following types of contracts (Karame; Androulaki, 2016, P. 172):

1) Making a Deposit:

> there are a number of application scenarios where users need to make deposits (e.g., when using a service which requires assurance in case of damage or misuse). Bitcoin can plan for this case by enabling the creation of deposits to potentially untrusted entities (Karame; Androulaki, 2016, p. 172).

2) Dispute Mediation:

> the aforementioned process of making deposits can be inherently extended to deal with dispute mediation. For instance, A and B can agree on a neutral dispute meditator M. Here, all transactions issued by A can be constructed so that they can

> be spent using the signatures of any two out of the three parties: A, B, and M (Karame; Androulaki, 2016, p. 172).

3) Managing Multiuser Funds:

> bitcoin additionally enables different users to collaboratively raise funds for any given project without the need for an external arbiter, for example, to handle disputes. For instance, assume that different entities A1,..., An decide to collaboratively raise funds of v BTCs in order to support a project. In this case, it is required that if v BTCs could not be jointly raised, then the funds committed by each entity should be reimbursed (Karame; Androulaki, 2016, p. 172).

4) Signing Public Deed of Sale and Purchase (Escritura Pública de Compra e Venda):

The Ordinal Theory (SECTION “2.5”) makes it possible for using Multisig to sign contracts such as Public Deed of Sale and Purchase. The use of Multisig to sign Public Deed of Sale and Purchases is applied in SECTION “3 METHODOLOGY”.

2.2 ETHEREUM BLOCKCHAIN TECHNOLOGY

Ethereum blockchain was the first platform to popularize smart contracts (FORBES, 2018). "Ethereum is a platform based on a peer-to-peer network that supports an immutable transaction record on a public shared ledger, known as blockchain” (Urquhart, 2022, p. 1), similar to Bitcoin Blockchain. The main difference between Ethereum and Bitcoin is that Ethereum is a “blockchain-based platform for smart contracts – Turing complete programs that are executed in a decentralized network” (Tikhomirov, 2017). The Bitcoin Blockchain, in comparison, provides limited development of smart contracts in the Bitcoin language called *Script* (Bitcoinist, 2022). Ethereum’s smart contract (Turing complete) feature:

> [...] is often described with the term ‘world computer,’ since this platform enables running distributed applications (i.e., smart contracts) in a distributed manner. It provides a way to create self-executing and self-enforcing contracts. Their execution is triggered via transactions. Once generated, nodes in the P2P system execute the related code. This causes a change of the state. All this is recorded in the blockchain. Thus, through the blockchain all nodes synchronize their replicated state globally, in a manner that is fully verifiable by any system participant. That is why the distributed code run on the blockchain is referred as a smart contract. Once deployed, it cannot be modified. Hence, parties, which agree on the use of this code, are aware that there is no possibility to breach the agreement. (They can, of course, decide to not use that contract anymore, if for some reason the contract becomes obsolete.) (Ferretti; D'angelo, 2020, p. 1).

In Ethereum, each smart contract deployed to the Ethereum blockchain is an account. “There are two types of accounts: externally owned accounts [wallet addresses], controlled by private keys, and [smart] contract accounts, controlled by their contract code. An externally owned account has no code, and one can send messages from an externally owned account by creating and signing a transaction; in a [smart] contract account, every time the [smart] contract account receives a message its code activates, allowing it to read and write to internal storage and send other messages or create contracts in turn” (Ethereum Whitepaper, 2022). Each Ethereum account has a 20 byte address that is used to transfer value and information between accounts (Ethereum Whitepaper, 2022).

In Ethereum, “transaction fee is charged in terms of Ethers” (Khan; Sarwar; Awais, 2021, p. 1). The cryptocurrency “Ether” is used to pay transaction fees for every transaction that signs a “data package that stores a message to be sent from an externally owned account” (Ethereum Whitepaper, 2022).

2.2.1 Messages and transactions

A “transaction” in Ethereum is executed by an externally owned account (wallet address) that signs a data package containing a message to be sent to another externally owned account or contract account. A “message” in Ethereum is just like a transaction, but it is only executed by smart contract accounts that only send “messages” to other smart contract accounts (Ethereum Whitepaper, 2022).

Smart '“contracts’ in Ethereum should not be seen as something that should be ‘fulfilled’ or ‘complied with’; rather, they are more like ‘autonomous agents’ that live inside of the Ethereum execution environment, always executing a specific piece of code when ‘poked’ by a message or transaction, and having direct control over their own ether balance and their own key/value store to keep track of persistent variables” (Ethereum Whitepaper, 2022).

“A message is produced when a [smart] contract currently executing code executes the CALL opcode, which produces and executes a message. Like a transaction, a message leads to the recipient [smart contract] account running its code. Thus, [smart] contracts can have relationships with other [smart] contracts in exactly the same way that

external actors can" (Ethereum Whitepaper, 2022). An "opcode" is a metadata field contained in a message that a contract account can access its data.

As an example use case of "opcode", "if a contract is functioning as an on-blockchain domain registration service, then it may wish to interpret the data being passed to it as containing two 'fields', the first field being a domain to register and the second field being the IP address to register it to. The contract would read these values from the message data and appropriately place them in storage" (Ethereum Whitepaper, 2022).

In Bitcoin, there is also an "opcode" called "OP_RETURN", which can also be used to store data. An example use case of "OP_RETURN" is "for digital asset proof-of-ownership, and has at times been used to convey additional information needed to send transactions" (Op_Return, 2022).

2.3 ETHEREUM NFTS (NON-FUNGIBLE TOKENS)

NFTs are an implementation of the ERC-721 (Ethereum Request for Comments 721) token standard into smart contracts on Ethereum (Decrypt, 2022). The CryptoPunks collectable characters which is a "project that inspired the modern [NFT] CryptoArt movement [...] are one of the earliest examples of a "Non-Fungible Token" on Ethereum, and were inspiration for the ERC-721 standard that powers most digital art and collectibles" (CryptoPunks, 2022).

The ERC-721 is a "type of Token [that] is unique and can have different value than another Token from the same Smart Contract, maybe due to its age, rarity or even something else like its visual" (ERC-721: NFTs, 2022). The creation of the Non-Fungible token ERC-721 standard was motivated by the limitation of the Fungible ERC-20 (Ethereum Request for Comments-20) token standard since the ERC-20 token standard "is insufficient for tracking [ERC-721] NFTs because each asset is distinct (non-fungible) whereas each of a quantity of [ERC-20] tokens is identical (fungible)" (Entriken *et al.*, 2018).

Non-fungible Tokens (NFTs) "can represent digital or real-world items like artwork and real estate" (Investopedia, 2022). As a result, an NFT and its representative object are both linked together" (Serrano, 2022). NFTs differ from Ethereum's native cryptocurrency called Ether because NFTs are digital assets created using smart contracts on the Ethereum blockchain (Hasan *et al.*, 2022, p. 76416). The combination of both words

FUNGIBLE and TOKENS means that “Tokens represents an asset and Fungible means something that is exchangeable. Let us consider an example, two pomegranates are exchangeable, because they are equal to each other in terms of their structure and value. Ethers [Ethereum’s native cryptocurrency] are fungible tokens as they all represent the same value and can be exchanged with one another” (Kumar *et al*., 2022, p. 261).

Ross, Cretu, Lemieux (2021, p. 2263) provide a comparison between fungible versus non-fungible tokens in TABLE 1.

TABLE 1 – FUNGIBLE VERSUS NON-FUNGIBLE TOKENS

	Fungible	NFT
Type	Interchangeable	Unique
Divisible	Yes, as in cryptocurrency	Not traditionally, but an item can be divided into multiple NFTs sold separately (eg. Maecenas) Emergence of fractionalized NFTs (f-NFTs) may be considered a fungible security
Conversion	Can make an NFT of an instance of a fungible token, similar to Colored Coins	Can pay for NFTs using fungible cryptocurrencies, stake a loan collateral

SOURCE: ROSS, CRETU, LEMIEUX (2021).

2.3.1 NFT metadata and property ownership transfer

An NFT created on a blockchain is only representative “of an object, not the object itself” (Ross; Cretu; Lemieux, 2021, p. 2264). Every object that an NFT represents is stored off-chain because storing objects (images, for example) is “expensive to do on Ethereum. If you want to store a 8 x 8 picture, storing this much data is pretty cheap, but if you want a picture with decent resolution, you’ll need to spend a lot more (Chainlink, 2020). For this reason, NFT objects are always stored off-chain due to the size and cost constraints of storing on the Ethereum blockchain. To link an NFT to its representative object, a metadata file containing the NFT object’s information, that includes a “link [to the

NFT object] and some information about the [NFT] asset" is stored off-chain (Alvar et al., 2023, p. 4759). The metadata file contains a URI (Uniform Resource Identifier) that points to an NFT object stored somewhere. As a result, each NFT is composed of three elements:

1. An NTF (token);
2. An object file (image, PDF contract, song etc) being represented by an NFT;
3. A metadata file containing the object's properties and information, and a link to the object file (Alvar et al., 2023, p. 4759).

According to Ross, Cretu, Lemieux (2021, p. 2264), NFT objects themselves:

> are always stored off-chain due to size and cost constraints resulting in this link providing the only connection to the created object. As a result, although the record of the NFT is secure, the NFT itself is dependent upon the continuing existence of the webhost [a cloud storage or Interplanetary File System (IPFS), for example]. A consequence is the loss of neutrality and decentralization inherent to the blockchain ethos, since these platforms come under the control of the elite few. Another consequence is fragility in the "archival bond" (Duranti, 1997), the unique link between the transaction record on chain (i.e., the ledger record) and the digital asset to which it refers (Ross; Cretu; Lemieux, 2021, p. 2264).

The metadata file is integral to the process of transferring property ownership from one entity to another since, according to Rehman *et al.* (2021), "the metadata of the underlying smart contract contains the terms and conditions for owning an NFT" (Rehman *et al*., 2021, p. 4). For this reason an NFT transfer alone, without terms and conditions of a Property Transfer agreement contained in a corresponding metadata file, becomes an incomplete process of transferring property ownership. In this regard, an NFT Art purchased without a corresponding metadata file stating terms and conditions of intellectual property, "gets the rights to utilize it only but not the rights for intellectual property" (Rehman *et al*., 2021, p. 4).

2.4 DECENTRALIZED STORAGE: INTERPLANETARY FILE SYSTEM (IPFS)

The Interplanetary File System (IPFS) is the most popular off-chain storage solution for NFT objects. According to a Forbes' article entitled "Top NFT Marketplaces of 2024" (Forbes, 2024), the two highest ranked NFT marketplaces, OpenSea (IPFS Blog &

News, 2021) and Rarible (Rarible Blog, 2022) allow using IPFS as a storage system for NFT objects in their marketplaces.

IPFS is a peer-to-peer protocol for “decentralized archiving” (IPFS, 2022) that enables users “to store large files off-chain and put immutable, permanent links in transactions — timestamping and securing content without having to put the data itself on-chain” (IPFS, 2022).

Even though IPFS allows decentralized storage of NFT objects, it also causes points of failure of centralized storage systems (Dupres, 2022); which, as a result, does not solve the “broken link problem” or “link rot” according to Ross, Cretu, Lemieux (2021, p.2270):

> While some NFT platforms attempt to address this issue by hosting their NFTs using interplanetary file system (IPFS), a peer-to-peer (P2P) web-based file system which helps to ensure that files are distributed across many hosts, this is not a universal practice (The Paris Agreement, 2016). Further, IPFS relies on the popularity of a seeded file to continue access: if an NFT is no longer of interest to this community, it, too, suffers from the broken link problem and the file is effectively lost (Ross; Cretu; Lemieux, 2021, p. 2270).

The “broken link problem” or “link rot” in IPFS relates to files stored on IPFS being effectively lost. As a result, “IPFS is not designed to store files permanently and so is therefore not the default storage option” (Metaplex Docs, 2022). This is caused by a process called “Garbage Collection” (IPFS Docs, 2025):

> Garbage Collection is a form of automatic resource management widely used in software development. The garbage collector attempts to reclaim memory occupied by objects that are no longer in use. IPFS uses garbage collection to free disk space on your IPFS node by deleting data that it thinks is no longer needed. (IPFS Docs, 2025).

2.5 NON-FUNGIBLE-TOKENS (NFTS) ON THE BITCOIN BLOKCHAIN THROUGH ORDINAL THEORY INSCRIPTIONS[9]

[9]SECTION “2.5 BITCOIN INSCRIPTIONS/NON-FUNGIBLE-TOKENS (NFTs)” contains text from SECTION “2.1. Bitcoin Blockchain Technology” of the published article at the following reference: SASAKI, E. E., GROSSMANN, D., WILDAUER, E. W. **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.** Advances on Knowledge Representation, vol. 1, no. 1, p. 137-168, 2025. DOI: 10.5281/zenodo.15041980. Available in: https://periodicos.ufmg.br/index.php/advances-kr/article/view/53994/47843.

Non-Fungible-Tokens (NFTs) are called Inscriptions on the Bitcoin Blockchain network. Inscriptions were launched on Bitcoin mainnet in January 2023 by Casey Rodarmor (2023a) through a protocol called Ordinal Theory that allows recording (inscribing) media on the Bitcoin Blockchain.

The Ordinal Theory made NFTs possible on the Bitcoin Blockchain 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. Thus, 1 (one) satoshi (or sat) equates to 0.00000001 BTC, i.e., 100 millionth of a BTC. (Kaur, 2023).

The Ordinal Theory is concerned with imbuing individual identities to satoshis (sats) by assigning them serial numbers. Every satoshi (sat) is numbered in ordinal sequence (starting at 0) in the order in which every satoshi was mined. The fixed ordinal identifier imbued on each satoshi enables Bitcoin applications that can store data on each individual satoshi and enables transfer ownership of an individual satoshi by sending it to a new wallet owner. (Ordinal Theory Handbook, 2023a; Rodarmor, 2023b).

“Individual satoshis can be inscribed with arbitrary content, creating unique Bitcoin-native digital artifacts that can be held in Bitcoin wallets and transferred using Bitcoin transactions. Inscriptions are as durable, immutable, secure, and decentralized as Bitcoin itself” (Ordinal Theory Handbook, 2023a). The Ordinal Theory was created to bring NFTs to the Bitcoin Blockchain because of the popularity of NFTs based on Ethereum’s ERC-721 standard. Unlike NFTs on Ethereum and other blockchains, NFT Ordinals are stored on-chain (i.e. stored on the Bitcoin blockchain) (Krishnakumar, 2023).

To put in perspective the possible number of Inscriptions that can be inscribed on the Bitcoin Blockchain, 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/inscribed 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) sats.

Moreover, 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 sats in circulation, every 10 minutes in average. In April 2024, the mining reward of 6.25 bitcoins halved to 3.125 bitcoins. This is due to Bitcoin being algorithmically programmed to halve

mining rewards, approximately, every 4 years, after 210,000 blocks are mined. (Bitcoin Block Reward Halving Countdown, 2023).

When the Bitcoin network launched in 2009, mining rewards started at 50 bitcoins. Since then, it has gone through four halving events, which halves mining rewards to 50% after 210,000 blocks are mined. The first halving event occurred on November 28th, 2012, which halved mining rewards from 50 to 25 bitcoins. The second halving event occurred on July 9th, 2016, which halved mining rewards to 12.5 bitcoins. The third halving event occurred on May 11th, 2020, which halved mining rewards to 6.25 bitcoins. The fourth halving event occured in April, 2024, which halved mining rewards to 3.125 bitcoins, i.e., 312,500,000 (312.5 million) sats.

2.5.1 Ordinal Theory Security Implication

A security implication associated with transferring ownership of an individual satoshi relates to sending it to miners as transaction fee. There are “Ordinal-aware” softwares that are specifically built for satoshi inscriptions. These softwares enable inscribing media to an individual satoshi and enable sending an individual satoshi to another wallet. But satoshis can be mistakenly transferred as transaction fees to miners if a wallet containing inscribed satoshis is unitentionally used to send bitcoins to another wallet. (Rodarmor, 2023b).

For this reason, a wallet containing satoshis should only be used with “Ordinal-aware” softwares, such as the Ordinal utility called ord (Ordinal Theory Handbook, 2023b), UniSat Wallet (Unisat, 2025), Xverse Wallet (Xverse, 2023), or Leather Wallet (Leather, 2023). And wallets intended for sending and receiving bitcoins should only be used with Bitcoin transaction softwares, such as Bitcoin wallets listed on Bitcoin.org (Bitcoin.org, 2024b).

Moreover, since the Bitcoin Network is a payment system mainly used to send bitcoin from one wallet to another, it should be emphasized that inscribing a sat (satoshi) with content/media is treated just like a Bitcoin transaction, which results in sending the inscribed sat to another wallet, even if it results in sending it to the same wallet.

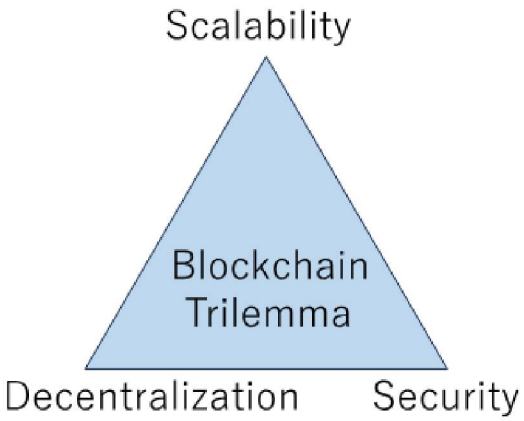
2.6 BLOCKCHAIN TRILEMMA[10]

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).

The definition of each property of the Blockchain Trilemma is:

- 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).

FIGURE 3 – BLOCKCHAIN TRILEMMA (Nakai et al., 2024, p. 80560)



SOURCE: AUTHOR (2025).

- 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

[10]SECTION “2.6 BLOCKCHAIN TRILEMMA” contains text from SECTION “2.2. Blockchain Trilemma” of the published article at the following reference: SASAKI, E. E., GROSSMANN, D., WILDAUER, E. W. **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.** Advances on Knowledge Representation, vol. 1, no. 1, p. 137-168, 2025. DOI: 10.5281/zenodo.15041980. Available in: https://periodicos.ufmg.br/index.php/advances-kr/article/view/53994/47843.

characteristic of decentralisation 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).

2.7 REAL ESTATE REGISTRY SYSTEM IN BRAZIL[11]

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, 2024).

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. (Brasil, 1988, Cartório no Brasil, 2024).

"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

[11]SECTION "2.7 REAL ESTATE REGISTRY SYSTEM IN BRAZIL" contains text from entire SECTION "2.3. Real Estate Registry System in Brazil" of the published article at the following reference: SASAKI, E. E., GROSSMANN, D., WILDAUER, E. W. **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.** Advances on Knowledge Representation, vol. 1, no. 1, p. 137-168, 2025. DOI: 10.5281/zenodo.15041980. Available in: https://periodicos.ufmg.br/index.php/advances-kr/article/view/53994/47843.

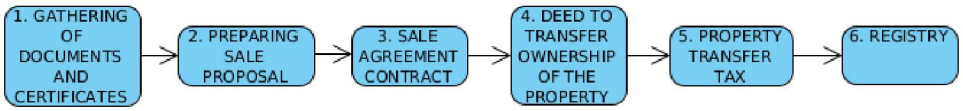
property to the buyer, through registration of the title at the Real Estate Registry Office" (Gomes, 2022).

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; Trindade; Vecchio, 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.

FIGURE 4 – STEPS TO BUYING A PROPERTY IN BRAZIL



SOURCE: AUTHOR (2024)

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).

2.8 RELATED WORKS[12]

Several projects that focus on providing Blockchain Notarization Services by recording and timestamping a cryptographic hash (SHA – Secure Hash Algorithms) of documents on a Blockchain. An overview of some Blockchain Notarization Service projects (TABLE 2), highlighting their architecture features applied to off-chain document storage, e-signature, and Blockchain platform.

TABLE 2 – ARCHITECTURE OF BLOCKCHAIN NOTARIZATION SERVICE PROJECTS

PLATFORMS	OFF-CHAIN DOCUMENT STORAGE	E-SIGNATURE	BLOCKCHAIN PLATFORM
E-NOTARIADO (NOTARCHAIN)	Cloud Backup	Yes	Notarchain (Hyperledger Fabric)
MENEZES; ARAÚJO; NISHIJIMA, 2023	IPFS	Yes	Ethereum
BLOCKNOTARY	IPFS	No	Bitcoin or Ethereum
SOUSA ET AL., 2020	Dedicated Conventional Database	Yes	Ethereum
STAMPD	Not Provided	No	Bitcoin, Bitcoin Cash or Dash
ACRONIS	Acronis Cyber Notary Cloud	Yes	Ethereum

SOURCE: AUTHOR (2025).

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

[12]SECTION “2.8 RELATED WORKS” contains text from SECTION “2.4. Related Works” of the published article at the following reference: SASAKI, E. E., GROSSMANN, D., WILDAUER, E. W. **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.** Advances on Knowledge Representation, vol. 1, no. 1, p. 137-168, 2025. DOI: 10.5281/zenodo.15041980. Available in: https://periodicos.ufmg.br/index.php/advances-kr/article/view/53994/47843.

notarial activity" (Colégio Notarial do Brasil, 2025). The e-Notariado platform is composed of a Cloud Backup solution for data storage, and a Blockchain solution called Notarchain (Colégio Notarial do Brasil, 2025), which implements IBM's (International Business Machine) Hyperledger Fabric Blockchain (HFB) Technology (Gusson, 2024) to provide its services. HFB "is an implementation that enables permissioned blockchains, which provide a general blockchain framework with identifiable participants for a variety of business applications" (Nakaike et al., 2020, p. 1).

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, 2025). 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 Sale and Purchase, Divorce, Living Will, Prenuptial Agreement, etc (e-Notariado, 2025).

An article, entitled "Blockchain and smart contract architecture for notaries services under civil law: a Brazilian experience" (Menezes; Araújo; Nishijima, 2023), proposes a solution that complies with the Brazilian state regulation (Civil Law judiciary) requirements to provide notary services. It uses a Brazilian state-regulated Public Key Infrastructure (ICP-Brasil) to validate users' identities and authenticate users' digital signatures made in Blockchain transactions. (Menezes; Araújo; Nishijima, 2023, p. 871 and 872).

The architecture of Menezes, Araújo, Nishijima's (2023) proposed solution is similar to Blocknotary's notarization service on the Bitcoin or Ethereum Blockchains (Blocknotary, 2025) in that "the documents are uploaded into the IPFS [Interplanetary File System] and the hash is stored within the [Ethereum] Blockchain with a timestamp. […] Our architecture is similar to the Blocknotary, but it overcomes the problem of individual (user) identification by means of the exchange of data with the ICP-Brasil" (Menezes; Araújo; Nishijima, 2023, p. 873).

Another article, entitled "Building a prototype based on Microservices and Blockchain technologies for notary's office: An academic experience report" (Sousa et al., 2020), proposes

> an approach, based on microservices and [Ethereum] blockchain, that allows the integration between notary's offices and other institutions, ensuring security and speed in the exchange of information between the parties. Such approach makes it possible to encapsulate smart contracts in specific microservices depending on the functionalities determined for the service. Therefore, the main contribution of this paper is threefold: (i) an approach for the proposed business model integrating blockchain and microservices; (ii) a prototype implementation that can generate a birth certificate and register it on a blockchain. (Sousa et al., 2020, p. 121-122).

The architecture of Sousa et al.'s (2020) proposed solution uses a dedicated "conventional database so that the document is stored off-chain" (Sousa et al., 2020, p. 128). It allows a notary's digital signature (Sousa et al., 2020, p. 125), and "a mock service was also developed to simulate the operation of the signature validation microservice. However, in future work, it is necessary that the signature validation microservice is integrated with a Certifying Authority (CA)" (Sousa et al., 2020, p. 127). Once a document has been digitally signed by the notary, "an invoice for payment is generated, delivered to the client, who in turn must make the payment in some notary's cashier department. [...] After completion of the procedure and having proof of payment for the service, all information collected, along with the notary's digital signature, will be recorded on the blockchain" (Sousa et al., 2020, p. 125-126).

Stampd (Stampd, 2025a) provides "a web interface for uploading hashes into a public blockchain for a fee" (Menezes; Araújo; Nishijima, 2023, p. 873) on "Bitcoin's, Bitcoin Cash's, [and/or] Dash's Blockchain" (Stampd, 2025a). Regarding Stampd's off-chain document storage and e-signature architecture features, Stampd "will not have access to your documents. They are not uploaded on our servers. They are locally processed in your browser to derive the appropriate cryptographic SHA256 hash imprint" (Stampd, 2025b). As for e-signature, it does not provide e-signature services.

Acronis (Acronis, 2025a) provides Blockchain Data Authentication through its Cyber Notary Cloud service, allowing "customers to notarize files of any type via a web console or API, generating a" (Acronis, 2025b) cryptographic hash (SHA – Secure Hash Algorithms) of a document and, then, recording and timestamping it on the Ethereum Blockchain. Acronis' Cyber Notary Cloud also provides e-signature and off-chain document storage. "Customers and required parties can electronically sign documents while generating publicly verifiable proof of the timestamp and integrity of signatures. [...] After the signed document or file is notarized, customers can verify it from any device, at any

time, directly from the solutions' user-interface or manually through the blockchain ledger" (Acronis, 2025b). As for off-chain document storage, it provides dedicated document storage management on its cloud platform.

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, 2025), 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,2025), "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).

Regarding on-chain media storage, Arweave, which is a permanent storage solution, built on the blockweave technology, "a derivative of the blockchain" (Arweave, 2022) that requires users "to pay a one-time, up-front fee [in AR (the native Arweave token) to the nodes] to store their data permanently" (CryptoWallet, 2024). Arweave aims to solve the "broken link problem" or "link rot" (SECTION "2.4 DECENTRALIZED STORAGE: INTERPLANETARY FILE SYSTEM") through creation of Atomic NFTs that improves the NFT standard by fusing media file, smart contract, and metadata file into one unique identifiable digital asset stored permanently on Arweave Permaweb's decentralized storage network (ATOMIC NFTS, 2023). In other words, "asset data, metadata, and contract all bundled together into a single Arweave ID" (SAM.ARWEAVE.DEV, 2021). Arweave also has a smart contract platform that allows developers to built on top of its decentralized network (OUTPROG, 2021).

There are some community projects that have implemented the Arweave's Atomic NFT Standard. According to @samecwilliams (Twitter username), who is founder of

Arweave, the music NFT marketplace called Pianity (Pianity, 2023) is the “first to bring Arweave's atomic NFTs to the music space [...] With atomic NFTs, the address of the NFT smart contract _is_ the address of the NFT's data. Permanent, on-chain assets, and no external metadata. One address. How NFTs were supposed to be” (Sam.arweave.vev, 2021). Another project that has implemented the Atomic NFT Standard is the smart contract company called Warp Contracts (Warp, 2023; Gww, 2023).

There is also the concept of Fractional NFTs (F-NFTs) that “represent percentage ownership or fractions of a complete NFT. The difference between the two is obvious: An NFT is a whole, while F-NFTs are simply fractions of the whole” (Bybit Learn, 2022). A company implementing Fractional NFTs in Real Estate is RealT (Realt, 2025) that offers fractional real estate investing allowing users to “buy into fractional, tokenized properties, leveraging the U.S. legal system and the permissionless, unrestricted token issuance of Ethereum” (Realt, 2025). According to RealT (2025), “fractional ownership democratizes access to real estate investment, and therefore distributes and minimizes the risks and labor involved with owning property” (Realt, 2025).

2.9 UNIFIED MODELING LANGUAGE (UML), MODEL–VIEW–CONTROLLER (MVC) DESIGN PATTERN, AND KNOWLEDGE REPRESENTATION (KR)[13]

The UML (UNIFIED MODELING LANGUAGE) diagrams are used as visual tools to model object oriented systems (Bezerra, 2015, p. 15). Additionally, this research project is organized implementing the Model-View-Controller (MVC) Design Pattern.

The Unified Modeling Language (UML) is used in order to “specify, visualize and document” (Object Management Group, 2005) requirements to develop the 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 Public Deeds of Sale and Purchase on the Bitcoin Blockchain.

[13]SECTION “2.9 UNIFIED MODELING LANGUAGE (UML), MODEL–VIEW–CONTROLLER (MVC) DESIGN PATTERN, AND KNOWLEDGE REPRESENTATION (KR)” contains text from SECTION “3. Methodology” of the published article at the following reference: SASAKI, E. E., GROSSMANN, D., WILDAUER, E. W. **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.** Advances on Knowledge Representation, vol. 1, no. 1, p. 137-168, 2025. DOI: 10.5281/zenodo.15041980. Available in: https://periodicos.ufmg.br/index.php/advances-kr/article/view/53994/47843.

Deployment diagrams show “relationships between the software and hardware components in the system and the physical distribution of the processing” (IBM Documentation, 2023).

Use case diagrams provide an external view to describe a system and its interactions with the exterior world and represent a high level view of how a system functions upon receiving a user request (Furlan, 1998, p. 169).

Sequence diagram “is an interaction diagram that emphasizes the time ordering of messages. A sequence diagram shows a set of objects and the messages sent and received by those objects. [...] You use sequence diagrams to illustrate the dynamic view of a system.” (Booch; Rumbaugh; Jacobson, 1998).

Class diagram is used to construction the class model from the analysis level to the specification level (Bezerra, 2015, p. 112). Class diagrams is important not only for visualizing, specifying, and documenting structural models, but also for constructing executable systems through forward and reverse engineering (Booch; Rumbaugh; Jacobson, 1998).

According to HCL-software (2025), the Model-View-Controller (MVC) Design Pattern is defined as:

> The model-view-controller (MVC) design pattern specifies that an application consist of a data model, presentation information, and control information. The pattern requires that each of these be separated into different objects. The model (for example, the data information) contains only the pure application data; it contains no logic describing how to present the data to a user. The view (for example, the presentation information) presents the model's data to the user. The view knows how to access the model's data, but it does not know what this data means or what the user can do to manipulate it. Finally, the controller (for example, the control information) exists between the view and the model. It listens to events triggered by the view (or another external source) and executes the appropriate reaction to these events. In most cases, the reaction is to call a method on the model. Since the view and the model are connected through a notification mechanism, the result of this action is then automatically reflected in the view. (HCL-software, 2025).

2.10 KNOWLEDGE REPRESENTATION (KR)[14]

[14]SECTION “2.10 KNOWLEDGE REPRESENTATION (KR)” contains text from SECTION “3.4. Knowledge Representation” of the published article at the following reference: SASAKI, E. E., GROSSMANN, D., WILDAUER, E. W. **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.** Advances on Knowledge Representation, vol. 1, no. 1, p. 137-168, 2025. DOI: 10.5281/zenodo.15041980. Available in: https://periodicos.ufmg.br/index.php/advances-kr/article/view/53994/47843.

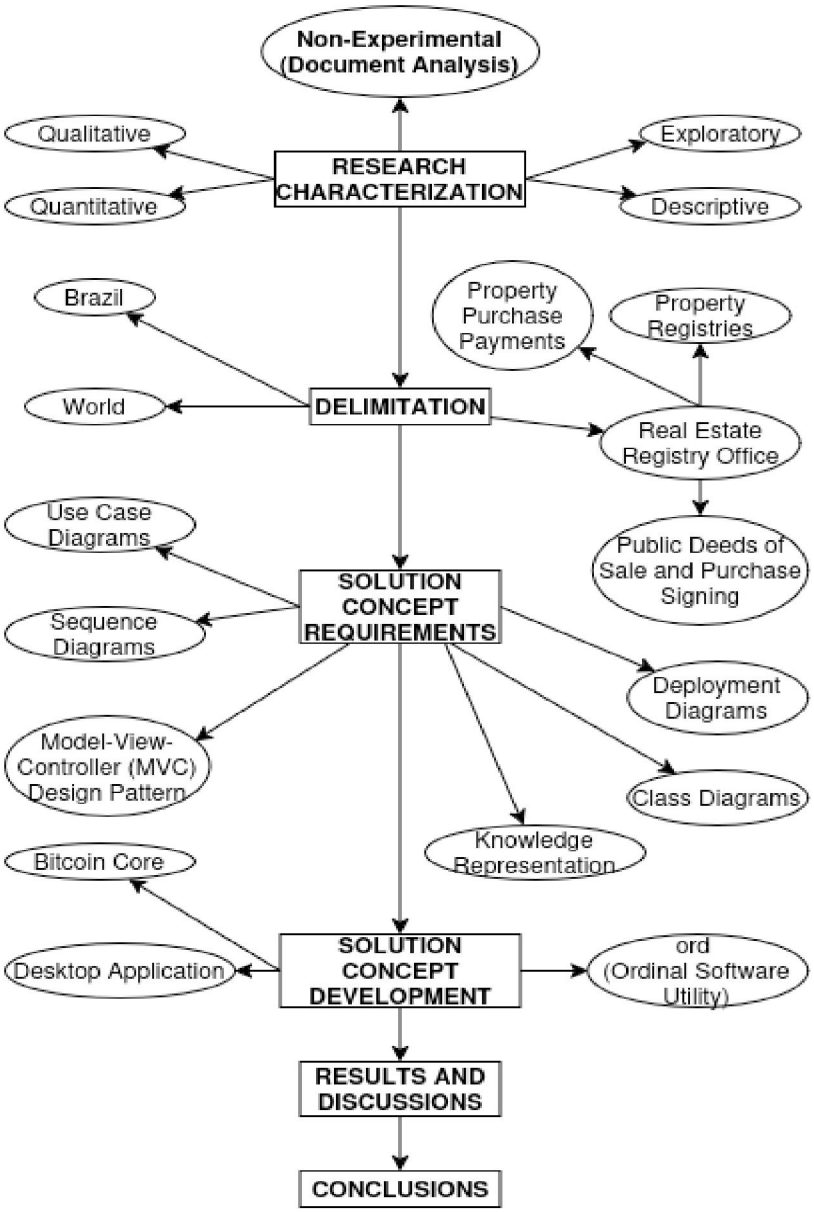
Knowledge Representation (KR) is an application of ontology within the knowledge domain of computer science (Almeida, 2013, p. 1682). “In computer science, ontologies are understood as devices that bring a machine-readable conceptual structure to a domain of interest” (Oellinger & Wennerberg, 2006). Moreover, in computer science, ontology “is a formal, explicit specification of shared a conceptualization” (Gómez-Pérez; Fernández-López; Corcho, 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 knowledge representation (KR), a subfield of artificial intelligence (AI), the term has been used since the 1960s to mean a general structure of concepts represented by a logical vocabulary. In the 1990s, the term continued to be used within the set of technologies encompassed under the label semantic web, which brought a kind of renaissance to AI by promising to bring the possibility of automatic inferences to the web. (Almeida, 2013, p. 1687).

3 METHODOLOGY

This research project develops 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 Purchase Payments, Property Registries and Property Transfers, and signing and registering Public Deeds of Sale and Purchase on the Bitcoin Blockchain. The methodology structure of this research is shown in FIGURE 5.

FIGURE 5 – METHODOLOGY MAP



SOURCE: AUTHOR (2024).

The following methodologies are used to explain this research in this chapter: research characterization, delimitation, Solution Concept requirements and Solution Concept development.

3.1 RESEARCH CHARACTERIZATION

This project uses “descriptive research method to investigate the facts aimed at describing the characteristics of” (Aithal; Aithal, 2023, p. 112) integrating Bitcoin Blockchain technology and the Brazilian Real Estate Registry System. Additionally, this project uses exploratory research method “to identify, understand, analyse, compare, evaluate, and interpret” (Aithal; Aithal, 2023, p. 113) the problem of transparency, uncertainty, and insecurity in the Brazilian Real Estate Registry System to present a solution by developing a Solution Concept that provides a method for signing and registering Public Deeds of Sale and Purchase, and registering Property Purchase Payments, Property Registries and Property Transfers on the Bitcoin Blockchain.

The outline of this project is carried out via non-experimental document analysis to comprehend the use of Bitcoin Blockchain technology in the Brazilian Real Estate Registry System. Documents are analyzed based on academic articles and books about Bitcoin and Ethereum blockchain technologies, Non-fungible Tokens (NFTs), Ordinal Theory, and Brazilian Real Estate Registry System.

The nature of this project is characterized as a qualitative research investigating integration of Bitcoin Blockchain technology and Brazilian Real Estate Registry System, and it analyzes statistical evidence that sustains using Bitcoin Blockchain technology to register Property Purchase Payments, Property Registries, and Public Deeds of Sale and Purchase on the Bitcoin Blockchain as an integral part of the Brazilian Real Estate Registry System.

3.2 DELIMITATION[15]

[15]SECTION “3.2 DELIMITATION” contains text from SECTION “3. Methodology” of the published article at the following reference: SASAKI, E. E., GROSSMANN, D., WILDAUER, E. W. **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.** Advances on Knowledge Representation, vol. 1, no. 1, p. 137-168, 2025. DOI: 10.5281/zenodo.15041980. Available in: https://periodicos.ufmg.br/index.php/advances-kr/article/view/53994/47843.

Because “a key part of blockchain ideology is the free movement of capital across borders” (Zook; Mccanless, 2025, p. 1), this project’s Solution Concept would allow users located in any geographic region in the world to use services (Property Purchase Payments, Property Registries, and Public Deeds of Sale and Purchase on the Bitcoin Blockchain) on the Bitcoin Blockchain provided by Real Estate Registry Offices in Brazil; even though, every Real Estate Registry Office that is part of the Brazilian Real Estate Registry System “has an ‘area of activity’ delimited by law, called real estate circumscription” (Registro de Imóveis, 2024).

Additionally, the Solution Concept is delimited within the following scope of operations:

- it is concerned with steps “4) DEED TO TRANSFER OWNERSHIP OF THE PROPERTY” and “6) REGISTRY” of the process of buying a property in Brazil, that is described in SECTION “2.7 REAL ESTATE REGISTRY SYSTEM IN BRAZIL”. It is taken into consideration that steps “1) GATHERING OF DOCUMENTS AND CERTIFICATES”, “2) PREPARING SALE PROPOSAL”, “3) SALE AGREEMENT CONTRACT” in SECTION 2.7 have already been properly completed. Also, it is taken into consideration that step “5) Property Transfer Tax” in SECTION 2.7 has been properly completed between the “DEED TO TRANSFER OWNERSHIP OF THE PROPERTY” and “REGISTRY” processes in the Solution Concept.
- it only contemplates direct property purchases without real estate broker intermediaries between Property Buyers and Property Owners.
- it also only contemplates one-time full upfront payments on property purchases between Property Buyers and Property Owners.

3.3 SOLUTION CONCEPT REQUIREMENTS[16]

The Solution Concept requirements are specified using four UML diagrams (SECTION “2.9”): deployment diagrams, use case diagrams, sequence diagrams, and class diagrams. The UML class diagrams are organized applying the Model-View-

[16]SECTION “3.3 SOLUTION CONCEPT REQUIREMENTS” contains text from SECTION “3. Methodology” of the published article at the following reference: SASAKI, E. E., GROSSMANN, D., WILDAUER, E. W. **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.** Advances on Knowledge Representation, vol. 1, no. 1, p. 137-168, 2025. DOI: 10.5281/zenodo.15041980. Available in: https://periodicos.ufmg.br/index.php/advances-kr/article/view/53994/47843.

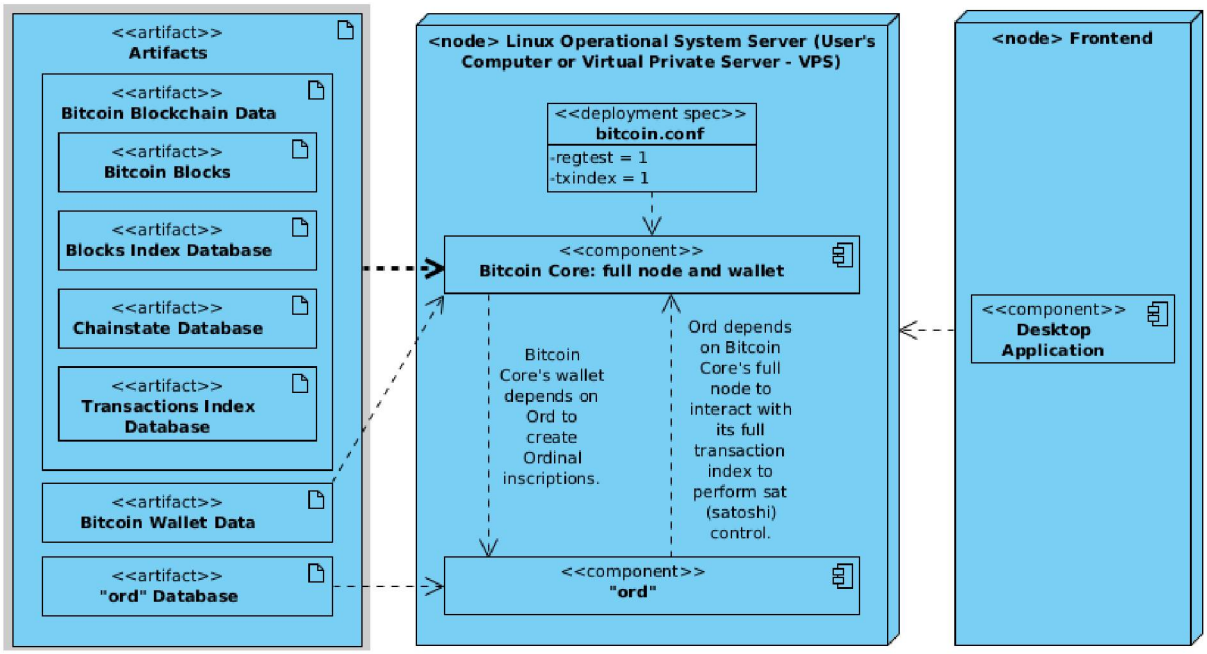
Controller (MVC) Design Pattern (SECTION “2.9”). Additionally, the Solution Concept applies the principles of Knowledge Representation (Section “2.9”) on Property Registries, Public Deeds of Sale and Purchase, and Property Transfers that are registered on the Bitcoin Blockchain to aid in building a machine-readable domain that is accessible to the public to increase transparency in the Brazilian Real Estate Registry System.

3.3.1 Deployment Diagram

The deployment Diagram in FIGURE 6 models the physical architecture of a Real Estate Registry System based on Bitcoin Blockchain.

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

FIGURE 6 – DEPLOYMENT DIAGRAM



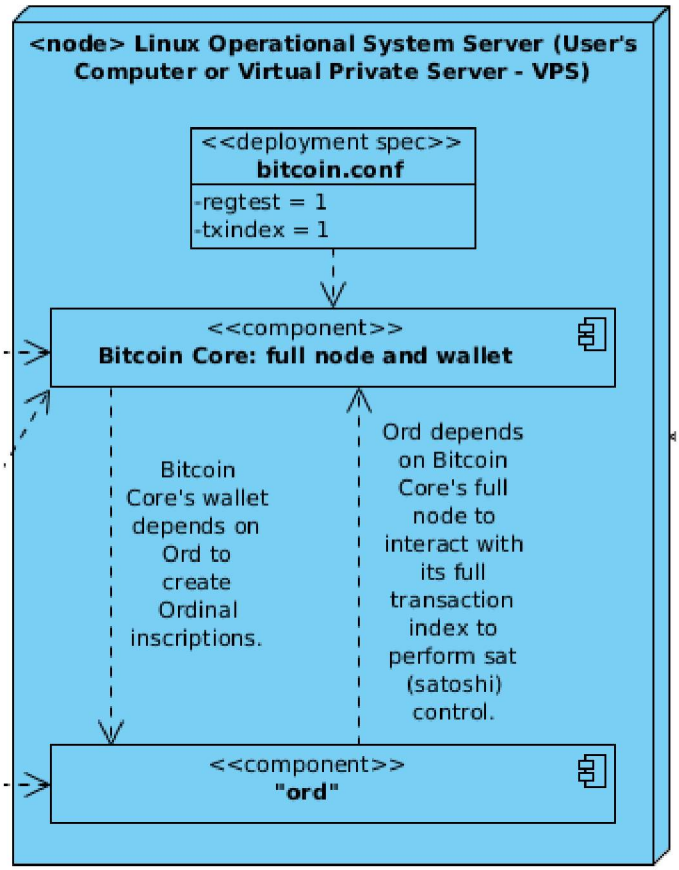
SOURCE: AUTHOR (2025)

3.3.1.1 Linux Server Node

The Linux Server node in the deployment diagram (FIGURE 7 – LINUX SERVER NODE) 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, 2023b).

FIGURE 7 – LINUX SERVER NODE



SOURCE: AUTHOR (2025)

Bitcoin Core is an open-source software (Bitcoin.org, 2024c). 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, 2024a).

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; Choo; Le-Khac, 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, 2023).

The Bitcoin Core wallet depends on an Ordinal Software Utility called "ord" because the "Bitcoin Core wallet cannot create inscriptions and does not perform sat control" (Ordinal Theory Handbook, 2023b).

The "ord" (Ordinal Software Utility) implements the Ordinal Theory to allow individual satoshis (sats) to be inscribed 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 index database. (ORDINAL THEORY HANDBOOK, 2023a; ORDINAL THEORY HANDBOOK, 2023b; ORDINAL THEORY HANDBOOK, 2023c).

The deployment specification file "bitcoin.conf" contains configuration settings (FIGURE 8 – DEPLOYMENT SPECIFICATION) for the Bitcoin Core "full node". It has two parameters: "txindex" and "regtest". Parameter "txindex", sets Bitcoin Core "full node" to store a copy of Bitcoin Core's transaction index on the "Linux Operational System Server".

FIGURE 8 – DEPLOYMENT SPECIFICATION

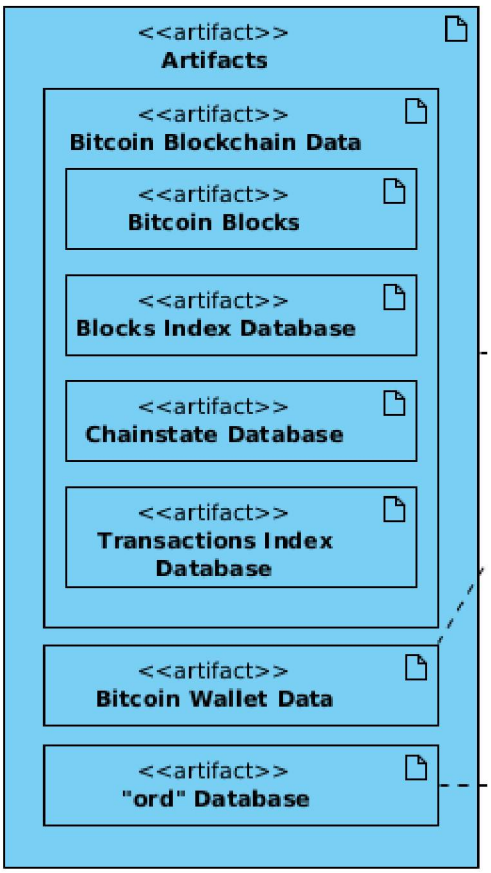
SOURCE: AUTHOR (2025)

The "regtest" parameter (FIGURE 8 – DEPLOYMENT SPECIFICATION) sets Bitcoin Core to use Bitcoin's regtest network, for development of this research project's Solution Concept. Bitcoin's regtest network lets "developers test their applications with reduced risks and limitations. […] For situations where interaction with random peers and blocks is unnecessary or unwanted, Bitcoin Core's regression test mode (regtest mode) lets you instantly create a brand-new private block chain with the same basic rules as testnet—but one major difference: you choose when to create new blocks, so you have complete control over the environment" (Bitcoin Developer, 2024).

3.3.1.2 Artifacts

Artifacts in the deployment diagram (FIGURE 9 – ARTIFACTS) consist of Bitcoin Blockchain Data, Bitcoin Wallet Data and “ord” Database.

FIGURE 9 – ARTIFACTS



SOURCE: AUTHOR (2025)

The Bitcoin Blockchain Data is a physical implementation of 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 .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, 2024a).

Blocks Index, Chainstate and Transactions Index databases are built from the Bitcoin Blocks data. Validation and operations become impracticably slow without them (Bitcoin Wiki, 2024a).

The Blocks Index Database (in $DATADIR/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, 2024a).

The Chainstate Database (in $DATADIR/chainstate) “maintains information about the resulting state of validation as a result of the currently best known chain” (Gr0kchain, 2023). 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, 2024a).

Transactions Index Database stores a copy of the transaction index database (in $DATADIR/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 inscription index database. (Gr0kchain, 2023; Ordinal Theory Handbook, 2023b).

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).

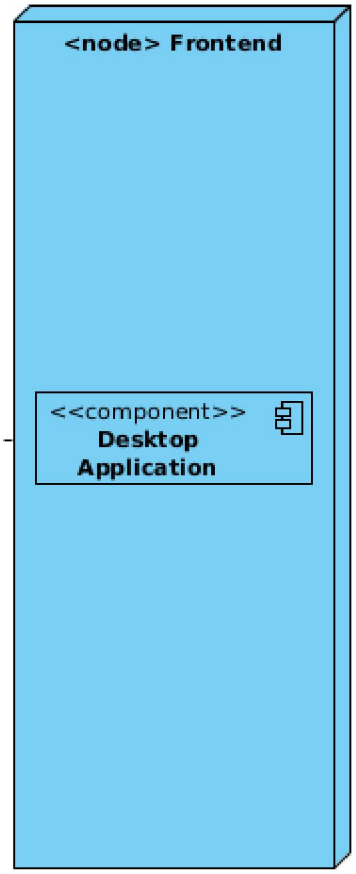
The Bitcoin Wallet Data is a physical implementation of Bitcoin Core wallet represented by a file called “wallet.dat” (in $DATADIR/wallets) which contains private and private keys information, scripts corresponding to addresses, metadata, and wallet transactions (Bitcoin Wiki, 2024c).

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

3.3.1.3 Frontend Node

The Frontend node in the deployment diagram (FIGURE 10) represented by a “Frontend” consists of a Desktop Application developed using Java Programming Language and Java Swing graphical user interface (GUI) components. The Solution Concept uses Java Swing JtabbedPane component as GUI (The Java Tutorials, 2025).

FIGURE 10 – FRONTEND

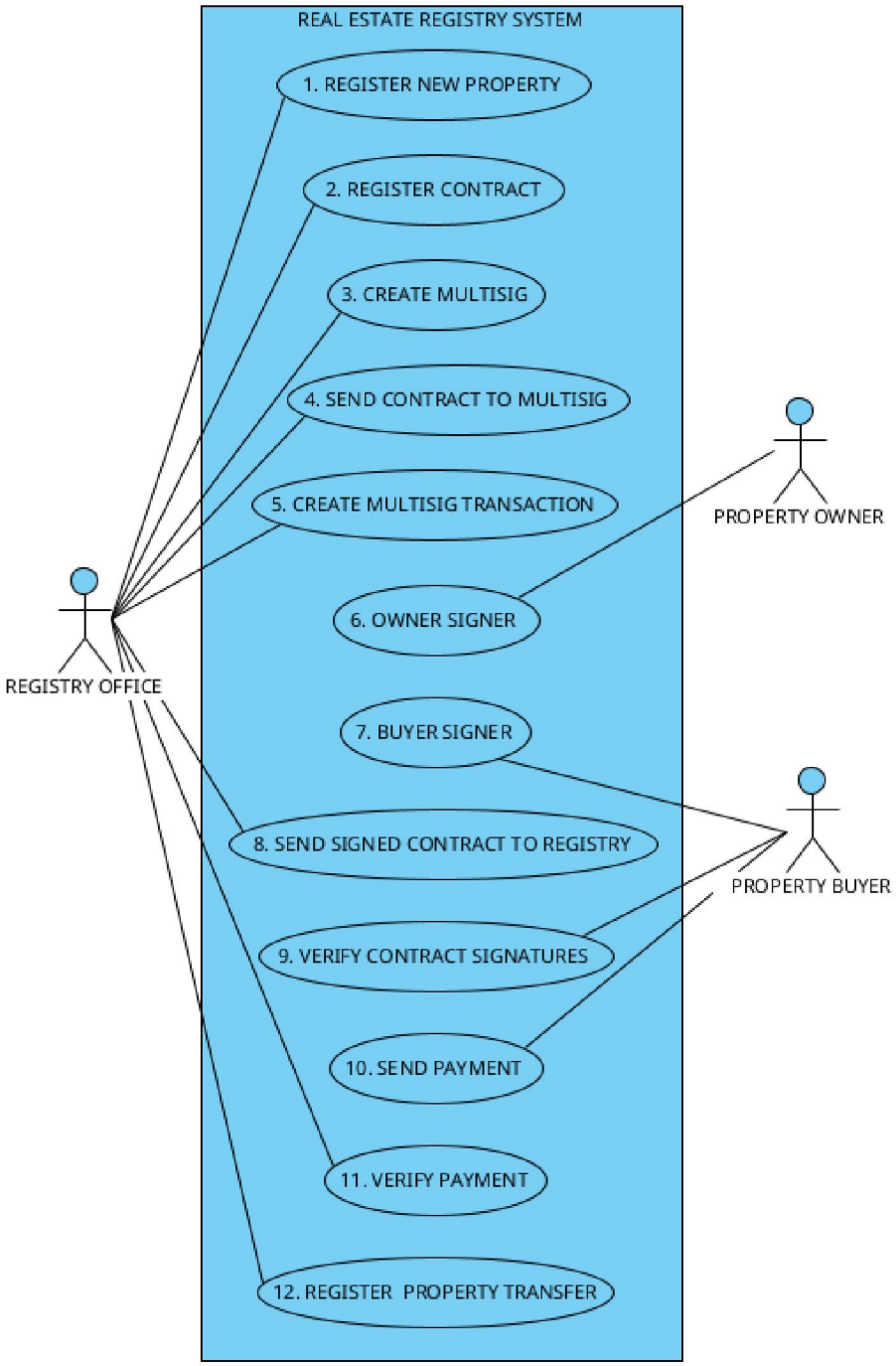


SOURCE: AUTHOR (2025)

3.3.2 Use Case Diagram

The Use Case Diagram of the Solution Concept illustrated in FIGURE 11 performs twelve use case operations:

FIGURE 11 – USE CASE DIAGRAM OF THE SOLUTION CONCEPT



SOURCE: AUTHOR (2024).

3.3.3 Sequence Diagrams of Solution Concept Application

Each of the twelve use case operations in “FIGURE 11 - USE CASE DIAGRAM OF THE SOLUTION CONCEPT” has the following sequence of steps that the designated user

(REGISTRY OFFICE, PROPERTY OWNER or PROPERTY BUYER) should complete in the Solution Concept application. The sequence of steps are:

a) SELECT OPERATION

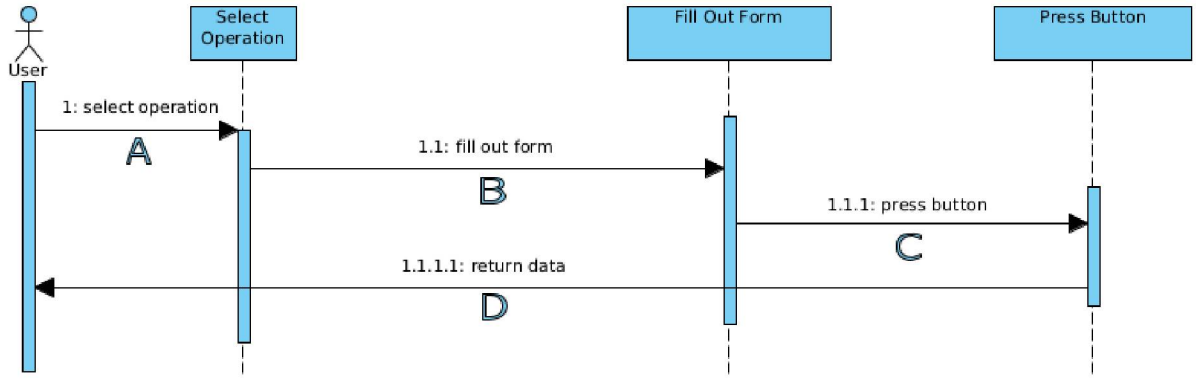
b) FILL OUT FORM

c) PRESS BUTTON

To process every operation, the FILL OUT FORM of each operation requires specific fields.

Those sequence of steps are illustrated following the sequence diagram of FIGURE 12:

FIGURE 12 – SEQUENCE DIAGRAM OF OPERATIONS

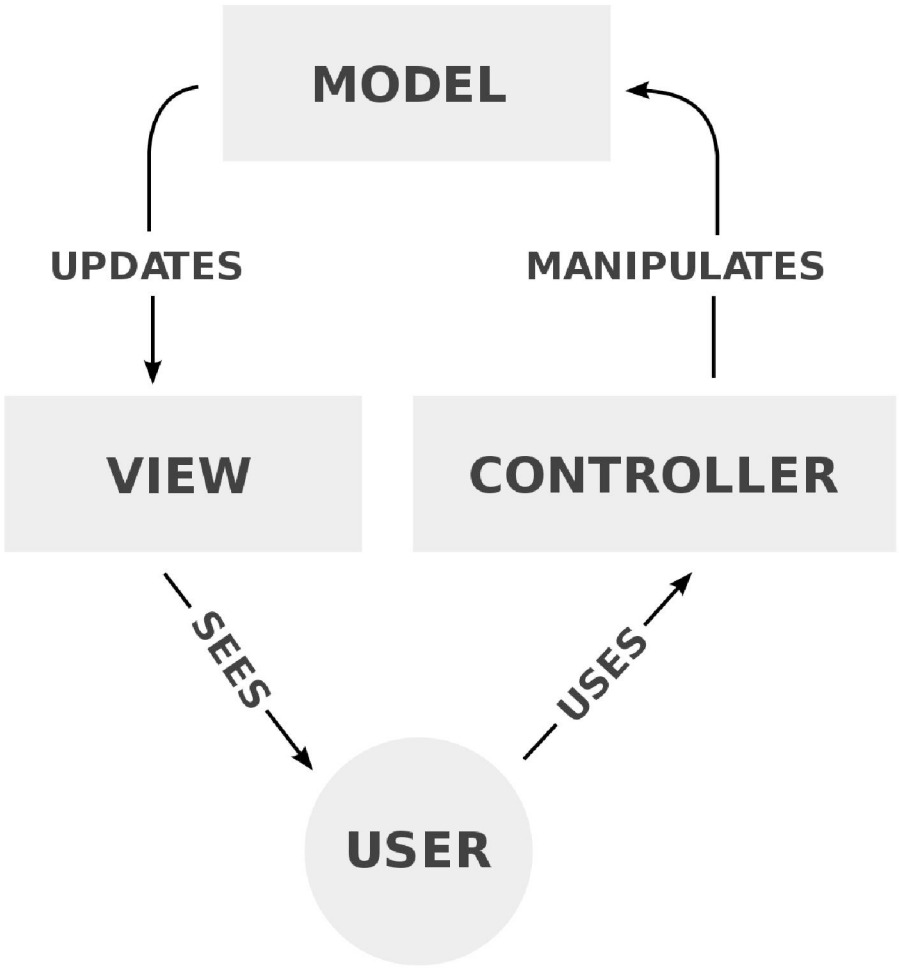


SOURCE: AUTHOR (2025).

3.3.4 Model-View-Controller (MVC) Design Pattern of Solution Concept Application

Each of the twelve use case operations in in “FIGURE 11 - USE CASE DIAGRAM OF THE SOLUTION CONCEPT” are implemented applying the Model-View-Controller (MVC) design pattern illustrated in FIGURE 13.

FIGURE 13 – MODEL-VIEW-CONTROLLER (MVC) DESIGN PATTERN

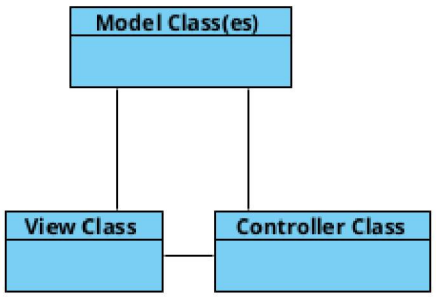


SOURCE: O'REILLY (2025).

3.3.5 Class Diagrams of Solution Concept Application

Each of the twelve use case operations in "FIGURE 11 - USE CASE DIAGRAM OF THE SOLUTION CONCEPT" that implement the MVC design pattern of FIGURE 13 is illustrated following the format of class diagrams of FIGURE 14.

FIGURE 14 – CLASS DIAGRAMS APPLYING THE MODEL-VIEW-CONTROLLER (MVC) DESIGN PATTERN



SOURCE: AUTHOR (2025).

3.3.6 Application of Knowledge Representation (KR)[17]

In the Solution Concept, Knowledge Representation (KR) is applied when Property Registries, Public Deeds of Sale and Purchase, and 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).

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).

IRIs allows for the exchange of metadata between Property Registries, Public Deeds of Sale and Purchase, and Property Transfers to identify relationships between "child(ren)" Property Transfer(s) and a "parent" Property Registry, and identify relationships between Public Deeds of Sale and Purchase and Property Transfers. JSON-LD is a

[17]SECTION “3.3.6 Application of Knowledge Representation (KR)” contains text from SECTION “3.4. Knowledge Representation” of the published article at the following reference: SASAKI, E. E., GROSSMANN, D., WILDAUER, E. W. **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.** Advances on Knowledge Representation, vol. 1, no. 1, p. 137-168, 2025. DOI: 10.5281/zenodo.15041980. Available in: https://periodicos.ufmg.br/index.php/advances-kr/article/view/53994/47843.

structured data, recommended by Google, for "providing information about a page and classifying the page content" (Google Developers, 2025). Moreover, it is "a JSON-based format to serialize Linked Data [...] in Web-based programming environments, to build interoperable Web services, and to store Linked Data in JSON-based storage engines" (W3C, 2020).

Specification of set of predicates that can be used to make statements/representations are built through RDF triples consisting of three components in the order subject, predicate, object as recommended by W3C (2014) and TechTarget Network (2022):

- “the **subject**, which is an IRI” (W3C, 2014), “is a resource being described by the triple” (TechTarget Network, 2022).
- “the **predicate**, which is an IRI” (W3C, 2014), “describes the relationship between the subject and the object” (TechTarget Network, 2022).
- “the **object**, which is an IRI, a literal” (W3C, 2014), “is a resource that is related to the subject” (TechTarget Network, 2022).

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

- *inscriptionID*: key to identify the inscription ID of a “parent” Property Registry. Every Property Transfer contains an *inscriptionID* value identified with the inscription ID of its “parent” Property Registry that was registered on the Bitcoin Blockchain.
- siblingID: key to identify the Property Transfer inscription ID of the youngest, i.e. latest, “child” Property Transfer related to same “parent” Property Registry. Only if the a “parent” Property Registry contains more than one “child” Property Transfer, will a “child” Property Transfer contain a *siblingID* value identified with the inscription ID of the youngest “child” Property Transfer. Otherwise, if a Property Transfer is the first “child” of a “parent” Property Registry, the *siblingID* value is null. (The *siblindID* functionality was not added to the Solution Concept, but it is included for recommendation for future work in SECTION “6 RECOMMENDATIONS FOR FUTURE WORK”).

3.4 SOLUTION CONCEPT DEVELOPMENT[18]

The twelve operations designed based on the Solution Concept Requirements (SECTION 3.3) that, all together, construct a Real Estate Registry System based on Bitcoin Blockchain were developed with the aid of tutorials that teach how to use the Bitcoin Core and “ord” (Ordinal Software Utility) components:

- Learning-Bitcoin-from-the-Command-Line (Blockchain Commons, 2021)
- Ordinal Theory Handbook (Ordinal Theory Handbook, 2023a)

The source code of the Solution Concept was published on GitHub under the open source MIT License, and can be accessed on: https://github.com/ybatinga/solution

The Solution Concept was tested on the Testnet3, Signet, and Regtest Networks of the Bitcoin Blockchain. Ultimately, the Regtest Network was chosen for this project’s Solution Concept because it allows the developer to instantly create “new blocks, so you have complete control over the environment” (Bitcoin Developer, 2024). On the other hand, although, the Testnet3 Network and the Signet Network, are faster than the Mainnet Network of the Bitcoin Blockchain, the Testnet3 and Signet Networks still face delayed confirmation times of transactions as also discussed in SECTION “4.1 SCALABILITY: LIMITATIONS AND CHALLENGES OF THE SOLUTION CONCEPT”. Although, it would be expected that obtaining timestamps of confirmed transactions on Testnet3 would be faster than on Mainnet because on Testnet3 “the mining difficulty is also set to a lower value than Mainnet, making the blockchain grow faster” (Franzoni et al., 2020, p. 4). Implementation of the Solution Concept on the Testnet3 Network endured scalability issues related to delayed confirmation of payment and registry transactions. Also, the Ordinal Explorer for the Testnet3 Network, which allows searching and browsing inscriptions on an internet web browser has been disabled. The Solution Concept was also

[18]SECTION “3.4 SOLUTION CONCEPT DEVELOPMENT” contains text from SECTION “4.1. Implementation of the Solution Concept” of the published article at the following reference: SASAKI, E. E., GROSSMANN, D., WILDAUER, E. W. **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.** Advances on Knowledge Representation, vol. 1, no. 1, p. 137-168, 2025. DOI: 10.5281/zenodo.15041980. Available in: https://periodicos.ufmg.br/index.php/advances-kr/article/view/53994/47843.

tested 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 Ordinal Explorer for the Signet Network enabled for internet web browsers.

Testnet3 Network “is an alternative Bitcoin block chain to be used for testing. Testnet 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, 2024d). 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 and Signet Networks, bitcoins can be “obtained via online services called faucets” (Franzoni et al., 2020, p. 4).

3.4.1 **Register New Property Operation**

REGISTER NEW PROPERTY OPERATION is described through use case, class and sequence diagrams.

3.4.1.1 Register New Property Use Case Diagram

REGISTER NEW PROPERTY USE CASE DIAGRAM (FIGURE 15) 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.

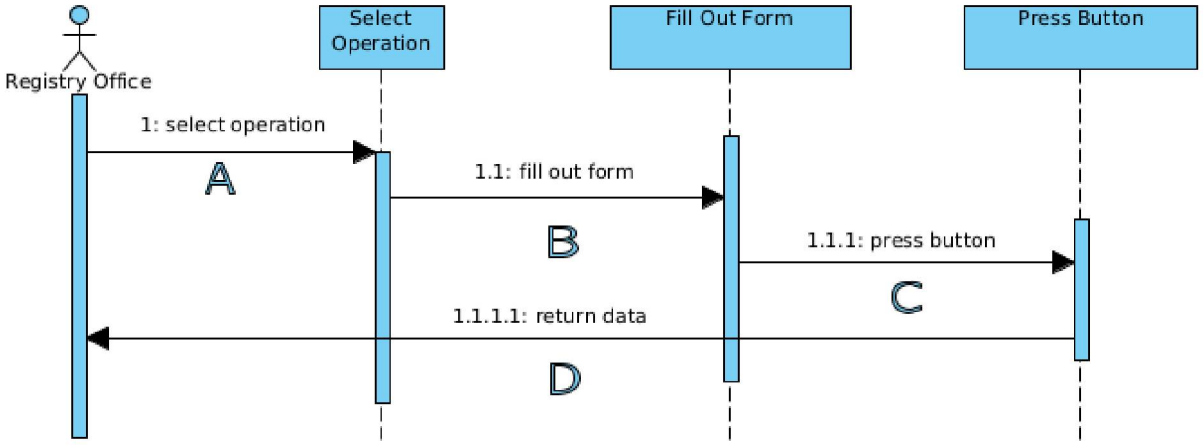
FIGURE 15 – REGISTER NEW PROPERTY USE CASE DIAGRAM

SOURCE: AUTHOR (2025).

3.4.1.2 Register New Property Sequence Diagram

REGISTER NEW PROPERTY SEQUENCE DIAGRAM in FIGURE 16 has the following sequence of steps that the REGISTRY OFFICE should complete in the Solution Concept application.

FIGURE 16 – REGISTER NEW PROPERTY SEQUENCE DIAGRAM



SOURCE: AUTHOR (2025).

The sequence of steps are:

a) Select Register New Property Operation

b) FILL OUT FORM: The FILL OUT FORM step (FIGURE 17) in the REGISTER NEW PROPERTY OPERATION requires filling out the following fields:

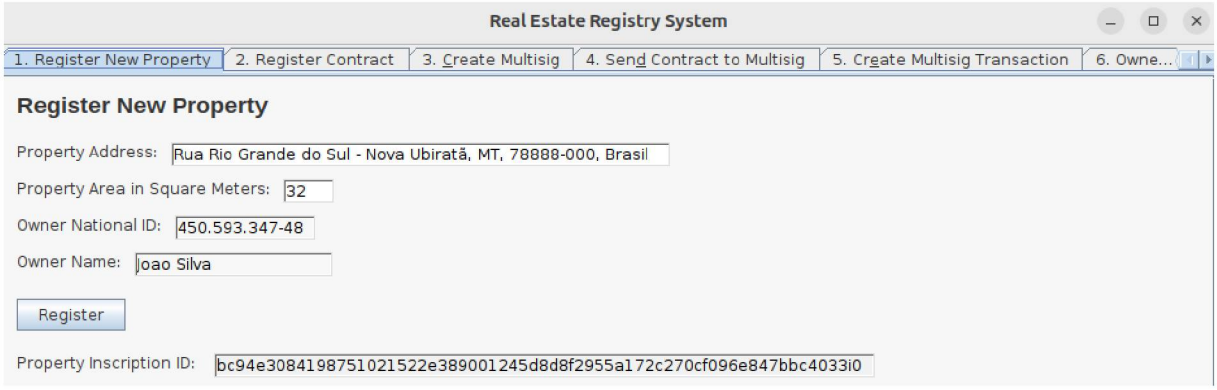
- Property Address
- Property Area in Square Meters
- Owner National ID
- Owner Name

c) PRESS REGISTER BUTTON

After pressing the REGISTER BUTTON (FIGURE 17) in the REGISTER NEW PROPERTY OPERATION, the system returns the following data:

- Property Inscription ID (unique identification of the inscription that was stored on the index database of the “ord” Software Utility)

FIGURE 17 – GRAPHICAL USER INTERFACE OF REGISTER NEW PROPERTY OPERATION



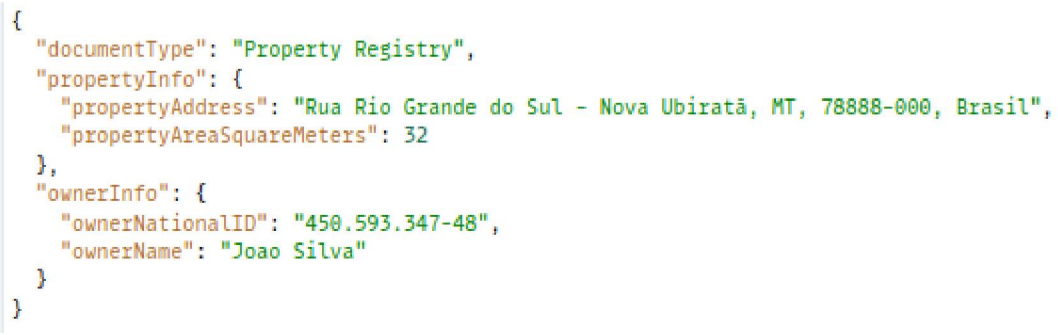
SOURCE: AUTHOR (2025).

3.4.1.3 Register New Property Knowledge Representation

For application of principles of Knowledge Representation related to bringing machine-readable structure (Oellinger & Wennerberg, 2006) through JSON-LD (JavaScript Object Notation – Linked Data), when the REGISTRY OFFICE completes the sequence of steps of registering a Property in SECTION “3.4.1.2 Register New Property Sequence Diagram”, the Property data is stored in JSON file format (FIGURE 18) on the Bitcoin Blockchain. Once the transaction of storing/registering the Property data in JSON file format is confirmed/timestamped on the Bitcoin Blockchain, a Property Inscription ID (*inscriptionID*) is obtained.

The Property Inscription ID (*inscriptionID*) is used as an IRI (Internationalized Resource Identifier) node that allows the Solution Concept to retrieve information about the Property Registry (W3C, 2020) in SECTIONS “3.4.2 Register Contract Operation” and “3.4.12 Register Property Transfer Operation”.

FIGURE 18 – PROPERTY REGISTRY IN JSON FILE FORMAT



SOURCE: AUTHOR (2025).

3.4.1.4 Register New Property Class Diagram

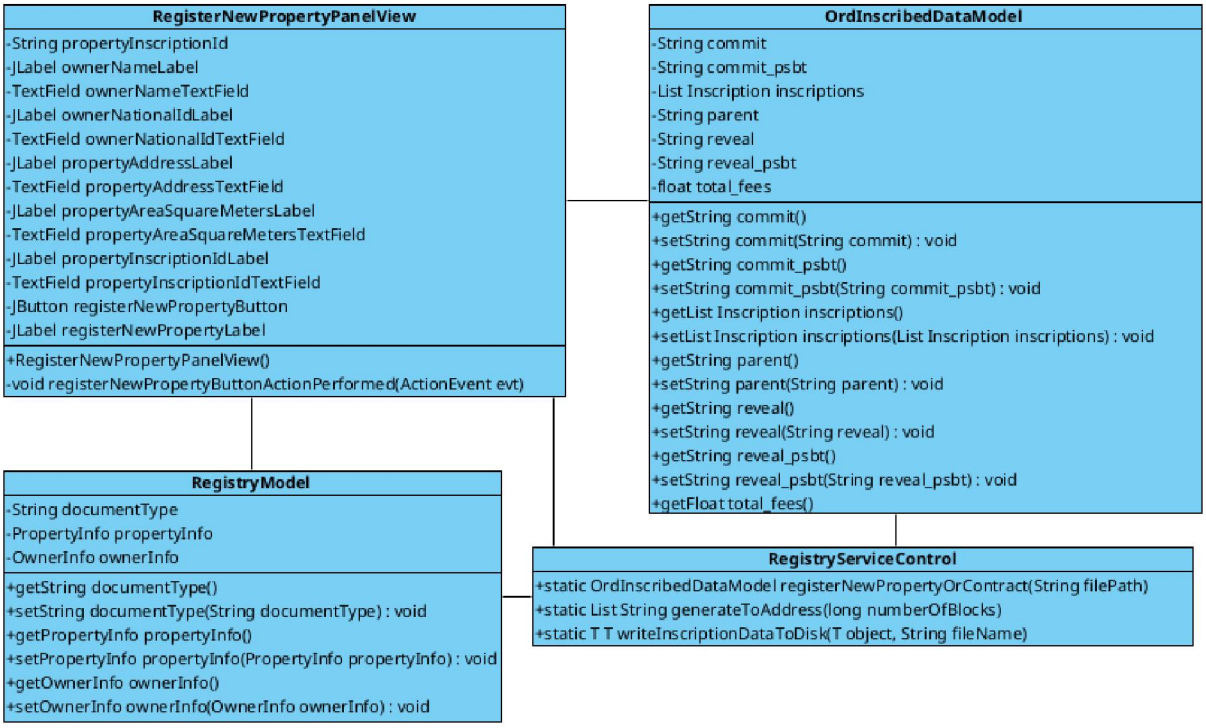
REGISTER NEW PROPERTY CLASS DIAGRAM in FIGURE 19 shows class associations applying the Model-View-Controller (MVC) design pattern illustrated in “FIGURE 14 - CLASS DIAGRAMS APPLYING THE MODEL-VIEW-CONTROLLER (MVC) DESIGN PATTERN”. These class associations operate when registering a new property in the Solution Concept. The classes are specified in the MVC design pattern as follows:

- **View Class:** RegisterNewPropertyPanelView[19]
- **Controller Class:** RegistryServiceControl[20]
- **Model Classes:** RegistryModel[21]; OrdInscribedDataModel[22]

The View Class RegisterNewPropertyPanelView presents a GUI (Graphical User Interface) (FIGURE 17) for the REGISTRY OFFICE to register a new property or register a property that already exists on the traditional Brazilian Real Estate Registry System and needs to be registered on the Bitcoin Blockchain.

[19]The source code of View Class RegisterNewPropertyPanelView can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/view/RegisterNewPropertyPanelView.form
[20]The source code of Control Class RegistryServiceControl can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/control/RegistryServiceControl.java
[21]The source code of Model Class RegistryModel can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/model/RegistryModel.java
[22]The source code of Model Class OrdInscribedDataModel can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/model/OrdInscribedDataModel.java

FIGURE 19 – REGISTER NEW PROPERTY CLASS DIAGRAM



SOURCE: AUTHOR (2025).

When the REGISTRY OFFICE presses the Register Button on View Class RegisterNewPropertyPanelView, the data filled out on the View Class form are stored in a Model Class RegistryModel object. Next, the Controller Class RegistryServiceControl mainly triggers method “registerNewPropertyOrContract” that gets the data stored in the RegistryModel object to register a new property on the Bitcoin Blockchain in JSON file format, by executing the “ord” (Ordinal Software Utility) on the Linux Server node shell. Finally, “ord” returns Model Class OrdInscribedDataModel that stores Property Inscription ID (unique identification of the inscription that was stored on the index database of the “ord” Software Utility) which is shown on the RegisterNewPropertyPanelView GUI. The Property Inscription ID is used to execute REGISTER CONTRACT OPERATION and REGISTER PROPERTY TRANSFER OPERATION.

3.4.2 Register Contract Operation

REGISTER CONTRACT OPERATION is described through use case, class and sequence diagrams.

3.4.2.1 Register Contract Use Case Diagram

REGISTER CONTRACT USE CASE DIAGRAM (FIGURE 18) represents a registration of a Public Deed of Sale and Purchase (Escritura Pública de Compra e Venda) on the Bitcoin Blockchain that requires the signatures of the PROPERTY OWNER and the PROPERTY BUYER. The contract contains data from the PROPERTY being negotiated between the PROPERTY OWNER and the PROPERTY BUYER. It also contains identification data from the PROPERTY OWNER and PROPERTY BUYER.

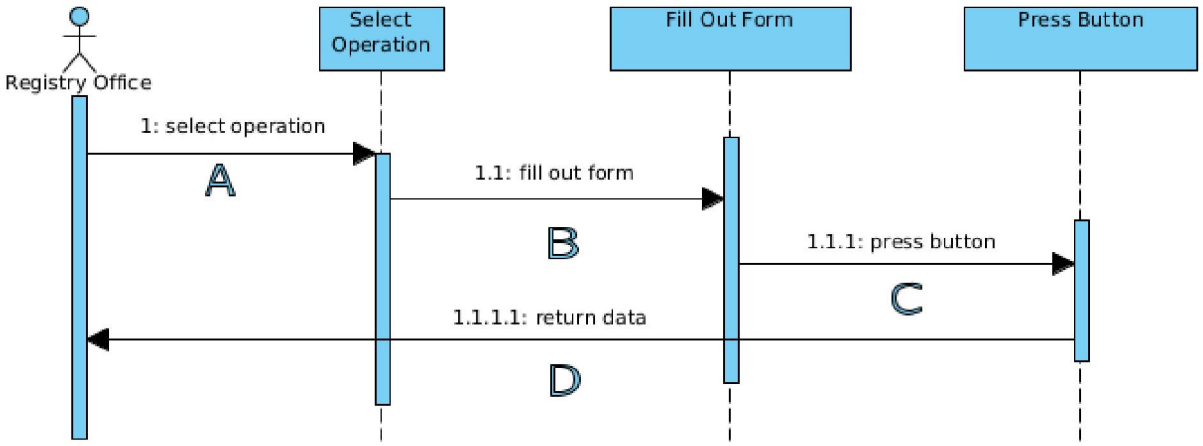
FIGURE 20 – REGISTER CONTRACT USE CASE DIAGRAM

SOURCE: AUTHOR (2025).

3.4.2.2 Register Contract Sequence Diagram

REGISTER CONTRACT SEQUENCE DIAGRAM in FIGURE 21 has the following sequence of steps that the REGISTRY OFFICE should complete in the Solution Concept application.

FIGURE 21 – REGISTER CONTRACT SEQUENCE DIAGRAM



SOURCE: AUTHOR (2025).

The sequence of steps are:

a) SELECT REGISTER CONTRACT OPERATION

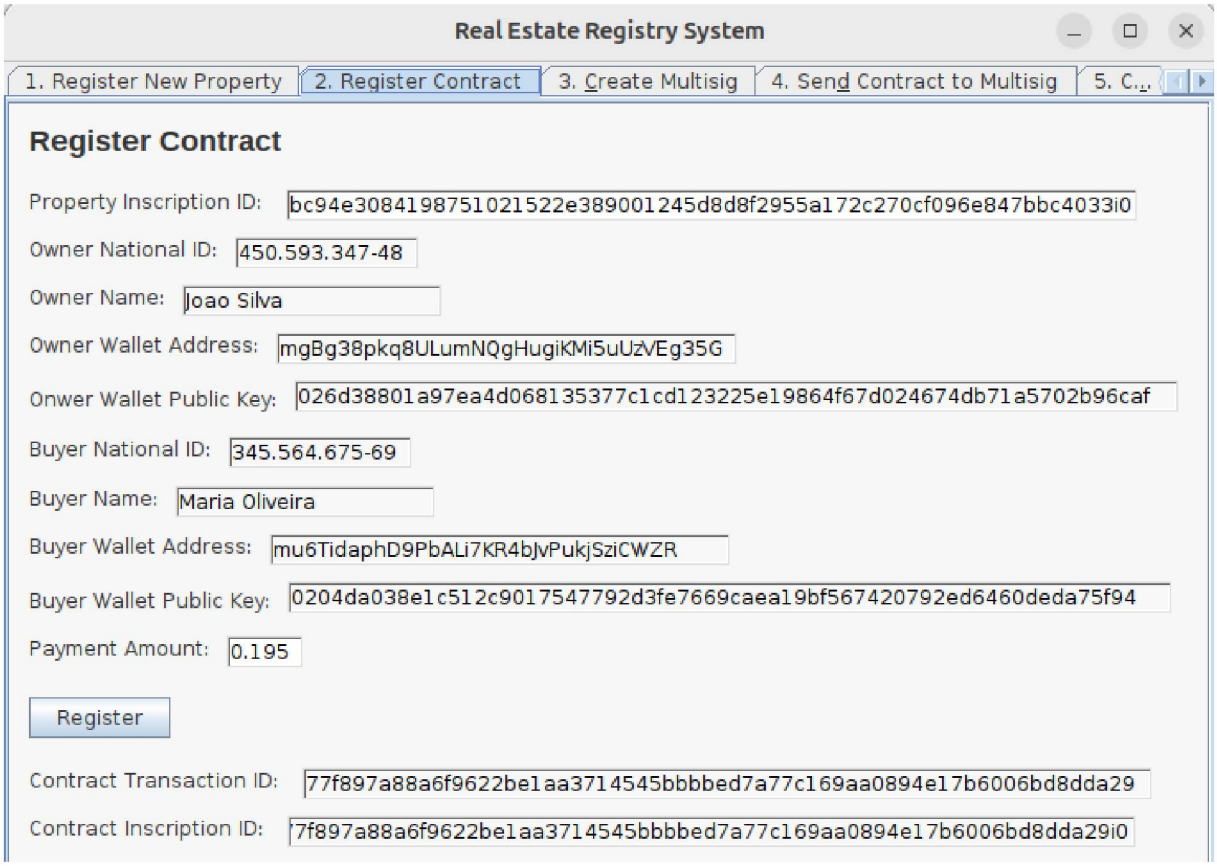
b) FILL OUT FORM: The FILL OUT FORM step (FIGURE 22) in the REGISTER CONTRACT OPERATION requires filling out the following fields:

- Property Inscription ID (unique identification of the inscription that was stored on the index database of the “ord” Software Utility)
- Owner National ID
- Owner Name
- Owner Wallet Address
- Onwer Wallet Public Key
- Buyer National ID
- Buyer Name
- Buyer Wallet Address
- Buyer Wallet Public Key
- Payment Amount

c) PRESS REGISTER BUTTON: After pressing the REGISTER BUTTON (FIGURE 22) in the REGISTER CONTRACT OPERATION, the system returns the following data:

- Contract Transaction ID (unique identification of the transaction registered on the Bitcoin Blockchain)
- Contract Inscription ID (unique identification of the inscription that was stored on the index database of the “ord” Software Utility)

FIGURE 22 – GRAPHICAL USER INTERFACE OF REGISTER CONTRACT OPERATION



SOURCE: AUTHOR (2025).

3.4.2.3 Register Contract Knowledge Representation

For application of principles of Knowledge Representation related to bringing machine-readable structure (Oellinger & Wennerberg, 2006) through JSON-LD (JavaScript

Object Notation – Linked Data), when the REGISTRY OFFICE completes the sequence of steps of registering a Public Deed of Sale and Purchase in SECTION “3.4.2.2 Register Contract Sequence Diagram”, the Public Deed of Sale and Purchase data is stored in JSON file format (FIGURE 23) on the Bitcoin Blockchain. Once the transaction of storing/registering the Public Deed of Sale and Purchase data in JSON file format is confirmed/timestamped on the Bitcoin Blockchain, a Contract Inscription ID (*inscriptionID*) and a Contract Transaction ID (transactionID) are obtained.

The Contract Inscription ID (*inscriptionID*) is used as an IRI (Internationalized Resource Identifier) node that allows the Solution Concept to retrieve information about the Public Deed of Sale and Purchase (W3C, 2020) in SECTION “3.4.12 Register Property Transfer Operation”.

For application of principles of Knowledge Representation related to specifying predicates to make statements/representations (Almeida, 2013, p. 1690), the IRI (Internationalized Resource Identifier) that dereferences a pointer (W3C, 2020) to the Property Registry node (FIGURE 18 - PROPERTY REGISTRY IN JSON FILE FORMAT) in the Public Deed of Sale and Purchase registered in JSON file format on the Bitcoin Blockchain (Figure 23). The IRI is represented by the key-value “‘*inscriptionID’: ‘bc94e3084198751021522e389001245d8d8f2955a172c270cf096e847bbc4033i0*’” of the *propertyInfo* object.

FIGURE 23 – PUBLIC DEED OF SALE AND PURCHASE (ESCRITURA PÚBLICA DE COMPRA E VENDA) IN JSON FILE FORMAT


```
{
  "documentType": "Public Deed of Sale and Purchase",
  "propertyInfo": {
    "inscriptionNumber": 147,
    "inscriptionID": "bc94e3084198751021522e389001245d8d8f2955a172c270cf096e847bbc4033i0",
    "inscriptionAddress": "bcrt1p04dvma99ln34khw8qnqx643cy07usp0rfs3syfqltsrh2a8mzx7sthvwmj",
    "blockHeightGenesis": 1435,
    "timestamp": "2025-03-01 14:37:26 UTC",
    "propertyAddress": "Rua Rio Grande do Sul - Nova Ubiratã, MT, 78888-000, Brasil",
    "propertyAreaSquareMeters": 32
  },
  "ownerInfo": {
    "ownerNationalID": "450.593.347-48",
    "ownerName": "Joao Silva",
    "ownerWalletAddress": "mgBg38pkq8ULumNQgHugiKMi5uUzVEg35G",
    "ownerWalletPublicKeyAddress": "026d38801a97ea4d068135377c1cd123225e19864f67d024674db71a5702b96caf"
  },
  "buyerInfo": {
    "buyerNationalID": "345.564.675-69",
    "buyerName": "Maria Oliveira",
    "buyerWalletAddress": "mu6TidaphD9PbALi7KR4bJvPukjSziCWZR",
    "buyerWalletPublicKeyAddress": "0204da038e1c512c9017547792d3fe7669caea19bf567420792ed6460deda75f94"
  },
  "publicDeedOfSaleAndPurchaseInfo": {
    "salePrice": 0.195
  }
}
```


SOURCE: AUTHOR (2025).

The Property Registry node identified by the *inscriptionID* key in the *propertyInfo* object, in the Public Deed of Sale and Purchase registered in JSON file format on the Bitcoin Blockchain (Figure 23), makes it possible for specifying the following predicate statement/representation in Figure 24:

FIGURE 24 – STATEMENT FOR REGISTER CONTRACT NODE

SOURCE: AUTHOR (2025).

3.4.2.4 Register Contract Class Diagram

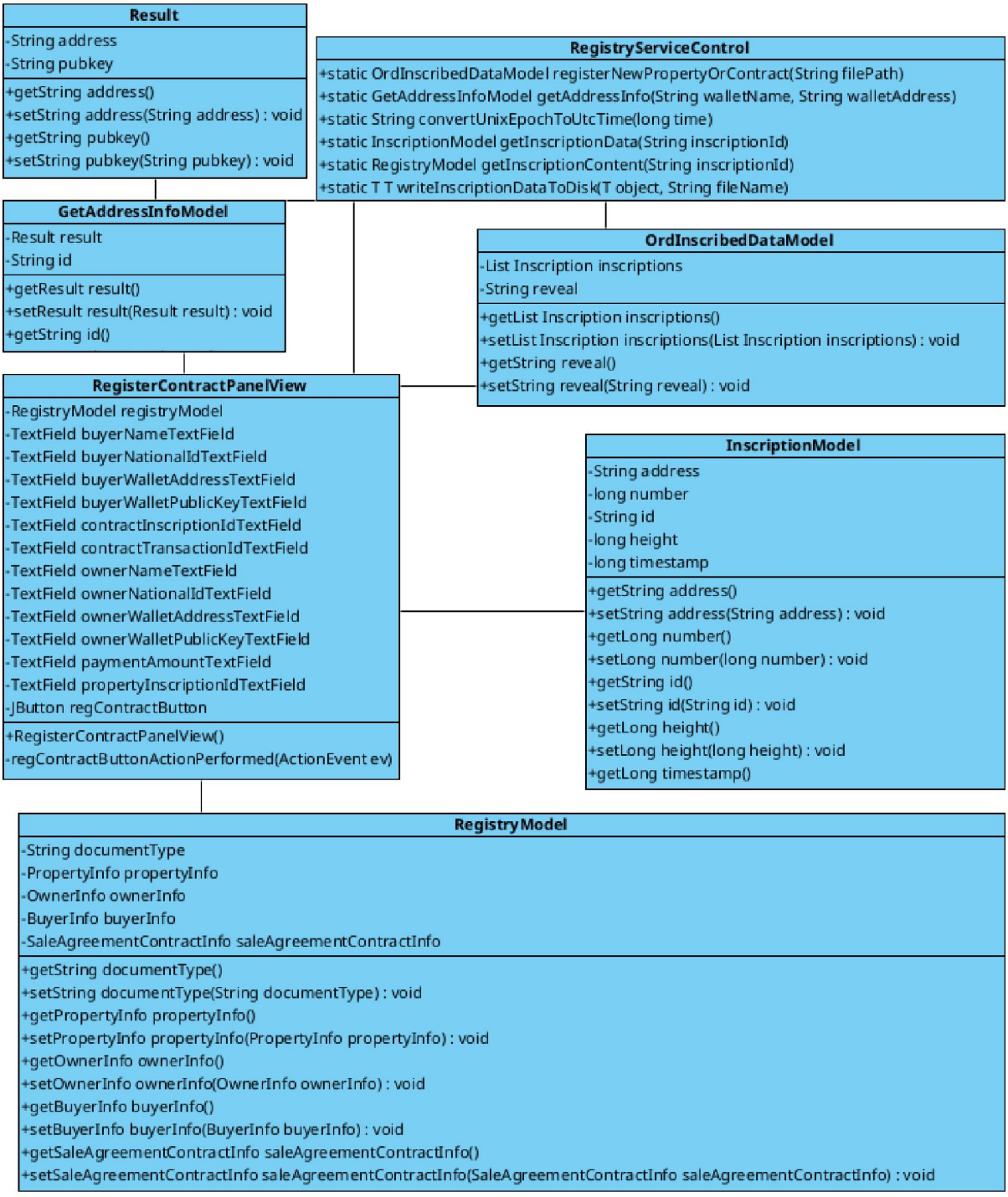
REGISTER NEW PROPERTY CLASS DIAGRAM in FIGURE 25 shows class associations applying the Model-View-Controller (MVC) design pattern illustrated in “FIGURE 14 - CLASS DIAGRAMS APPLYING THE MODEL-VIEW-CONTROLLER (MVC) DESIGN PATTERN”. These class associations operate when registering a new property in the Solution Concept. The classes are specified in the MVC design pattern as follows:

- **View Class:** RegisterContractPanelView[23]
- **Controller Class:** RegistryServiceControl[24]
- **Model Classes:** RegistryModel[25]; OrdInscribedDataModel[26]; InscriptionModel[27]

The View Class RegisterContractPanelView presents a GUI (Graphical User Interface) (FIGURE 22) for the REGISTRY OFFICE to register a Public Deed of Sale and Purchase on the Bitcoin Blockchain. The RegisterContractPanelView prefills the Bitcoin wallet information of the PROPERTY OWNER and PROPERTY BUYER on the GUI by running twice method “RegistryServiceControl.getAddressInfo”, that executes command “getAddressInfo” on Bitcoin Core which retrieves Bitcoin wallet address information (Bitcoin Developer, 2025b). The first execution retrieves the Bitcoin wallet address information of the PROPERTY BUYER, which is stored in a Model Class GetAddressInfoModel object. The second execution retrieves the Bitcoin wallet address information of the PROPERTY OWNER, which is stored in another Model Class GetAddressInfoModel object. Next, the Bitcoin wallet address information contained in both PROPERTY BUYER and PROPERTY OWNER GetAddressInfoModel classes are shown on the RegisterContractPanelView GUI.

[23]The source code of View Class RegisterContractPanelView can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/view/RegisterContractPanelView.java
[24]The source code of Control Class RegistryServiceControl can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/control/RegistryServiceControl.java
[25]The source code of Model Class RegistryModel can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/model/RegistryModel.java
[26]The source code of Model Class OrdInscribedDataModel can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/model/OrdInscribedDataModel.java
[27]The source code of Model Class InscriptionModel can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/model/InscriptionModel.java

FIGURE 25 – REGISTER CONTRACT CLASS DIAGRAM



SOURCE: AUTHOR (2025).

When the REGISTRY OFFICE presses the Register Button on View Class RegisterContractPanelView, the data filled out on the View Class form are stored in Model Class RegistryModel object. Next, Controller Class RegistryServiceControl triggers method “getInscriptionContent” that retrieves inscription data with the Property Inscription ID of the property registered in the REGISTER NEW PROPERTY OPERATION, on the “ord” (Ordinal Software Utility) inscription index database. The property data retrieved with the Property Inscription ID is stored into the RegistryModel object. Next, Controller Class RegistryServiceControl mainly triggers method “registerNewPropertyOrContract” that gets data stored in the RegistryModel object to register the contract on the Bitcoin Blockchain, by executing the “ord” (Ordinal Software Utility) on the Linux Server node shell. Finally, “ord” returns Model Class OrdInscribedDataModel that stores “Contract Transaction ID” and “Contract Inscription ID” which are shown on the RegisterContractPanelView GUI. The “Contract Transaction ID” is used to execute SEND CONTRACT TO MULTISIG OPERATION. And both “Contract Transaction ID” and “Contract Inscription ID” are used to execute REGISTER PROPERTY TRANSFER OPERATION.

3.4.3 Create Multisig Operation

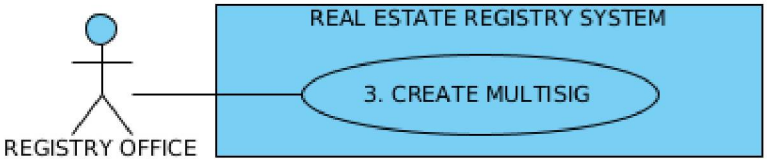
CREATE MULTISIG OPERATION is described through use case, class and sequence diagrams.

3.4.3.1 Create Multisig Use Case Diagram

In CREATE MULTISIG USE CASE DIAGRAM (FIGURE 26), the REGISTRY OFFICE starts the process of obtaining the signatures of the PROPERTY OWNER and the PROPERTY BUYER on the Public Deed of Sale and Purchase. For this reason, the REGISTRY OFFICE creates “a simple 2-of-2 multisig” (Blockchain Commons, 2022b) address by extracting “a unique hash” (Blockchain Commons, 2022b) based on the public keys of the PROPERTY OWNER and PROPERTY BUYER Bitcoin wallet addresses. The 2-of-2 Multisig address requires the Bitcoin wallet address private keys of the PROPERTY OWNER and the PROPERTY BUYER to sign the 2-of-2 Multisig transaction. In the Solution Concept, when PROPERTY OWNER and the PROPERTY BUYER sign the 2-of-

2 Multisig transaction with their private keys, it also represents the signing of the Public Deed of Sale and Purchase.

FIGURE 26 – CREATE MULTISIG USE CASE DIAGRAM

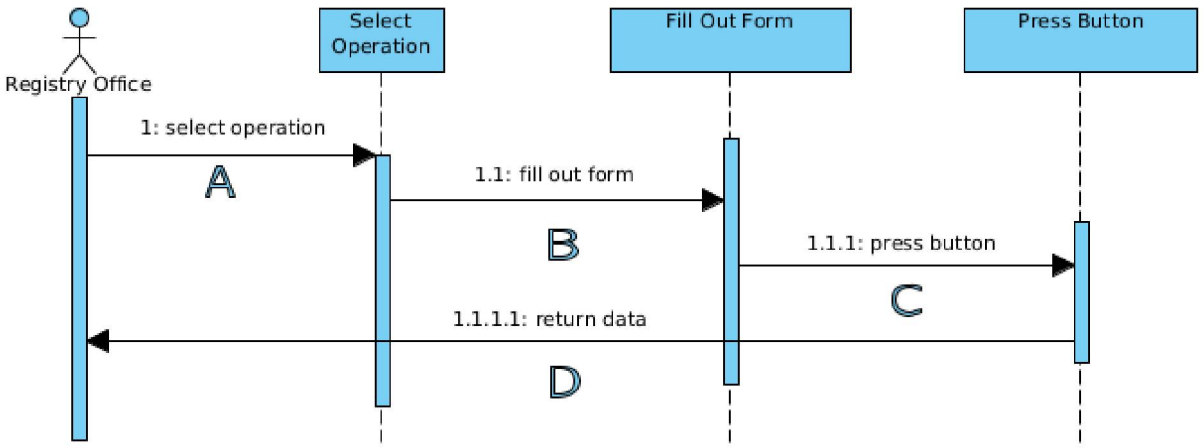


SOURCE: AUTHOR (2025).

3.4.3.2 Create Multisig Sequence Diagram

CREATE MULTISIG SEQUENCE DIAGRAM in FIGURE 23 has the following sequence of steps that the REGISTRY OFFICE should complete in the Solution Concept application.

FIGURE 27 – CREATE MULTISIG SEQUENCE DIAGRAM



SOURCE: AUTHOR (2025).

The sequence of steps are:

a) SELECT CREATE MULTISIG OPERATION

b) FILL OUT FORM: The FILL OUT FORM step (FIGURE 24) in the CREATE MULTISIG OPERATION requires filling out the following fields:

- Buyer Wallet Public Key
- Owner Wallet Public Key

c) **PRESS CREATE BUTTON:** After pressing the CREATE BUTTON (FIGURE (FIGURE 24) in the CREATE MULTISIG OPERATION, the system returns the following data:

- Multisig Address
- Redeem Script (needed to sign the contract along with the private keys of the PROPERTY OWNER AND PROPERTY BUYER) (Blockchain Commons, 2022b)

FIGURE 28 – GRAPHICAL USER INTERFACE OF CREATE MULTISIG OPERATION

SOURCE: AUTHOR (2025).

3.4.3.3 Create Multisig Class Diagram

CREATE MULTISIG CLASS DIAGRAM in FIGURE 29 shows class associations applying the Model-View-Controller (MVC) design pattern illustrated in “FIGURE 14 - CLASS DIAGRAMS APPLYING THE MODEL-VIEW-CONTROLLER (MVC) DESIGN

PATTERN". These class associations operate when creating a multisig address in the Solution Concept. The classes are specified in the MVC design pattern as follows:

- **View Class:** CreateMultisigAddressPanelView[28]
- **Controller Class:** RegistryServiceControl[29]
- **Model Classes:** GetAddressInfoModel[30]

The View Class CreateMultisigAddressPanelView presents a GUI (Graphical User Interface) (FIGURE 24) for the REGISTRY OFFICE to create a multisig address.

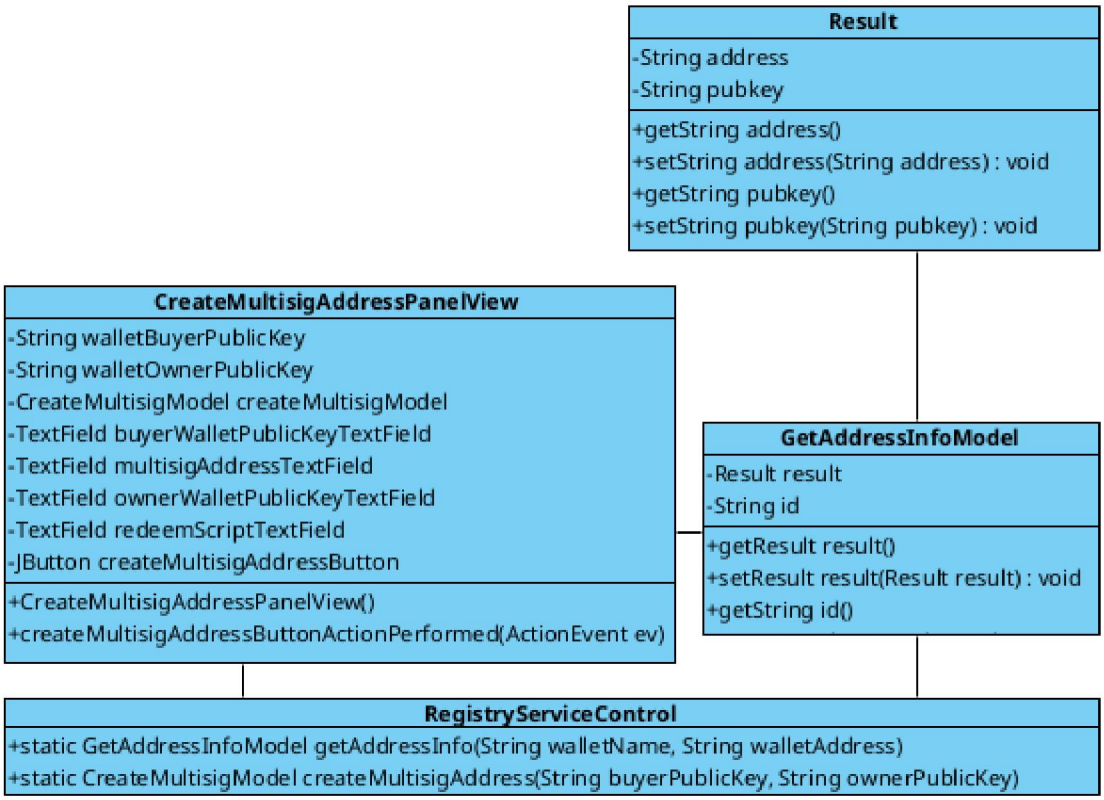
The CreateMultisigAddressPanelView prefills the "Buyer Wallet Public Key" and "Owner Wallet Public Key" fields on the GUI by running twice method "RegistryServiceControl.getAddressInfo", that executes command "getAddressInfo" on Bitcoin Core which retrieves Bitcoin wallet address information (Bitcoin Developer, 2025b). The first execution retrieves the Bitcoin wallet address information of the PROPERTY BUYER, which is stored in a Model Class GetAddressInfoModel object. The second execution retrieves the Bitcoin wallet address information of the PROPERTY OWNER, which is stored in another Model Class GetAddressInfoModel object. Next, the public keys contained in both GetAddressInfoModel classes are then stored in "walletBuyerPublicKey" and "walletOwnerPublicKey" attributes, respectivelly. Finally, the public keys are shown on the CreateMultisigAddressPanelView GUI.

When the REGISTRY OFFICE presses the Create Button on View Class CreateMultisigAddressPanelView, the Controller Class RegistryServiceControl triggers method "createMultisigAddress" (Bitcoin Developer, 2025a) that executes command "createmultisig" on Bitcoin Core which creates a multisig address based on public keys of the PROPERTY OWNER and PROPERTY BUYER Bitcoin wallet addresses. Finally, Bitcoin Core returns Model Class CreateMultisigModel that stores "Multisig Address" and "Redeem Script" which are shown on the CreateMultisigAddressPanelView GUI. The "Multisig Address" is used to execute CREATE MULTISIG TRANSACTION OPERATION.

[28]The source code of View Class CreateMultisigAddressPanelView can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/view/CreateMultisigAddressPanelView.java
[29]The source code of Control Class RegistryServiceControl can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/control/RegistryServiceControl.java
[30]The source code of Model Class GetAddressInfoModel can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/model/GetAddressInfoModel.java

And “Redeem Script” is used to execute OWNER SIGNER and BUYER SIGNER OPERATIONS.

FIGURE 29 – CREATE MULTISIG CLASS DIAGRAM



SOURCE: AUTHOR (2025).

3.4.4 Send Contract to Multisig Operation

SEND CONTRACT TO MULTISIG OPERATION is described through use case, class and sequence diagrams.

3.4.4.1 Send Contract to Multisig Use Case Diagram

In SEND CONTRACT TO MULTISIG USE CASE DIAGRAM (FIGURE 30), the REGISTRY OFFICE sends the Public Deed of Sale and Purchase to the Multisig address, as part of the process of obtaining the signatures of PROPERTY OWNER and PROPERTY BUYER on the Public Deed of Sale and Purchase.

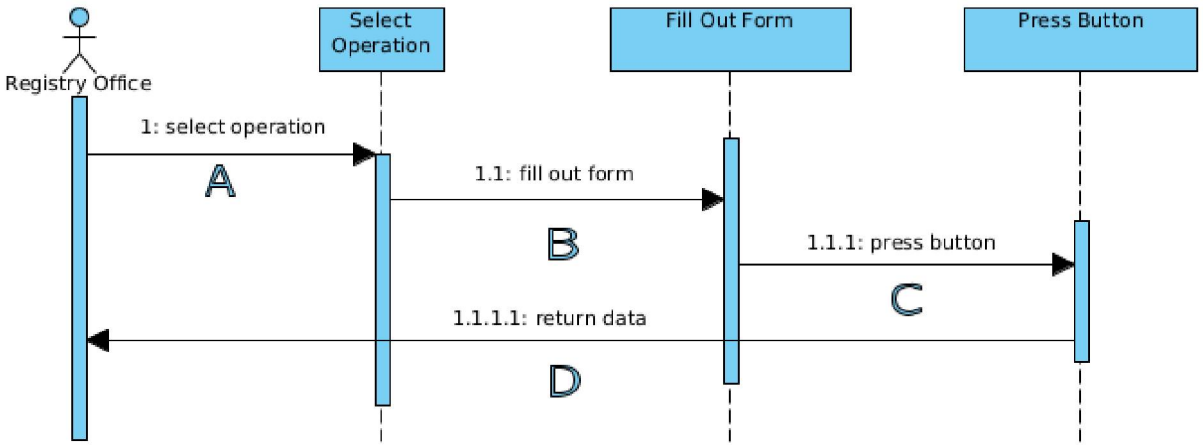
FIGURE 30 – SEND CONTRACT TO MULTISIG USE CASE DIAGRAM

SOURCE: AUTHOR (2025).

3.4.4.2 Send Contract to Multisig Sequence Diagram

SEND CONTRACT TO MULTISIG SEQUENCE DIAGRAM in FIGURE 31 has the following sequence of steps that the REGISTRY OFFICE should complete in the Solution Concept application.

FIGURE 31 – SEND CONTRACT TO MULTISIG SEQUENCE DIAGRAM



SOURCE: AUTHOR (2025).

The sequence of steps are:

a) SELECT SEND CONTRACT TO MULTISIG OPERATION

b) FILL OUT FORM: The FILL OUT FORM step (FIGURE 32) in the SEND CONTRACT TO MULTISIG OPERATION requires filling out the following fields:

- Contract Transaction ID (unique identification of the transaction registered on the Bitcoin Blockchain)

- Multisig Address

c) PRESS SEND BUTTON: After pressing the SEND BUTTON (FIGURE 32) in the SEND CONTRACT TO MULTISIG OPERATION, the system returns the following data:

- Transaction ID of Contract Sent to Multisig (unique identification of the transaction registered on the Bitcoin Blockchain)

FIGURE 32 – GRAPHICALUSER INTERFACE OF SEND CONTRACT TO MULTISIG OPERATION

SOURCE: AUTHOR (2025).

3.4.4.3 Send Contract to Multisig Class Diagram

SEND CONTRACT TO MULTISIG CLASS DIAGRAM in FIGURE 33 shows class associations applying the Model-View-Controller (MVC) design pattern illustrated in “FIGURE 14 - CLASS DIAGRAMS APPLYING THE MODEL-VIEW-CONTROLLER (MVC) DESIGN PATTERN”. These class associations operate when sending a Public Deed of Sale and Purchase to a Multisig address in the Solution Concept. The classes are specified in the MVC design pattern as follows:

- **View Class:** SendContractToMultisigPanelView[31]

[31]The source code of View Class SendContractToMultisigPanelView can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/view/SendContractToMultisigPanelView.java

- **Controller Class:** RegistryServiceControl[32]
- **Model Classes:** GetRawTransactionModel[33]

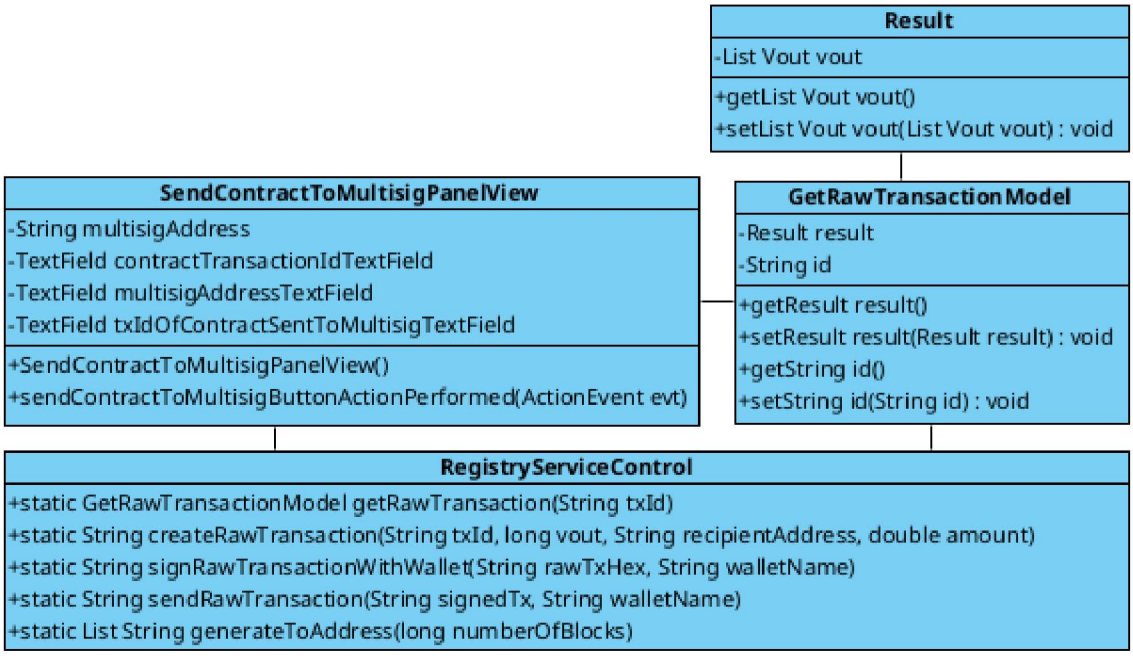
The View Class SendContractToMultisigPanelView presents a GUI (Graphical User Interface) (FIGURE 32) for the REGISTRY OFFICE to send a Public Deed of Sale and Purchase that was registered on the Bitcoin Blockchain to a Multisig address.

When the REGISTRY OFFICE presses the Send Button on View Class SendContractToMultisigPanelView, the process of sending the Public Deed of Sale and Purchase to a Multisig address is triggered through several method calls on Control class RegistryServiceControl. It starts by calling method "RegistryServiceControl.getRawTransaction" that executes command "getrawtransaction" (Bitcoin Developer, 2025c) on Bitcoin Core. The "getrawtransaction" command retrieves, with "Contract Transaction ID", the index number for the transaction output (vout - vector output) (Learn Me a Bitcoin, 2024) of the Public Deed of Sale and Purchase that was registered on the Bitcoin Blockchain in the REGISTER CONTRACT OPERATION. Next, method "RegistryServiceControl.createRawTransaction" is called to execute command "createRawTransaction" (Bitcoin Developer, 2025d) on Bitcoin Core. The "createRawTransaction" command creates a transaction that is, then, signed through a method call on "RegistryServiceControl.signRawTransactionWithWallet" that executes command "signrawtransactionwithwallet" (Bitcoin Developer, 2025e) on Bitcoin Core. Next, the Public Deed of Sale and Purchase registered on the Bitcoin Blockchain is sent to the Multisig address through a method call to "RegistryServiceControl.sendRawTransaction" that executes command "sendrawtransaction" (Bitcoin Developer, 2025f) on Bitcoin Core. Finally, the "sendrawtransaction" command returns "Transaction ID of Contract Sent to Multisig" which is shown on the CreateMultisigAddressPanelView GUI. The "Transaction ID of Contract Sent to Multisig" is used to execute the CREATE MULTISIG TRANSACTION OPERATION.

[32]The source code of Control Class RegistryServiceControl can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/control/RegistryServiceControl.java

[33]The source code of Model Class GetRawTransactionModel can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/model/GetRawTransactionModel.java

FIGURE 33 – SEND CONTRACT TO MULTISIG CLASS DIAGRAM



SOURCE: AUTHOR (2025).

3.4.5 **Create Multisig Transaction Operation**

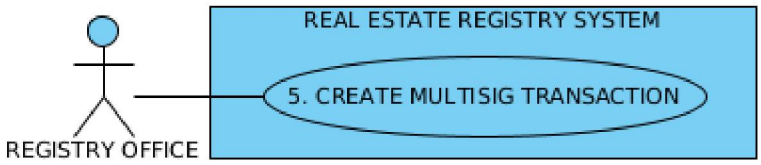
CREATE MULTISIG TRANSACTION OPERATION is described through use case, class and sequence diagrams.

3.4.5.1 Create Multisig Transaction Use Case Diagram

In CREATE MULTISIG TRANSACTION USE CASE DIAGRAM (FIGURE 34), the REGISTRY OFFICE creates the Multisig transaction that allows the PROPERTY OWNER and PROPERTY BUYER to sign the Public Deed of Sale and Purchase. Normally, when a party signs a simple Bitcoin transaction, it results in sending bitcoin to another party. Likewise, when two or more parties a sign a Multisig transaction, it results in sending bitcoin to another party. Therefore, when the PROPERTY OWNER and PROPERTY BUYER sign the Multisig transaction, they not only sign the Public Deed of Sale and Purchase, but they also end up sending the Public Deed of Sale and Purchase, that is registered on a satoshi (sat), to another wallet. And for this project's Solution Concept, when the PROPERTY OWNER and PROPERTY BUYER sign the Multisig transaction, the

Public Deed of Sale and Purchase, that is registered on a sat, is sent to the REGISTRY OFFICE's wallet.

FIGURE 34 – CREATE MULTISIG TRANSACTION USE CASE DIAGRAM

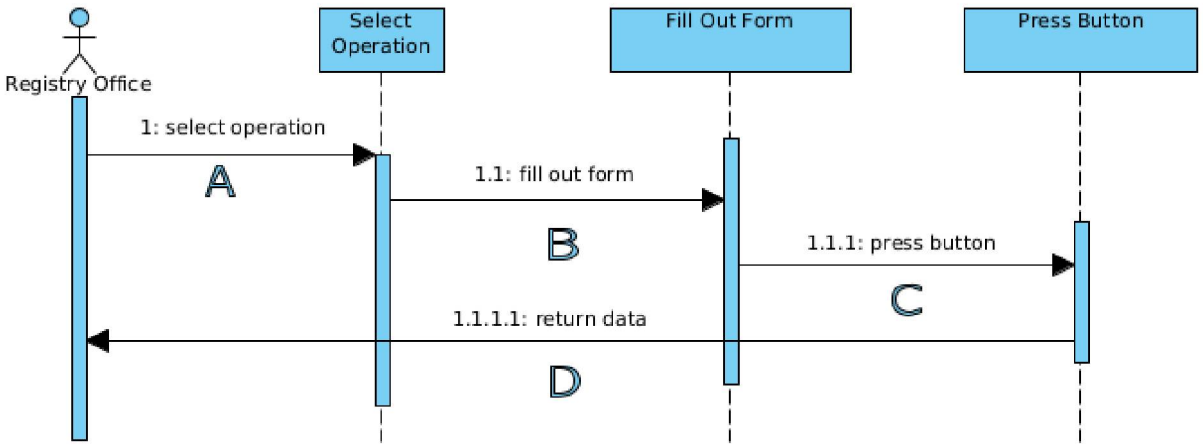


SOURCE: AUTHOR (2025).

3.4.5.2 Create Multisig Transaction Sequence Diagram

CREATE MULTISIG TRANSACTION SEQUENCE DIAGRAM in FIGURE 35 has the following sequence of steps that the REGISTRY OFFICE should complete in the Solution Concept application.

FIGURE 35 – CREATE MULTISIG TRANSACTION SEQUENCE DIAGRAM



SOURCE: AUTHOR (2025).

The sequence of steps are:

a) SELECT CREATE MULTISIG TRANSACTION OPERATION

b) FILL OUT FORM: The FILL OUT FORM step (FIGURE 36) in the CREATE MULTISIG TRANSACTION OPERATION requires filling out the following fields:

- Transaction ID of Contract Sent to Multisig (unique identification of the transaction registered on the Bitcoin Blockchain)

c) PRESS CREATE BUTTON: After pressing the CREATE BUTTON (FIGURE 36) in the CREATE MULTISIG TRANSACTION OPERATION, the system returns the following data:

- Multisig Raw Transaction Hex (encoded transaction that, when decoded with `decoderawtransaction` command on Bitcoin `Core`, contains data which informs that the transaction ID that contains the Contract Inscription will be sent to the REGISTER OFFICE's wallet address once the MULTISIG TRANSACTION is signed by the PROPERTY OWNER and PROPERTY BUYER) (Blockchain Commons, 2022a)

FIGURE 36 – GRAPHICAL USER INTERFACE OF CREATE MULTISIG TRANSACTION OPERATION

SOURCE: AUTHOR (2025).

3.4.5.3 Create Multisig Transaction Class Diagram

CREATE MULTISIG TRANSACTION CLASS DIAGRAM in FIGURE 37 shows class associations applying the Model-View-Controller (MVC) design pattern illustrated in "FIGURE 14 - CLASS DIAGRAMS APPLYING THE MODEL-VIEW-CONTROLLER (MVC) DESIGN PATTERN". These class associations operate when the REGISTRY OFFICE creates a 2-of-2 Multisig transaction that allows the PROPERTY OWNER and PROPERTY

BUYER to sign the Public Deed of Sale and Purchase. The classes are specified in the MVC design pattern as follows:

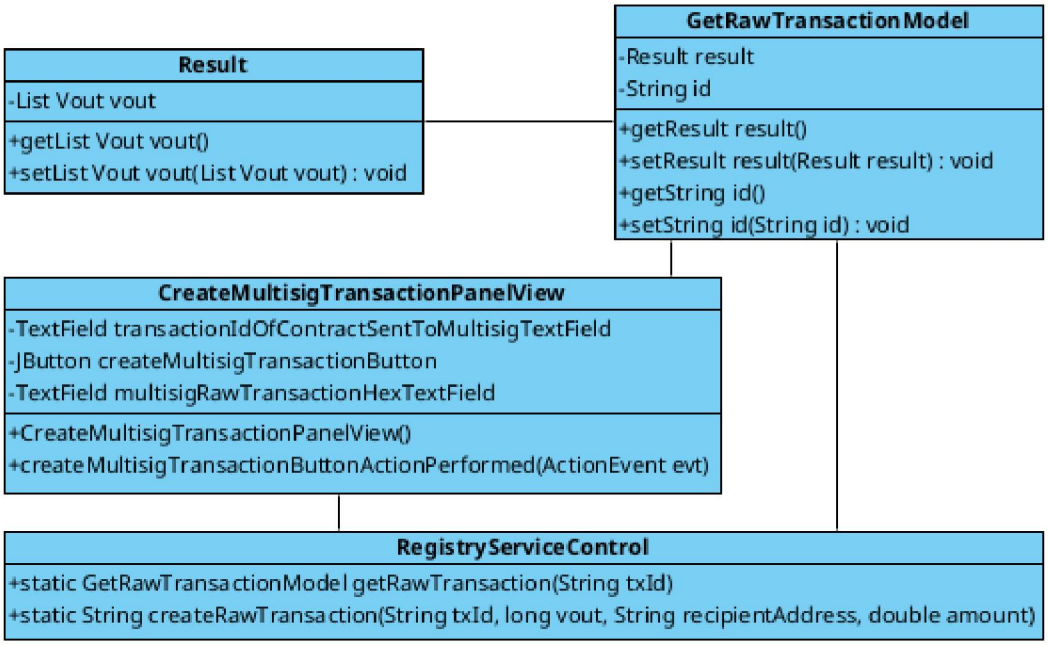
- **View Class:** CreateMultisigTransactionPanelView
- **Controller Class:** RegistryServiceControl[34]
- **Model Classes:** GetRawTransactionModel[35]

The View Class CreateMultisigTransactionPanelView presents a GUI (Graphical User Interface) (FIGURE 36) for the REGISTRY OFFICE to create the 2-of-2 Multisig transaction. When the REGISTRY OFFICE presses the Create Button on View Class CreateMultisigTransactionPanelView, the process of creating a 2-of-2 Multisig transaction is triggered through two method calls on Control class RegistryServiceControl. It starts by calling method “RegistryServiceControl.getRawTransaction” that executes command “getrawtransaction” (Bitcoin Developer, 2025c) on Bitcoin Core. The “getrawtransaction” command retrieves, with “Transaction ID of Contract Sent to Multisig”, the index number for the transaction output (vout - vector output) (Learn Me a Bitcoin, 2024) of the Public Deed of Sale and Purchase that was sent to the Multisig address in the SEND CONTRACT TO MULTISIG OPERATION. Next, method “RegistryServiceControl.createRawTransaction” is called to execute command “createRawTransaction” (Bitcoin Developer, 2025d) on Bitcoin Core. The “createRawTransaction” command creates a Multisig transaction, so that the PROPERTY OWNER and PROPERTY BUYER can sign the Public Deed of Sale and Purchase in the OWNER SIGNER and BUYER SIGNER OPERATIONS. Finally, the “createRawTransaction” command returns “Multisig Raw Transaction Hex” which is shown on the CreateMultisigTransactionPanelView GUI. The “Multisig Raw Transaction Hex” is used to execute the OWNER SIGNER OPERATION.

[34]The source code of Control Class RegistryServiceControl can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/control/RegistryServiceControl.java

[35]The source code of Model Class GetRawTransactionModel can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/model/GetRawTransactionModel.java

FIGURE 37 – CREATE MULTISIG TRANSACTION CLASS DIAGRAM



SOURCE: AUTHOR (2025).

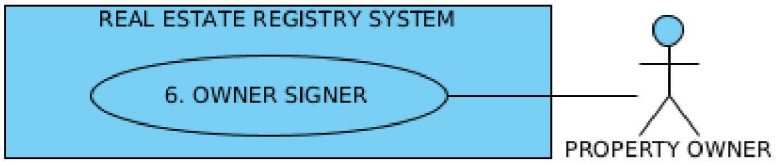
3.4.6 Owner Signer Operation

OWNER SIGNER OPERATION is described through use case, class and sequence diagrams.

3.4.6.1 Owner Signer Use Case Diagram

Once the REGISTRY OFFICE has created the 2-of-2 Multisig transaction in the CREATE MULTISIG TRANSACTION OPERATION, it requests the PROPERTY OWNER signature on the Public Deed of Sale and Purchase. In OWNER SIGNER USE CASE DIAGRAM (FIGURE 38), the PROPERTY OWNER signs the 2-of-2 Multisig transaction with the private key of its corresponding Bitcoin public key wallet address, along with the Redeem Script (obtained from the CREATE MULTISIG OPERATION) and Multisig Raw Transaction Hex (obtained from the CREATE MULTISIG TRANSACTION OPERATION). The PROPERTY OWNER signature completes the first of two signatures required by the 2-of-2 Multisig transaction. In the Solution Concept, when the PROPERTY OWNER signs the 2-of-2 Multisig transaction with private key of its Bitcoin wallet address, it also represents the signing of the Public Deed of Sale and Purchase.

FIGURE 38 – OWNER SIGNER USE CASE DIAGRAM

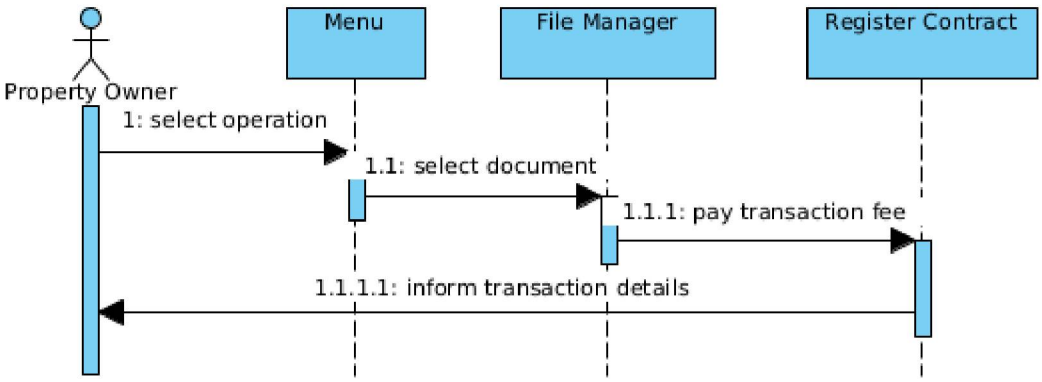


SOURCE: AUTHOR (2025).

3.4.6.2 Owner Signer Sequence Diagram

OWNER SIGNER SEQUENCE DIAGRAM in FIGURE 39 has the following sequence of steps that the PROPERTY OWNER should complete in the Solution Concept application.

FIGURE 39 – OWNER SIGNER TRANSACTION SEQUENCE DIAGRAM



SOURCE: AUTHOR (2025).

The sequence of steps are:

a) SELECT OWNER SIGNER OPERATION

b) FILL OUT FORM: The FILL OUT FORM step (FIGURE 40) in the OWNER SIGNER OPERATION requires filling out the following fields:

- Owner Wallet Address
- Owner Wallet Address Public Key
- Owner Wallet Address Private Key
- Redeem Script (needed to sign the contract along with the private keys of the PROPERTY OWNER AND PROPERTY BUYER) (Blockchain Commons, 2022b)
- Multisig Raw Transaction Hex (when decoded with "`decoderawtransaction`" `command on Bitcoin Core`, the Transaction Hex contains data which informs that the transaction ID containing the Contract Inscription will be sent to the REGISTER OFFICE's wallet address once the MULTISIG TRANSACTION is signed by the PROPERTY OWNER and PROPERTY BUYER) (Blockchain Commons, 2022a; `Bitcoin Developer, 2025h`)

c) PRESS SIGN CONTRACT BUTTON: After pressing the SIGN CONTRACT BUTTON (FIGURE 40) in the OWNER SIGNER OPERATION, the system returns the following data:

- Owner Signature Hex (hex-encoded data of the PROPERTY OWNER's signature)

FIGURE 40 – GRAPHICAL USER INTERFACE OF OWNER SIGNER OPERATION

SOURCE: AUTHOR (2025).

3.4.6.3 Owner Signer Class Diagram

OWNER SIGNER CLASS DIAGRAM in FIGURE 41 shows class associations applying the model-view-controller (mvc) design pattern illustrated in “FIGURE 14 - CLASS DIAGRAMS APPLYING THE MODEL-VIEW-CONTROLLER (MVC) DESIGN PATTERN”. These class associations operate when the PROPERTY OWNER signs the 2-of-2 Multisig transaction with the private of its Bitcoin wallet address. The classes are specified in the MVC design pattern as follows:

- **View Class:** OwnerSignerPanelView[36]
- **Controller Class:** RegistryServiceControl[37]
- **Model Classes:** GetRawTransactionModel[38]; GetAddressInfoModel[39]

The View Class OwnerSignerPanelView presents a GUI (Graphical User Interface) (FIGURE 40) for the PROPERTY OWNER to sign the Multisig transaction created in the CREATE MULTISIG TRANSACTION OPERATION, which in the Solution Concept, represents the signing of the Public Deed of Sale and Purchase.

To sign the Multisig transaction, three pieces of information are required:

- private key corresponding to the PROPERTY OWNER’S public key
- Redeem Script (needed to sign the contract along with the private keys of the PROPERTY OWNER AND PROPERTY BUYER) (Blockchain Commons, 2022b)

[36]The source code of View Class OwnerSignerPanelView can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/view/OwnerSignerPanelView.java
[37]The source code of Control Class RegistryServiceControl can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/control/RegistryServiceControl.java
[38]The source code of Model Class GetRawTransactionModel can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/model/GetRawTransactionModel.java
[39]The source code of Model Class GetAddressInfoModel can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/model/GetAddressInfoModel.java

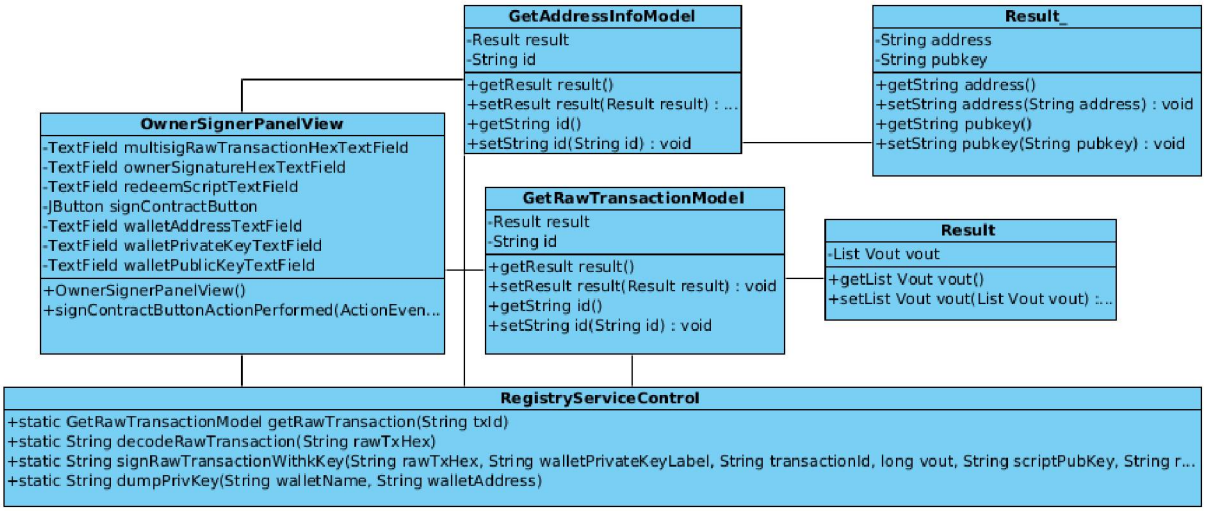
- Multisig Raw Transaction Hex (when decoded with "`decoderawtransaction`" command on `Bitcoin Core`, the Transaction Hex contains data which informs that the transaction ID containing the Contract Inscription will be sent to the REGISTER OFFICE's wallet address once the MULTISIG TRANSACTION is signed by the PROPERTY OWNER and PROPERTY BUYER) (Blockchain Commons, 2022a; `Bitcoin Developer, 2025h`)

The View Class OwnerSignerPanelView runs method "RegistryServiceControl.getAddressInfo" that executes command "getAddressInfo" on Bitcoin Core (Bitcoin Developer, 2025b) to retrieve the PROPERTY OWNER's Bitcoin wallet address and its related public key, which is stored in a Model Class GetAddressInfoModel object. Next, it runs method "RegistryServiceControl.dumpPrivKey" that executes command "dumpprivkey" on Bitcoin Core which "reveals the private key corresponding to" (Bitcoin Developer, 2025g) the PROPERTY OWNER's Bitcoin wallet address. Subsequently, the PROPERTY OWNER's Bitcoin wallet address, public key, and private key are prefilled and shown on the OwnerSignerPanelView GUI Form (FIGURE 40). Next, "Redeem Script" (obtained from the CREATE MULTISIG OPERATION) and "Multisig Raw Transaction Hex" (obtained from the CREATE MULTISIG TRANSACTION OPERATION) is filled out by the PROPERTY OWNER on the OwnerSignerPanelView GUI Form.

When the PROPERTY OWNER presses the Sign Button on View Class OwnerSignerPanelView, the process of obtaining from the PROPERTY OWNER the first signature on the Public Deed of Sale and Purchase is triggered through several method calls on Control class RegistryServiceControl. It starts by calling method "RegistryServiceControl.decodeRawTransaction" that executes command "decoderawtransaction" (Bitcoin Developer, 2025h) on Bitcoin Core. The "decoderawtransaction" command decodes "Multisig Raw Transaction Hex" to obtain the "Transaction ID of Contract Sent to Multisig". Next, it calls method "RegistryServiceControl.getRawTransaction" that executes command "getrawtransaction" (Bitcoin Developer, 2025c) on Bitcoin Core. The "getrawtransaction" command retrieves, with "Transaction ID of Contract Sent to Multisig", the index number for the transaction output (vout - vector output) (Learn Me a Bitcoin, 2024) of the Public Deed of Sale and

Purchase registered on the Bitcoin Blockchain that was sent to the Multisig address, in the SEND CONTRACT TO MULTISIG OPERATION.

FIGURE 41 – OWNER SIGNER CLASS DIAGRAM



SOURCE: AUTHOR (2025).

Next, the Public Deed of Sale and Purchase is signed by the PROPERTY OWNER through a method call on “RegistryServiceControl.signRawTransactionWithkKey” that executes command “signrawtransactionwithkey” (Bitcoin Developer, 2025i) on Bitcoin Core, which returns “Owner Signature Hex“ (hex-encoded data of the PROPERTY OWNER’s signature), that is shown on the OwnerSignerPanelView GUI. The “Owner Signature Hex“ is used to execute the BUYER SIGNER OPERATION.

3.4.7 Buyer Signer Operation

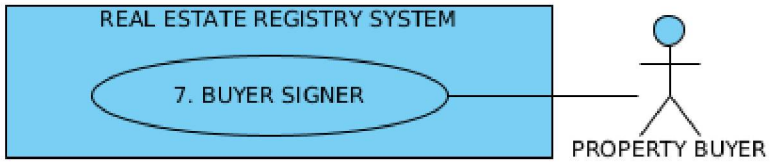
BUYER SIGNER OPERATION is described through use case, class and sequence diagrams.

3.4.7.1 Buyer Signer Use Case Diagram

Once the PROPERTY OWNER has signed the 2-of-2 Multisig transaction, the REGISTRY OFFICE requests the PROPERTY BUYER signature on the Public Deed of Sale and Purchase.

In BUYER SIGNER USE CASE DIAGRAM (FIGURE 42) , the PROPERTY BUYER signs the 2-of-2 Multisig transaction with private key of its Bitcoin wallet address, completing the second of two signatures required by the 2-of-2 Multisig transaction. In the Solution Concept, when the PROPERTY BUYER signs the 2-of-2 Multisig transaction with its Bitcoin wallet address private key, it also represents the signing of the Public Deed of Sale and Purchase.

FIGURE 42 – OWNER SIGNER USE CASE DIAGRAM

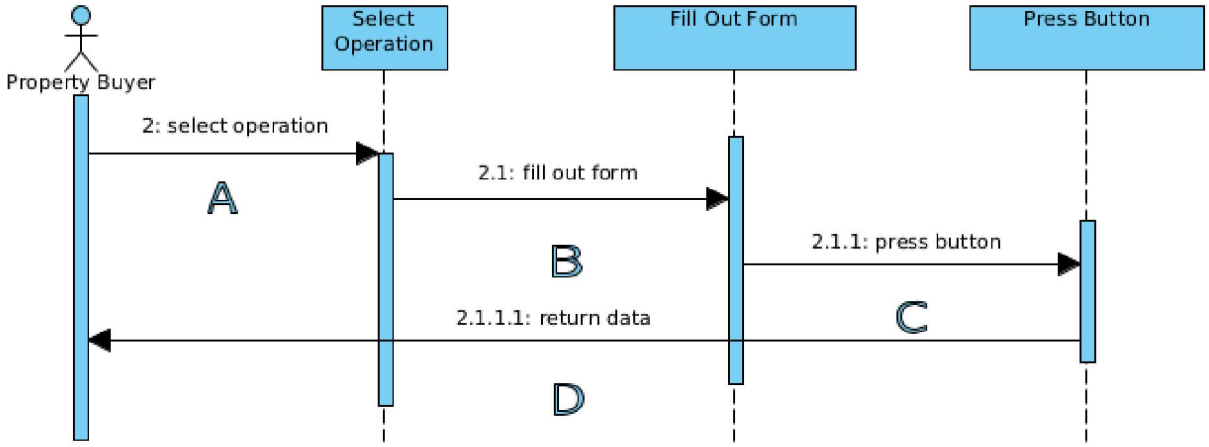


SOURCE: AUTHOR (2025).

3.4.7.2 Buyer Signer Sequence Diagram

BUYER SIGNER SEQUENCE DIAGRAM in FIGURE 43 has the following sequence of steps that the PROPERTY BUYER should complete in the Solution Concept application.

FIGURE 43 – BUYER SIGNER TRANSACTION SEQUENCE DIAGRAM



SOURCE: AUTHOR (2025).

The sequence of steps are:

a) SELECT BUYER SIGNER OPERATION

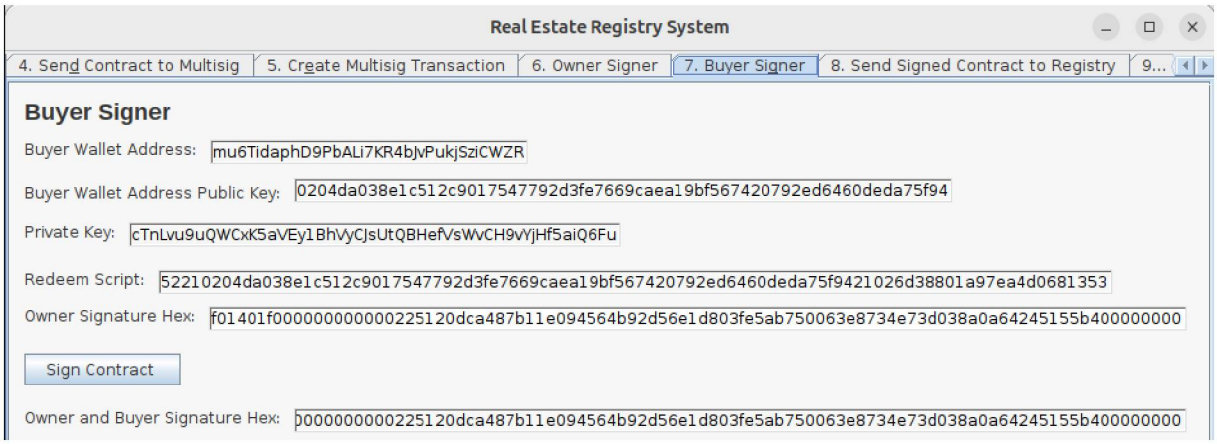
b) FILL OUT FORM: The FILL OUT FORM step (FIGURE 44) in the BUYER SIGNER OPERATION requires filling out the following fields:

- Buyer Wallet Address
- Buyer Wallet Address Public Key
- Buyer Wallet Address Private Key
- Redeem Script (needed to sign the contract along with the private keys of the PROPERTY OWNER AND PROPERTY BUYER) (Blockchain Commons, 2022b)
- Owner Signature Hex (hex-encoded data of the PROPERTY OWNER's signature)

c) PRESS SIGN CONTRACT BUTTON: After pressing the SIGN CONTRACT BUTTON (FIGURE 44) in the BUYER SIGNER OPERATION, the system returns the following data:

- Owner and Buyer Signature Hex (hex-encoded data of the PROPERTY OWNER and PROPERTY BUYER's signatures)

FIGURE 44 – GRAPHICAL USER INTERFACE OF BUYER SIGNER OPERATION



SOURCE: AUTHOR (2025).

3.4.7.3 Buyer Signer Class Diagram

BUYER SIGNER CLASS DIAGRAM in FIGURE 45 shows class associations applying the model-view-controller (mvc) design pattern illustrated in "FIGURE 14 - CLASS DIAGRAMS APPLYING THE MODEL-VIEW-CONTROLLER (MVC) DESIGN PATTERN". These class associations operate when the PROPERTY BUYER signs the 2-of-2 Multisig transaction with the private of its Bitcoin wallet address. The classes are specified in the MVC design pattern as follows:

- **View Class:** BuyerSignerPanelView[40]
- **Controller Class:** RegistryServiceControl[41]
- **Model Classes:** GetRawTransactionModel[42]; GetAddressInfoModel[43]

[40]The source code of View Class BuyerSignerPanelView can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/view/BuyerSignerPanelView.java
[41]The source code of Control Class RegistryServiceControl can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/control/RegistryServiceControl.java
[42]The source code of Model Class GetRawTransactionModel can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/model/GetRawTransactionModel.java
[43]The source code of Model Class GetAddressInfoModel can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/model/GetAddressInfoModel.java

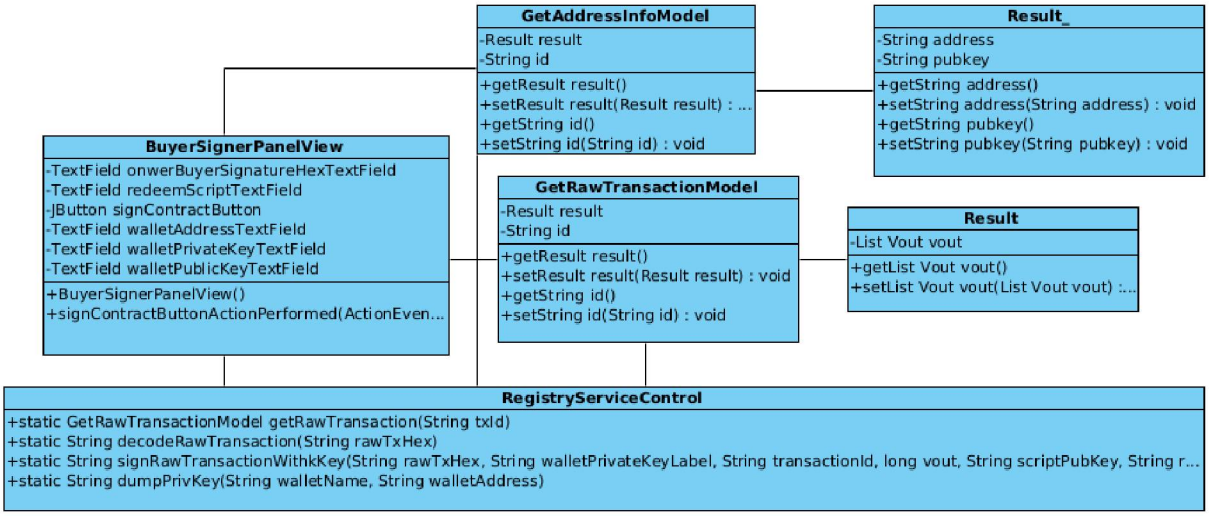
The View Class BuyerSignerPanelView presents a GUI (Graphical User Interface) (FIGURE 44) for the PROPERTY BUYER to sign the Multisig transaction created in the CREATE MULTISIG TRANSACTION OPERATION, which in the Solution Concept, represents the signing of the Public Deed of Sale and Purchase.

To sign the Multisig transaction, three pieces of information are required:

- private key corresponding to the PROPERTY BUYER public key
- Redeem Script (needed to sign the contract along with the private keys of the PROPERTY OWNER AND PROPERTY BUYER) (Blockchain Commons, 2022b)
- Owner Signature Hex (hex-encoded data of the PROPERTY OWNER's signature)

The View Class BuyerSignerPanelView runs method "RegistryServiceControl.getAddressInfo" that executes command "getAddressInfo" on Bitcoin Core (Bitcoin Developer, 2025b) to retrieve the PROPERTY BUYER Bitcoin wallet address and its related public key, which is stored in a Model Class GetAddressInfoModel object. Next, it runs method "RegistryServiceControl.dumpPrivKey" that executes command "dumpprivkey" on Bitcoin Core which "reveals the private key corresponding to" (Bitcoin Developer, 2025g) the PROPERTY BUYER Bitcoin wallet address. Subsequently, the PROPERTY BUYER Bitcoin wallet address, public key, and private key are prefilled and shown on the BuyerSignerPanelView GUI Form (FIGURE 44). Next, "Redeem Script" (obtained from the CREATE MULTISIG OPERATION) and "Owner Signature Hex" (obtained from the OWNER SIGNER OPERATION) is filled out by the PROPERTY BUYER on the BuyerSignerPanelView GUI Form.

FIGURE 45 – BUYER SIGNER CLASS DIAGRAM



SOURCE: AUTHOR (2025).

When the PROPERTY BUYER presses the Sign Button on View Class BuyerSignerPanelView, the process of obtaining from the PROPERTY BUYER the second signature on the Public Deed of Sale and Purchase is triggered through several method calls on Control class RegistryServiceControl. It starts by calling method “RegistryServiceControl.decodeRawTransaction” that executes command “decoderawtransaction” (Bitcoin Developer, 2025h) on Bitcoin Core. The “decoderawtransaction” command decodes “Owner Signature Hex” to obtain the “Transaction ID of Contract Sent to Multisig”. Next, it calls method “RegistryServiceControl.getRawTransaction” that executes command “getrawtransaction” (Bitcoin Developer, 2025c) on Bitcoin Core. The “getrawtransaction” command retrieves, with “Transaction ID of Contract Sent to Multisig”, the index number for the transaction output (vout - vector output) (Learn Me a Bitcoin, 2024) of the Public Deed of Sale and Purchase registered on the Bitcoin Blockchain that was sent to the Multisig address, in the SEND CONTRACT TO MULTISIG OPERATION.

Next, the Public Deed of Sale and Purchase is signed by the PROPERTY BUYER through a method call on “RegistryServiceControl.signRawTransactionWithkKey” that executes command “signrawtransactionwithkey” (Bitcoin Developer, 2025i) on Bitcoin Core, which returns “Owner and Buyer Signature Hex” (hex-encoded data of the PROPERTY OWNER and PROPERTY BUYER’s signatures), that is shown on the

BuyerSignerPanelView GUI. The “Owner and Buyer Signature Hex“ is used to execute the SEND SIGNED CONTRACT TO REGISTRY OPERATION.

3.4.8 **Send Signed Contract to Registry Operation**

SEND SIGNED CONTRACT TO REGISTRY OPERATION is described through use case, class and sequence diagrams.

3.4.8.1 Send Signed Contract to Registry Use Case Diagram

In SEND SIGNED CONTRACT TO REGISTRY USE CASE DIAGRAM (FIGURE 46), once the PROPERTY BUYER has signed the 2-of-2 Multisig transaction, the REGISTRY OFFICE sends the signed 2-of-2 Multisig transaction to be registered and timestamped on the Bitcoin Blockchain network, which results in sending the signed Public Deed of Sale and Purchase (Escritura Pública de Compra e Venda) that is contained in the 2-of-2 Multisig transaction to the REGISTRY OFFICE’s wallet, so the REGISTRY OFFICE can register transfer to property to the PROPERTY BUYER by executing the REGISTER PROPERTY TRANSFER OPERATION.

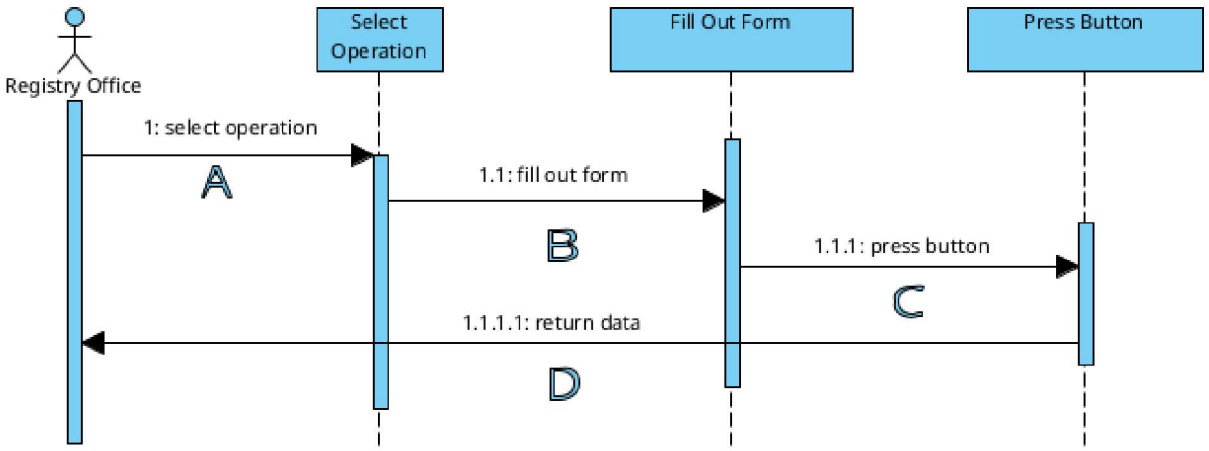
FIGURE 46 – SEND SIGNED CONTRACT TO REGISTRY USE CASE DIAGRAM

SOURCE: AUTHOR (2025).

3.4.8.2 Send Signed Contract to Registry Sequence Diagram

SEND SIGNED CONTRACT TO REGISTRY SEQUENCE DIAGRAM in FIGURE 47 has the following sequence of steps that the REGISTRY OFFICE should complete in the Solution Concept application.

FIGURE 47 – SEND SIGNED CONTRACT TO REGISTRY SEQUENCE DIAGRAM



SOURCE: AUTHOR (2025).

The sequence of steps are:

a) SELECT SEND SIGNED CONTRACT TO REGISTRY OPERATION

b) FILL OUT FORM: The FILL OUT FORM step (FIGURE 48) in the SEND SIGNED CONTRACT TO REGISTRY OPERATION requires filling out the following fields:

- Owner and Buyer Signature Hex (hex-encoded data of the PROPERTY OWNER and PROPERTY BUYER'S signatures)

c) PRESS SEND BUTTON: After pressing the SEND BUTTON (FIGURE 48) in the SEND SIGNED CONTRACT TO REGISTRY OPERATION, the system returns the following data:

- Transaction ID of Signed Contract Sent to Registry Office Address (unique identification of the transaction registered on the Bitcoin Blockchain)

FIGURE 48 – GRAPHICAL USER INTERFACE OF SEND SIGNED CONTRACT TO REGISTRY OPERATION

SOURCE: AUTHOR (2025).

3.4.8.3 Send Signed Contract to Registry Class Diagram

SEND SIGNED CONTRACT TO REGISTRY CLASS DIAGRAM in FIGURE 49 shows class associations applying the model-view-controller (mvc) design pattern illustrated in “FIGURE 14 - CLASS DIAGRAMS APPLYING THE MODEL-VIEW-CONTROLLER (MVC) DESIGN PATTERN”. These class associations operate when the REGISTRY OFFICE sends the signed 2-of-2 Multisig transaction to be registered and timestamped on the Bitcoin Blockchain network, which results in sending the signed Public Deed of Sale and Purchase that is contained in the 2-of-2 Multisig transaction to the REGISTRY OFFICE’s wallet, so the REGISTRY OFFICE can register transfer to property to the PROPERTY BUYER by executing the REGISTER PROPERTY TRANSFER OPERATION. The classes are specified in the MVC design pattern as follows:

- **View Class:** SendSignedContractToRegistryPanelView[44]
- **Controller Class:** RegistryServiceControl[45]

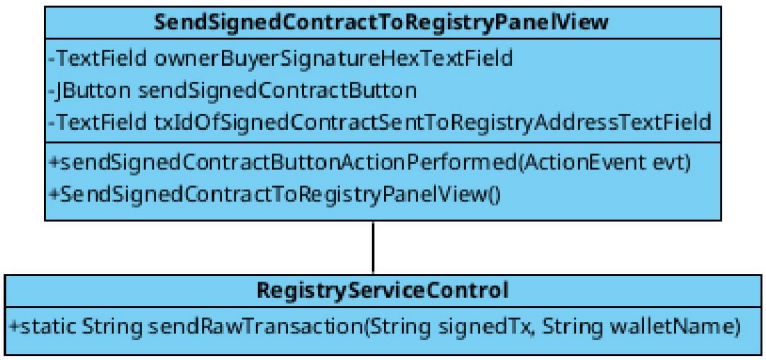
The View Class SendSignedContractToRegistryPanelView presents a GUI (Graphical User Interface) (FIGURE 48) for the REGISTRY OFFICE to send the signed Public Deed of Sale and Purchase to the REGISTRY OFFICE’s wallet.

[44]The source code of View Class SendSignedContractToRegistryPanelView can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/view/SendSignedContractToRegistryPanelView.java

[45]The source code of Control Class RegistryServiceControl can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/control/RegistryServiceControl.java

When the REGISTRY OFFICE presses the Send Button on View Class SendSignedContractToRegistryPanelView, it calls method “RegistryServiceControl.sendRawTransaction” that executes command “sendrawtransaction” (Bitcoin Developer, 2025f) on Bitcoin Core, which takes as parameter the “Owner and Buyer Signature Hex” (hex-encoded data of the PROPERTY OWNER and PROPERTY BUYER'S signatures) that was filled out by the REGISTRY OFFICE on the SendSignedContractToRegistryPanelView GUI Form. Finally, the “sendrawtransaction” command returns “Transaction ID of Signed Contract Sent to Registry Office Address” which is shown on the SendSignedContractToRegistryPanelView GUI. The “Transaction ID of Signed Contract Sent to Registry Office Address” is used to execute the VERIFY CONTRACT SIGNATURES and REGISTER PROPERTY TRANSFER OPERATIONS.

FIGURE 49 – SEND SIGNED CONTRACT TO REGISTRY CLASS DIAGRAM



SOURCE: AUTHOR (2025).

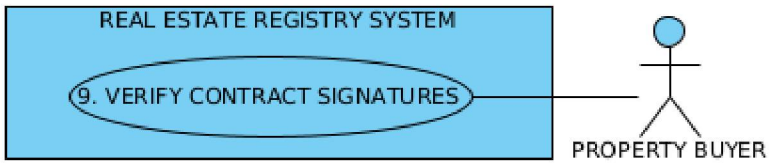
3.4.9 Verify Contract Signatures Operation

VERIFY CONTRACT SIGNATURES OPERATION is described through use case, class and sequence diagrams.

3.4.9.1 Verify Contract Signatures Use Case Diagram

In VERIFY CONTRACT SIGNATURES USE CASE DIAGRAM (FIGURE 50), the PROPERTY BUYER verifies if the Public Deed of Sale and Purchase has been signed by the PROPERTY OWNER and sent to the REGISTRY OFFICE's wallet, so that the PROPERTY BUYER can send the payment which was agreed in the Public Deed of Sale and Purchase to the PROPERTY OWNER.

FIGURE 50 – VERIFY CONTRACT SIGNATURES USE CASE DIAGRAM



SOURCE: AUTHOR (2025).

3.4.9.2 Verify Contract Signatures Sequence Diagram

VERIFY CONTRACT SIGNATURES SEQUENCE DIAGRAM in FIGURE 51 has the following sequence of steps that the PROPERTY BUYER should complete in the Solution Concept application.

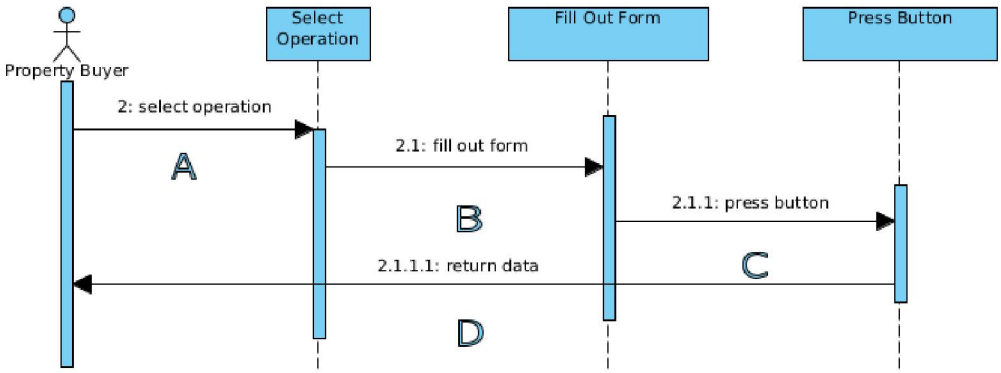
The sequence of steps are:

a) SELECT VERIFY CONTRACT SIGNATURES OPERATION

b) FILL OUT FORM: The FILL OUT FORM step (FIGURE 52) in the VERIFY CONTRACT SIGNATURES OPERATION requires filling out the following fields:

- Transaction ID of Signed Contract Sent to REGISTRY OFFICE Address (unique identification of the transaction registered on the Bitcoin Blockchain)
- Redeem Script (needed to sign the contract along with the private keys of the PROPERTY OWNER AND PROPERTY BUYER) (Blockchain Commons, 2022b)
- Owner Wallet Address Public Key
- Buyer Wallet Address Public Key

FIGURE 51 – VERIFY CONTRACT SIGNATURES SEQUENCE DIAGRAM



SOURCE: AUTHOR (2025).

The sequence of steps are:

a) SELECT VERIFY CONTRACT SIGNATURES OPERATION

b) FILL OUT FORM: The FILL OUT FORM step (FIGURE 52) in the VERIFY CONTRACT SIGNATURES OPERATION requires filling out the following fields:

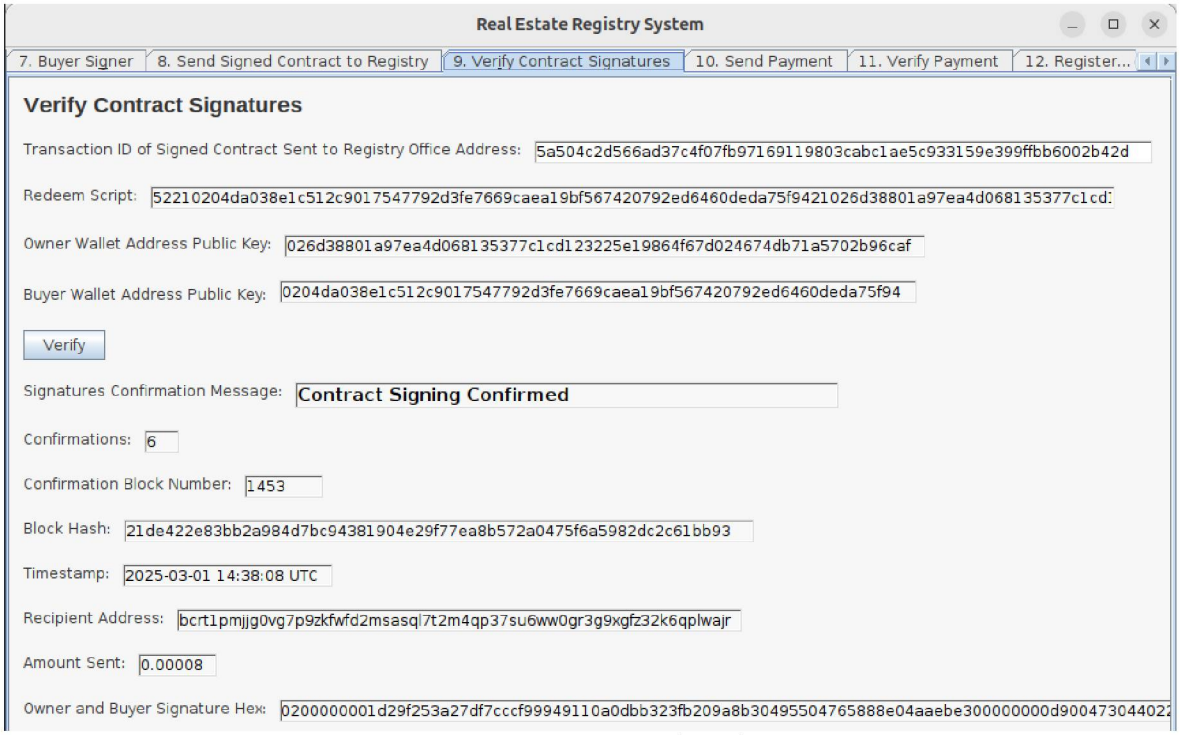
- Transaction ID of Signed Contract Sent to REGISTRY OFFICE Address (unique identification of the transaction registered on the Bitcoin Blockchain)
- Redeem Script (needed to sign the contract along with the private keys of the PROPERTY OWNER AND PROPERTY BUYER) (Blockchain Commons, 2022b)
- Owner Wallet Address Public Key
- Buyer Wallet Address Public Key

c) PRESS VERIFY BUTTON: After pressing the VERIFY BUTTON (FIGURE 52) in the VERIFY CONTRACT SIGNATURES OPERATION, the system returns the following data:

- Signatures Confirmation Message

- Confirmations
- Confirmation Block Number
- Block Hash

FIGURE 52 – GRAPHICAL USER INTERFACE OF VERIFY CONTRACT SIGNATURES OPERATION



SOURCE: AUTHOR (2025).

- Timestamp
- Recipient Address (REGISTRY OFFICE wallet address)
- Amount Sent
- Owner and Buyer Signature Hex (hex-encoded data of the PROPERTY OWNER and PROPERTY BUYER’s signatures)

3.4.9.3 Verify Contract Signatures Class Diagram

VERIFY CONTRACT SIGNATURES CLASS DIAGRAM in FIGURE 53 shows class associations applying the model-view-controller (mvc) design pattern illustrated in “FIGURE 14 - CLASS DIAGRAMS APPLYING THE MODEL-VIEW-CONTROLLER (MVC) DESIGN PATTERN”. These class associations operate when the PROPERTY BUYER verifies if the Public Deed of Sale and Purchase has been signed by the PROPERTY OWNER and sent to the REGISTRY OFFICE’s wallet, so that the PROPERTY BUYER can send the payment which was agreed in the Public Deed of Sale and Purchase to the PROPERTY OWNER. The classes are specified in the MVC design pattern as follows:

- **View Class:** VerifyContractSignaturesPanelView[46]
- **Controller Class:** RegistryServiceControl[47]
- **Model Classes:** GetRawTransactionModel[48]; GetAddressInfoModel[49]; GetBlockModel[50]

The View Class VerifyContractSignaturesPanelView presents a GUI (Graphical User Interface) (FIGURE 52) for the REGISTRY OFFICE to verify if the Public Deed of Sale and Purchase has been signed by the PROPERTY OWNER and sent to the REGISTRY OFFICE’s wallet.

The VerifyContractSignaturesPanelView prefills the “Buyer Wallet Public Key” and “Owner Wallet Public Key” fields on the GUI by running twice method “RegistryServiceControl.getAddressInfo”, that executes command “getAddressInfo” on Bitcoin Core which retrieves Bitcoin wallet address information (Bitcoin Developer, 2025b). The first execution retrieves the Bitcoin wallet address information of the PROPERTY BUYER, which is stored in a Model Class GetAddressInfoModel object. The second execution retrieves the Bitcoin wallet address information of the PROPERTY OWNER, which is stored in another Model Class GetAddressInfoModel object. Next, the public keys contained in both GetAddressInfoModel classes are then stored in “walletBuyerPublicKey”

[46]The source code of View Class VerifyContractSignaturesPanelView can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/view/VerifyContractSignaturesPanelView.java

[47]The source code of Control Class RegistryServiceControl can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/control/RegistryServiceControl.java

[48]The source code of Model Class GetRawTransactionModel can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/model/GetRawTransactionModel.java

[49]The source code of Model Class GetAddressInfoModel can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/model/GetAddressInfoModel.java

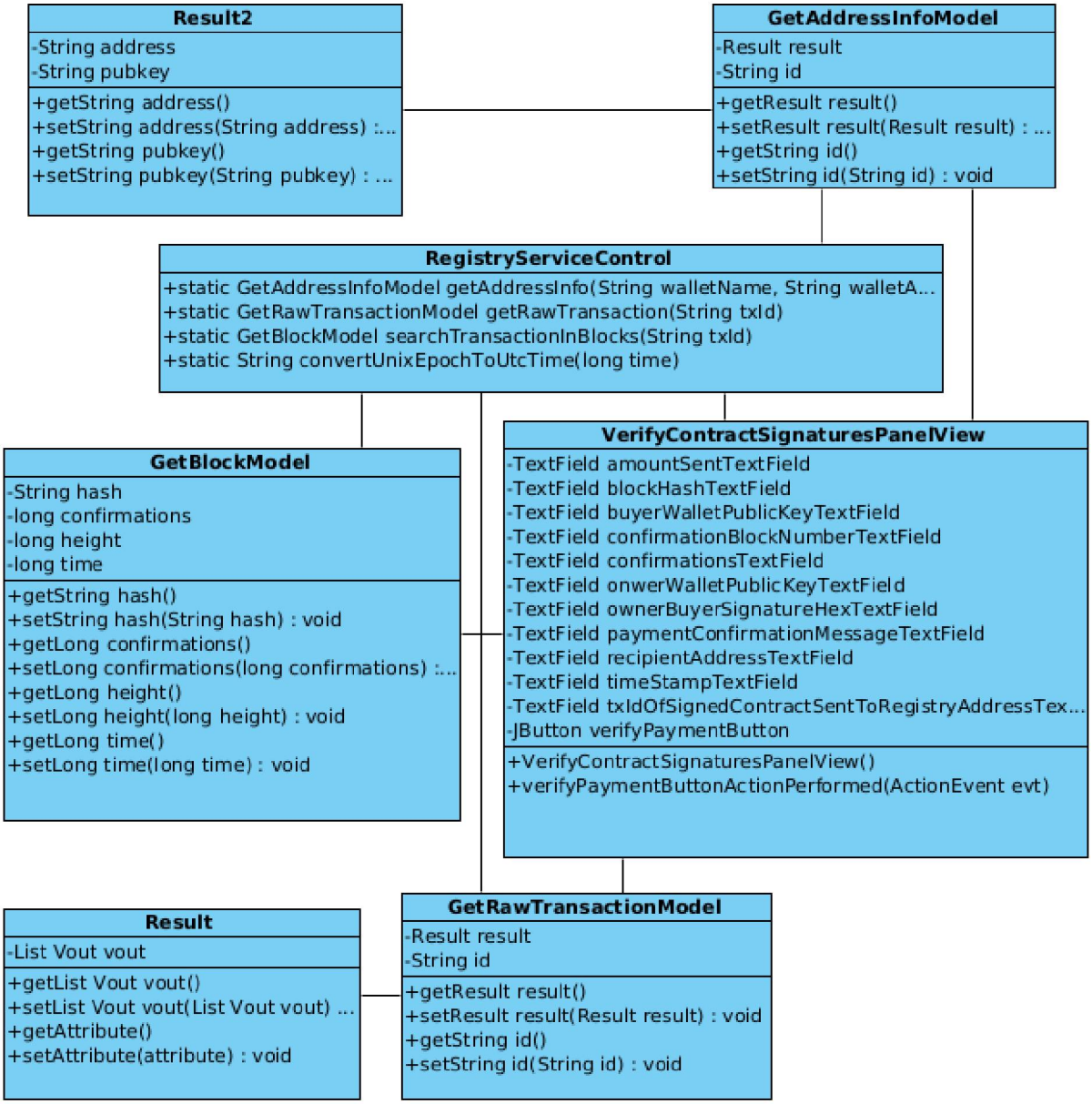
[50]The source code of Model Class GetBlockModel can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/model/GetBlockModel.java

and “walletOwnerPublicKey” attributes, respectively. Finally, the public keys are shown on the CreateMultisigAddressPanelView GUI.

When the REGISTRY OFFICE presses the Verify Button on View Class VerifyContractSignaturesPanelView, the process of verifying if the Public Deed of Sale and Purchase has been signed by the PROPERTY OWNER and sent to the REGISTRY OFFICE’s wallet is triggered through several method calls on Control class RegistryServiceControl. It starts by calling method “RegistryServiceControl.searchTransactionInBlocks” to search for a block on the Bitcoin Blockchain that contains registration of the “Transaction ID of Signed Contract Sent to REGISTRY OFFICE Address”. Next, it calls method “RegistryServiceControl.getRawTransaction” that executes command “getrawtransaction” (Bitcoin Developer, 2025c) on Bitcoin Core. The “getrawtransaction” command retrieves, with “Transaction ID of Signed Contract Sent to REGISTRY OFFICE Address”, the “Owner and Buyer Signature Hex” (hex-encoded data of the PROPERTY OWNER and PROPERTY BUYER’s signatures).

Subsequently, View Class VerifyContractSignaturesPanelView verifies if the “Owner and Buyer Signature Hex” contains the “Buyer Wallet Public Key”, “Owner Wallet Public Key”, and “Redeem Script”. If it is confirmed that the “Buyer Wallet Public Key”, “Owner Wallet Public Key”, and “Redeem Script” are contained within the “Owner and Buyer Signature Hex”, a message "Contract Signing Confirmed" is shown on the GUI, along with several other information about the “Transaction ID of Signed Contract Sent to REGISTRY OFFICE Address” that was registered on the Bitcoin Blockchain. Otherwise, a message "Contract Signing NOT Confirmed" is shown on the GUI.

FIGURE 53 – VERIFY CONTRACT SIGNATURES CLASS DIAGRAM



SOURCE: AUTHOR (2025).

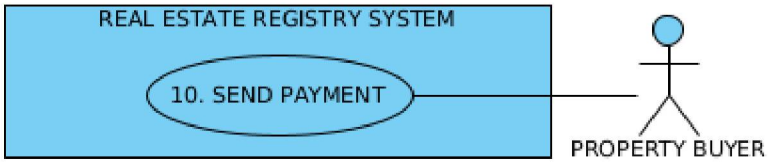
3.4.10 Send Payment Operation

SEND PAYMENT OPERATION is described through use case, class and sequence diagrams.

3.4.10.1 Send Payment Use Case Diagram

In SEND PAYMENT USE CASE DIAGRAM (FIGURE 54), the PROPERTY BUYER sends the payment in the amount that was agreed in the Public Deed of Sale and Purchase from the PROPERTY BUYER's Bitcoin wallet address to the PROPERTY OWNER's Bitcoin wallet address.

FIGURE 54 – SEND PAYMENT USE CASE DIAGRAM



SOURCE: AUTHOR (2025).

3.4.10.2 Send Payment Sequence Diagram

SEND PAYMENT SEQUENCE DIAGRAM in FIGURE 55 has the following sequence of steps that the PROPERTY BUYER should complete in the Solution Concept application.

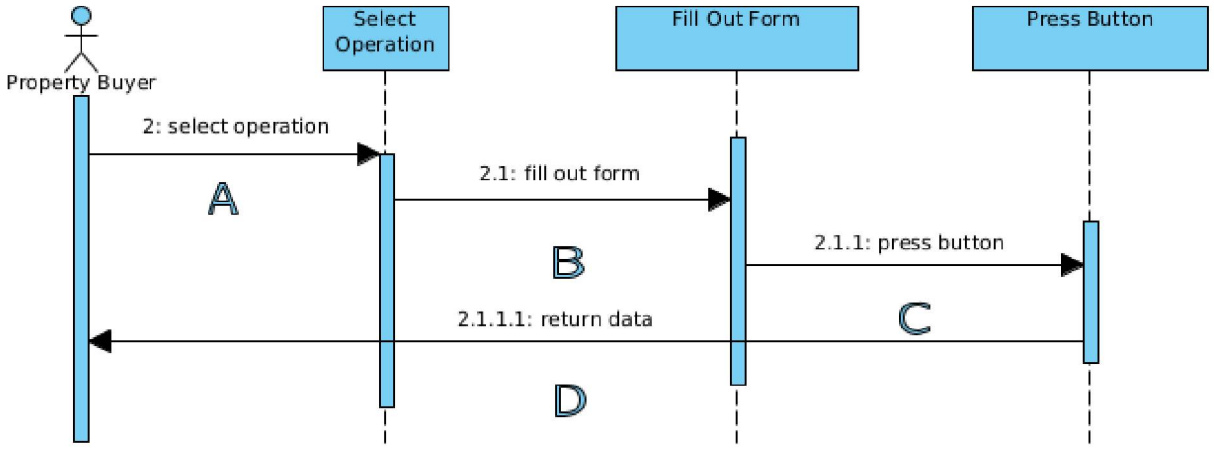
The sequence of steps are:

a) SELECT SEND PAYMENT OPERATION

b) FILL OUT FORM: The FILL OUT FORM step (FIGURE 56) in the SEND PAYMENT OPERATION requires filling out the following fields:

- Owner Wallet Address
- Payment Amount

FIGURE 55 – SEND PAYMENT SEQUENCE DIAGRAM

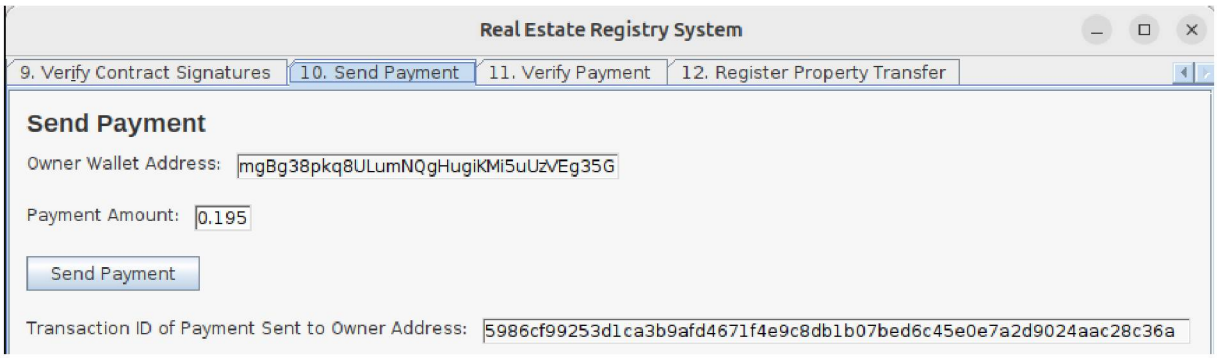


SOURCE: AUTHOR (2025).

c) PRESS CREATE BUTTON: After pressing the SEND PAYMENT BUTTON (FIGURE 56) in the SEND PAYMENT OPERATION, the system returns the following data:

- Transaction ID of Payment Sent to Owner Address (unique identification of the transaction registered on the Bitcoin Blockchain)

FIGURE 56 – GRAPHICAL USER INTERFACE OF SEND PAYMENT OPERATION



SOURCE: AUTHOR (2025).

3.4.10.3 Send Payment Class Diagram

SEND PAYMENT CLASS DIAGRAM in FIGURE 57 shows class associations applying the model-view-controller (mvc) design pattern illustrated in “FIGURE 14 - CLASS DIAGRAMS APPLYING THE MODEL-VIEW-CONTROLLER (MVC) DESIGN PATTERN”. These class associations operate when the PROPERTY BUYER sends the payment in the amount that was agreed in the Public Deed of Sale and Purchase from the PROPERTY BUYER's Bitcoin wallet address to the PROPERTY OWNER's Bitcoin wallet address. The classes are specified in the MVC design pattern as follows:

- **View Class:** SendPaymentFromBuyerToOwnerPanelView[51]
- **Controller Class:** RegistryServiceControl[52]

The View Class SendPaymentFromBuyerToOwnerPanelView presents a GUI (Graphical User Interface) (FIGURE 56) for the PROPERTY BUYER to send payment to the PROPERTY OWNER. When the PROPERTY BUYER presses the Send Button on View Class SendPaymentFromBuyerToOwnerPanelView, after having filled out the “Owner Wallet Address” and “Payment Amount” fields on the GUI, the process of sending payment to the PROPERTY OWNER is triggered through several method calls on Control class RegistryServiceControl.

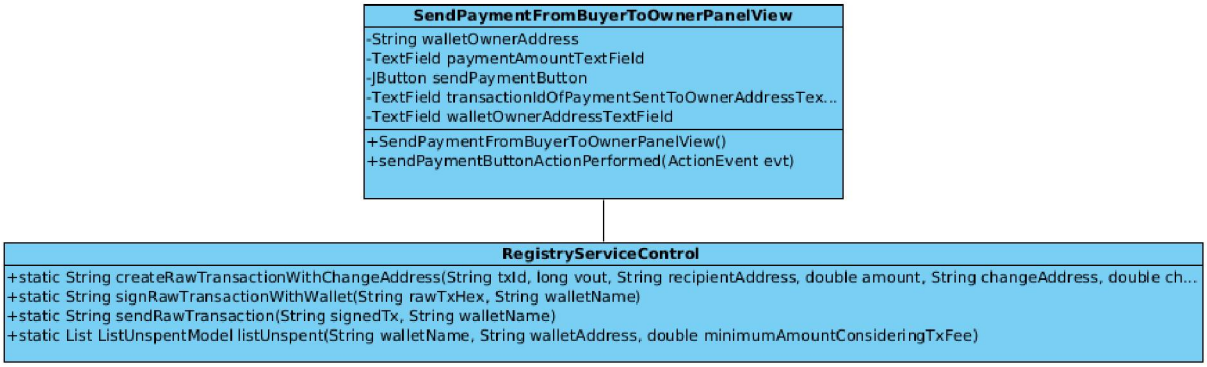
It starts by calling method “RegistryServiceControl.listUnspent” that executes command “listunspent” on Bitcoin Core which “returns array of unspent transaction outputs” (Bitcoin Developer, 2025k). The “listunspent” command is used to retrieve an unspent transaction that contains enough bitcoin to pay the amount filled out on “Payment Amount” field on the GUI plus transaction fee of 1500 sats. Next, method “RegistryServiceControl.createRawTransactionWithChangeAddress” is called to execute command “createRawTransaction” (Bitcoin Developer, 2025d) on Bitcoin Core to create a spendable transaction that is, then, signed through a method call on “RegistryServiceControl.signRawTransactionWithWallet” that executes command “signrawtransactionwithwallet” (Bitcoin Developer, 2025e) on Bitcoin Core. Next, the

[51]The source code of View Class SendPaymentFromBuyerToOwnerPanelView can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/view/SendPaymentFromBuyerToOwnerPanelView.java

[52]The source code of Control Class RegistryServiceControl can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/control/RegistryServiceControl.java.

payment in the amount filled out on “Payment Amount” field on the GUI is sent to the PROPERTY OWNER's Bitcoin wallet address. Finally, the “sendrawtransaction” command returns “Transaction ID of Payment Sent to Owner Address” which is shown on the CreateMultisigAddressPanelView GUI. The “Transaction ID of Payment Sent to Owner Address” is used to execute the VERIFY PAYMENT and REGISTER PROPERTY TRANSFER OPERATIONS.

FIGURE 57 – SEND PAYMENT CLASS DIAGRAM



SOURCE: AUTHOR (2025).

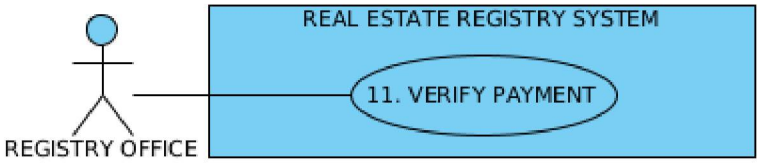
3.4.11 Verify Payment Operation

VERIFY PAYMENT OPERATION is described through use case, class and sequence diagrams.

3.4.11.1 Verify Payment Use Case Diagram

In VERIFY PAYMENT USE CASE (FIGURE 58), the REGISTRY OFFICE verifies if the PROPERTY BUYER has sent the payment in the amount that was agreed in the Public Deed of Sale and Purchase to the PROPERTY OWNER's Bitcoin wallet address. Thereby the REGISTRY OFFICE can then transfer the property from the PROPERTY OWNER to the PROPERTY BUYER.

FIGURE 58 – VERIFY PAYMENT USE CASE DIAGRAM

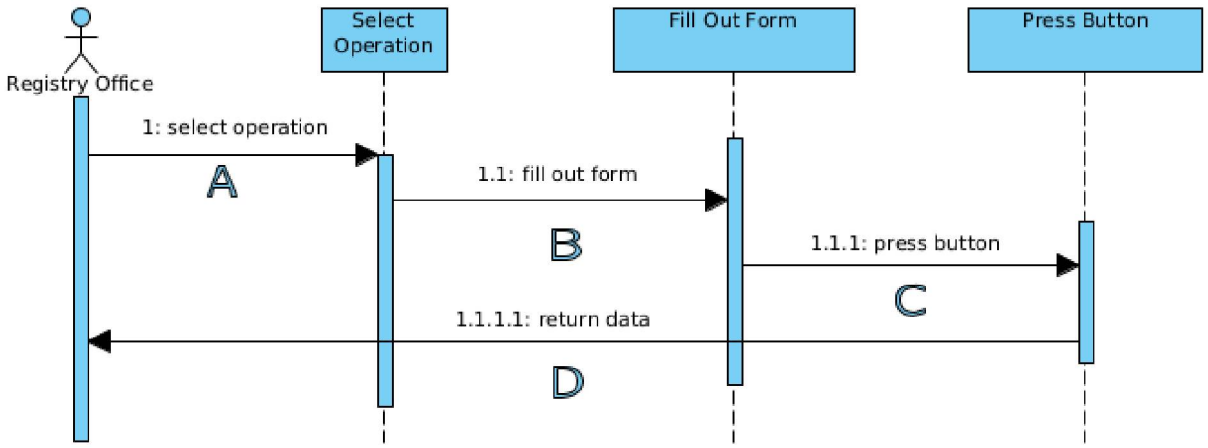


SOURCE: AUTHOR (2025).

3.4.11.2 Verify Payment Sequence Diagram

VERIFY PAYMENT SEQUENCE DIAGRAM in FIGURE 59 has the following sequence of steps that the REGISTRY OFFICE should complete in the Solution Concept application.

FIGURE 59 – VERIFY PAYMENT SEQUENCE DIAGRAM



SOURCE: AUTHOR (2025).

The sequence of steps are:

a) SELECT VERIFY PAYMENT OPERATION

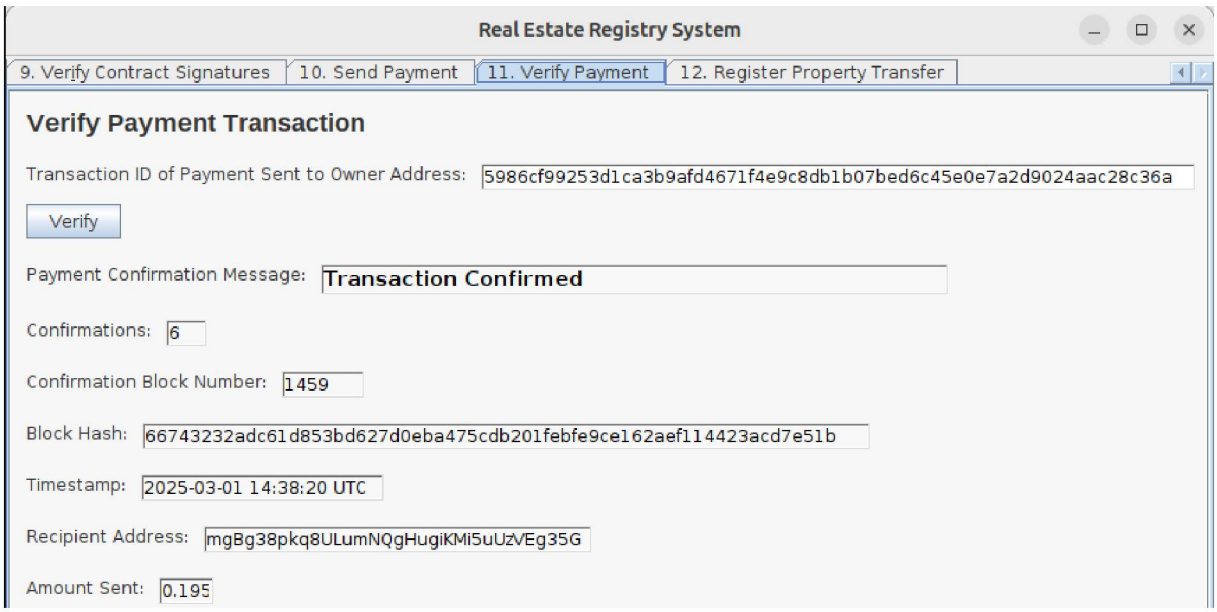
b) FILL OUT FORM: The FILL OUT FORM step (FIGURE 60) in the VERIFY PAYMENT OPERATION requires filling out the following fields:

- Transaction ID of Payment Sent to Owner Address (unique identification of the transaction registered on the Bitcoin Blockchain)

c) PRESS VERIFY BUTTON: After pressing the VERIFY BUTTON (FIGURE 60) in the VERIFY PAYMENT OPERATION, the system returns the following data:

- Payment Confirmation Message
- Confirmations
- Confirmation Block Number
- Block Hash
- Timestamp
- Recipient Address (PROPERTY OWNER Wallet Address)
- Amount Sent

FIGURE 60 – GRAPHICAL USER INTERFACE OF VERIFY PAYMENT OPERATION



SOURCE: AUTHOR (2025).

3.4.11.3 Verify Payment Class Diagram

The REGISTRY OFFICE verifies if the PROPERTY BUYER has sent the payment in the amount that was agreed in the Public Deed of Sale and Purchase to the PROPERTY OWNER's Bitcoin wallet address. Thereby the REGISTRY OFFICE can then transfer the property from the PROPERTY OWNER to the PROPERTY BUYER.

VERIFY PAYMENT CLASS DIAGRAM in FIGURE 61 shows class associations applying the model-view-controller (mvc) design pattern illustrated in “FIGURE 14 - CLASS DIAGRAMS APPLYING THE MODEL-VIEW-CONTROLLER (MVC) DESIGN PATTERN”. These class associations operate when the REGISTRY OFFICE verifies if the PROPERTY BUYER has sent the payment in the amount that was agreed in the Public Deed of Sale and Purchase to the PROPERTY OWNER's Bitcoin wallet address. The classes are specified in the MVC design pattern as follows:

- **View Class:** VerifyPaymentPanelView[53]
- **Controller Class:** RegistryServiceControl[54]
- **Model Classes:** GetRawTransactionModel[55]; GetBlockModel[56]

The View Class VerifyContractSignaturesPanelView presents a GUI (Graphical User Interface) (FIGURE 60) for the REGISTRY OFFICE to verify if the PROPERTY BUYER has sent the property purchase payment to the PROPERTY OWNER's Bitcoin wallet address.

When the REGISTRY OFFICE presses the Verify Button on View Class VerifyPaymentPanelView, the process of verifying if the PROPERTY BUYER has sent the property purchase payment to the PROPERTY OWNER’s Bitcoin wallet address is triggered through several method calls on Control class RegistryServiceControl. It starts by calling method “RegistryServiceControl.searchTransactionInBlocks” to search for a block on the Bitcoin Blockchain that contains registration of the “Transaction ID of Payment Sent

[53]The source code of View Class VerifyPaymentPanelView can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/view/VerifyPaymentPanelView.java
[54]The source code of Control Class RegistryServiceControl can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/control/RegistryServiceControl.java
[55]The source code of Model Class GetRawTransactionModel can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/model/GetRawTransactionModel.java
[56]The source code of Model Class GetBlockModel can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/model/GetBlockModel.java

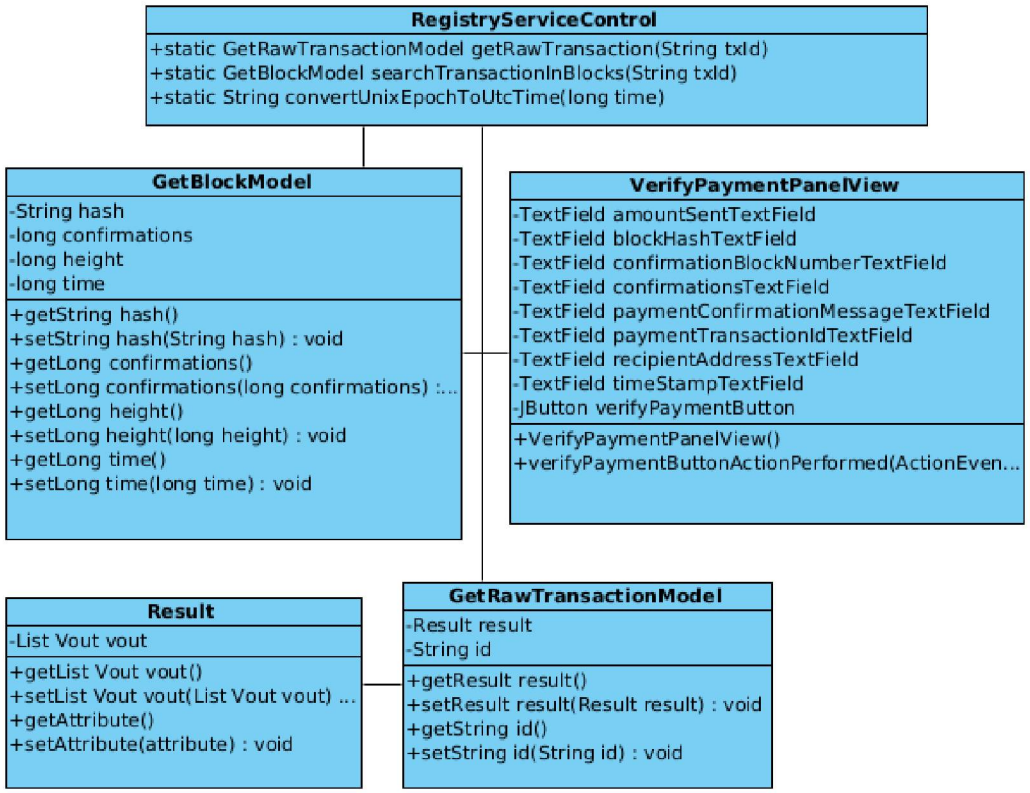
to Owner Address". Next, method "RegistryServiceControl.searchTransactionInBlocks" returns Model Class GetBlockModel.

If it is confirmed that Model Class GetBlockModel stores data of the block that contains registration of the "Transaction ID of Payment Sent to Owner Address", a message "Transaction Confirmed" is shown on the GUI, along with the amount sent to the PROPERTY OWNER's Bitcoin wallet address and several other information about the "Transaction ID of Payment Sent to Owner Address" that was registered on the Bitcoin Blockchain. The amount sent to the PROPERTY OWNER's Bitcoin wallet address is informed through a calls method call on "RegistryServiceControl.getRawTransaction" that executes command "getrawtransaction" (Bitcoin Developer, 2025c) on Bitcoin Core, which retrieves with "Transaction ID of Payment Sent to Owner Address ", the amount sent the to the PROPERTY OWNER's Bitcoin wallet address.

Otherwise, if it is not confirmed that Model Class GetBlockModel stores data of the block that contains registration of the "Transaction ID of Payment Sent to Owner Address",a message "Transaction has NOT been confirmed on the blockchain" is shown on the GUI.

Finally, the REGISTRY OFFICE completes two verifications. The first is to verify that the message "Transaction Confirmed" is shown on the GUI. The second is to verify that the amount sent the to the PROPERTY OWNER's Bitcoin wallet address matches the amount agreed in the Public Deed of Sale and Purchase. Once these two verifications are completed, the REGISTRY OFFICE executes the REGISTER PROPERTY TRANSFER OPERATION.

FIGURE 61 – VERIFY PAYMENT CLASS DIAGRAM



SOURCE: AUTHOR (2025).

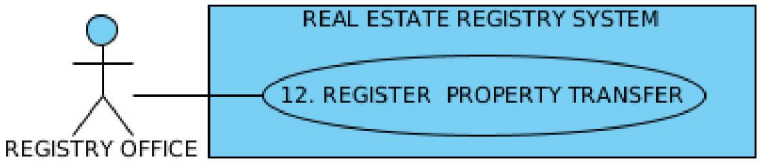
3.4.12 **Register Property Transfer Operation**

REGISTER PROPERTY TRANSFER OPERATION is described through use case, sequence diagrams, and class diagrams. Additionally principles of Knowledge Representation are applied to the Property Transfer registered on the Bitcoin Blockchain.

3.4.12.1 Register Property Transfer Use Case Diagram

The REGISTER PROPERTY TRANSFER USE CASE DIAGRAM (FIGURE 62) represents the transfer of property ownership from the PROPERTY OWNER to the PROPERTY BUYER. The REGISTRY OFFICE transfers ownership of the property that was negotiated in the Public Deed of Sale and Purchase which was signed by the PROPERTY OWNER and the PROPERTY BUYER.

FIGURE 62 – REGISTER PROPERTY TRANSFER CASE DIAGRAM

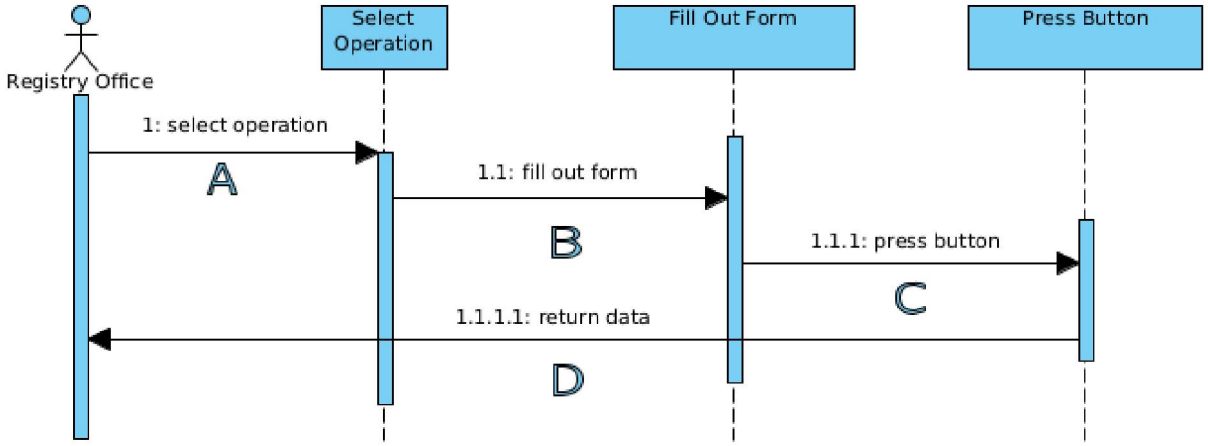


SOURCE: AUTHOR (2025).

3.4.12.2 Register Property Transfer Sequence Diagram

REGISTER PROPERTY TRANSFER SEQUENCE DIAGRAM in FIGURE 63 has the following sequence of steps that the REGISTRY OFFICE should complete in the Solution Concept application.

FIGURE 63 – VERIFY PAYMENT SEQUENCE DIAGRAM



SOURCE: AUTHOR (2025).

The sequence of steps are:

a) SELECT REGISTER PROPERTY TRANSFER OPERATION

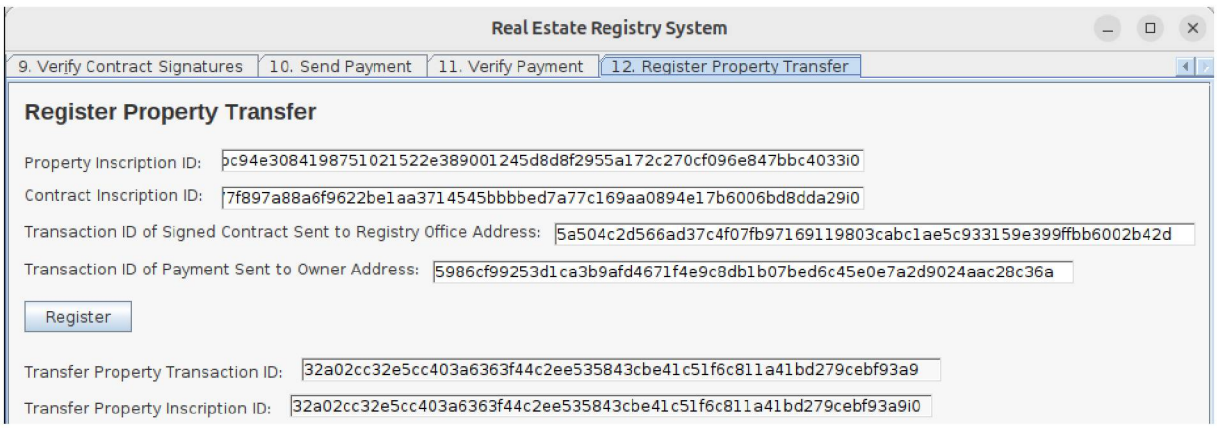
b) FILL OUT FORM: The FILL OUT FORM step (FIGURE 64) in the REGISTER PROPERTY TRANSFER OPERATION requires filling out the following fields:

- Property Inscription ID (unique identification of the transaction registered on the Bitcoin Blockchain)
- Contract Inscription ID (unique identification of the inscription that was stored on the index database of the “ord” Software Utility)
- Transaction ID of Signed Contract Sent to REGISTRY OFFICE Address (unique identification of the transaction registered on the Bitcoin Blockchain)
- Transaction ID of Payment Sent to Owner Address (unique identification of the transaction registered on the Bitcoin Blockchain)

c) PRESS REGISTER BUTTON: After pressing the REGISTER BUTTON (FIGURE 64) in the REGISTER PROPERTY TRANSFER OPERATION, the system returns the following data:

- Transfer Property Transaction ID (unique identification of the transaction registered on the Bitcoin Blockchain)
- Transfer Property Inscription ID (unique identification of the transaction registered on the Bitcoin Blockchain)

FIGURE 64 – GRAPHICAL USER INTERFACE OF REGISTER PROPERTY TRANSFER OPERATION



SOURCE: AUTHOR (2025).

3.4.12.3 Register Property Transfer Knowledge Representation

For application of principles of Knowledge Representation related to bringing machine-readable structure (Oellinger & Wennerberg, 2006) through JSON-LD (JavaScript Object Notation – Linked Data), when the REGISTRY OFFICE completes the sequence of steps of registering the Property Transfer in SECTION “3.4.11.2 Verify Payment Sequence Diagram ”, the Property Transfer data is stored in JSON file format (FIGURE 65) on the Bitcoin Blockchain. Once the transaction of storing/registering the Property Transfer data in JSON file format is confirmed/timestamped on the Bitcoin Blockchain, a Transfer Property Inscription ID (*inscriptionID*) and a Transfer Property Transaction ID (transactionID) are obtained.

For application of principles of Knowledge Representation related to specifying predicates to make statements/representations (Almeida, 2013, p. 1690), the Property Transfer registered in JSON file format on the Bitcoin Blockchain (Figure 65) dereferences two IRI (Internationalized Resource Identifier) pointers (W3C, 2020):

- pointer to the Property Registry node (FIGURE 18 - PROPERTY REGISTRY IN JSON FILE FORMAT) represented by the key-value “'*inscriptionID': 'bc94e3084198751021522e389001245d8d8f2955a172c270cf096e847bbc4033i0*'” of the *propertyInfo* object.
- pointer to the Register Contract node (FIGURE 23 – PUBLIC DEED OF SALE AND PURCHASE (ESCRITURA PÚBLICA DE COMPRA E VENDA) IN JSON FILE FORMAT) represented by the key-value “'*inscriptionID': '77f897a88a6f9622be1aa3714545bbbbed7a77c169aa0894e17b6006bd8dda29i0*'” of the *publicDeedOfSaleAndPurchaseInfo* object.

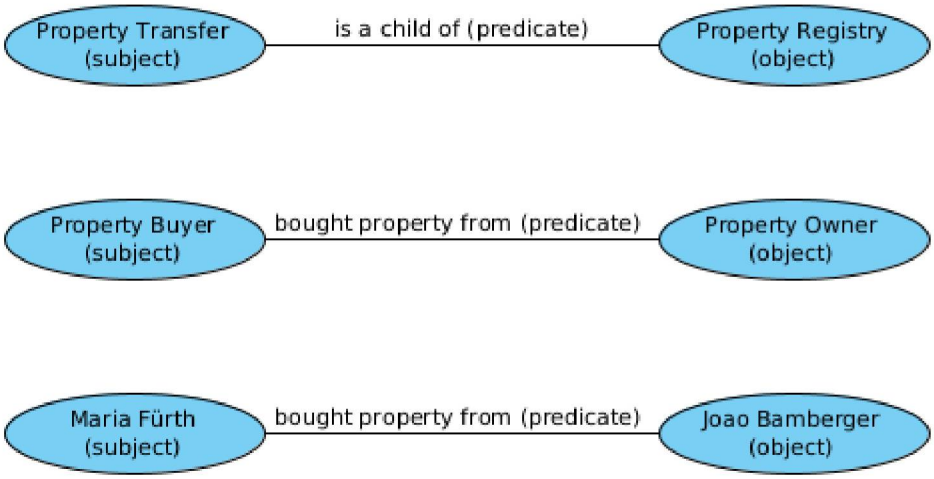
FIGURE 65 – PROPERTY TRANSFER IN JSON FILE FORMAT


```
{
  "documentType": "Property Transfer",
  "propertyInfo": {
    "inscriptionNumber": 147,
    "inscriptionID": "bc94e3084198751021522e389001245d8d8f2955a172c270cf096e847bbc4033i0",
    "inscriptionAddress": "bcrt1p04dvma99ln34khw8qnqx643cy07usp0rfs3syfqltsrh2a8mzx7sthvwmj",
    "blockHeightGenesis": 1435,
    "timestamp": "2025-03-01 14:37:26 UTC",
    "propertyAddress": "Rua Rio Grande do Sul - Nova Ubiratã, MT, 78888-000, Brasil",
    "propertyAreaSquareMeters": 32
  },
  "ownerInfo": {
    "ownerNationalID": "450.593.347-48",
    "ownerName": "Joao Silva",
    "ownerWalletAddress": "mgBg38pkq8ULumNQgHugiKMi5uUzVEg35G",
    "ownerWalletPublicKeyAddress": "026d38801a97ea4d068135377c1cd123225e19864f67d024674db71a5702b96caf"
  },
  "buyerInfo": {
    "buyerNationalID": "345.564.675-69",
    "buyerName": "Maria Oliveira",
    "buyerWalletAddress": "mu6TidaphD9PbALi7KR4bJvPukjSziCWZR",
    "buyerWalletPublicKeyAddress": "0204da038e1c512c9017547792d3fe7669caea19bf567420792ed6460deda75f94"
  },
  "publicDeedOfSaleAndPurchaseInfo": {
    "inscriptionNumber": 148,
    "inscriptionID": "77f897a88a6f9622be1aa3714545bbbbed7a77c169aa0894e17b6006bd8dda29i0",
    "inscriptionAddress": "bcrt1pmjjg0vg7p9zkfwfd2msasql7t2m4qp37su6ww0gr3g9xgfz32k6qplwajr",
    "blockHeightGenesis": 1441,
    "salePrice": 0.195,
    "timestamp": "2025-03-01 14:37:38 UTC",
    "signedContractSentToRegistryOfficeInfo": {
      "transactionID": "5a504c2d566ad37c4f07fb97169119803cabc1ae5c933159e399ffbb6002b42d",
      "blockHeight": 1453,
      "blockHash": "21de422e83bb2a984d7bc94381904e29f77ea8b572a0475f6a5982dc2c61bb93",
      "recipientAddress": "bcrt1pmjjg0vg7p9zkfwfd2msasql7t2m4qp37su6ww0gr3g9xgfz32k6qplwajr",
      "timestamp": "2025-03-01 14:38:08 UTC"
    }
  },
  "paymentInfo": {
    "transactionID": "5986cf99253d1ca3b9afd4671f4e9c8db1b07bed6c45e0e7a2d9024aac28c36a",
    "blockHeight": 1459,
    "blockHash": "66743232adc61d853bd627d0eba475cdb201febfe9ce162aef114423acd7e51b",
    "recipientAddress": "mgBg38pkq8ULumNQgHugiKMi5uUzVEg35G",
    "paymentAmount": 0.19500000000000000066613381477509392425417900085449218 75,
    "timestamp": "2025-03-01 14:38:20 UTC"
  }
}
```


SOURCE: AUTHOR (2025).

The Property Registry node (FIGURE 18 –) identified by the *inscriptionID* key of the *propertyInfo* object, in the Property Transfer registered in JSON file format on the Bitcoin Blockchain (Figure 65), makes it possible for specifying the following predicate statements/representations in Figure 66:

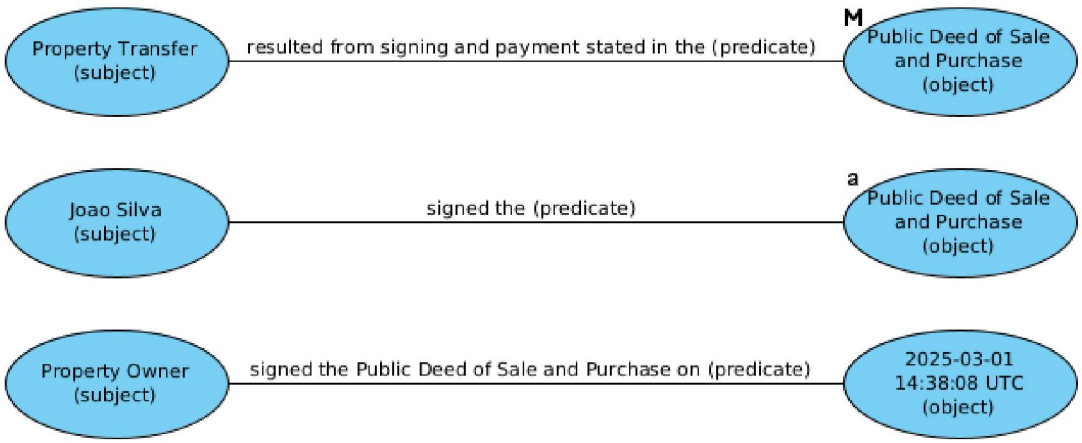
FIGURE 66 – STATEMENTS PROPERTY REGISTRY NODE



SOURCE: AUTHOR (2025).

The Register Contract node (FIGURE 23 – PUBLIC DEED OF SALE AND PURCHASE (ESCRITURA PÚBLICA DE COMPRA E VENDA) IN JSON FILE FORMAT) identified by the *inscriptionID* key of the *publicDeedOfSaleAndPurchaseInfo* object, in the Property Transfer registered in JSON file format on the Bitcoin Blockchain (Figure 65), makes it possible for specifying the following predicate statement/representation in Figure 66:

FIGURE 67 – STATEMENTS FOR REGISTER CONTRACT NODE



SOURCE: AUTHOR (2025).

3.4.12.4 Register Property Transfer Class Diagram

REGISTER PROPERTY TRANSFER CLASS DIAGRAM in FIGURE 68 shows class associations applying the model-view-controller (mvc) design pattern illustrated in “FIGURE 14 - CLASS DIAGRAMS APPLYING THE MODEL-VIEW-CONTROLLER (MVC) DESIGN PATTERN”. These class associations operate when the REGISTRY OFFICE transfers ownership of the property that was negotiated in the Public Deed of Sale and Purchase which was signed by the PROPERTY OWNER and the PROPERTY BUYER. The Property Transfer is registered on the Bitcoin Blockchain by linking the Property Transfer inscription as a “child” of the “parent” Property Registry inscription. The classes are specified in the MVC design pattern as follows:

- **View Class:** RegisterPropertyTransferPanelView[57]
- **Controller Class:** RegistryServiceControl[58]

[57]The source code of View Class RegisterPropertyTransferPanelView can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/view/RegisterPropertyTransferPanelView.java
[58]The source code of Control Class RegistryServiceControl can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/control/RegistryServiceControl.java

- **Model Classes:** GetRawTransactionModel[59]; OrdInscribedDataModel[60]; GetBlockModel[61]; InscriptionModel[62]; RegistryModel[63]

The View Class RegisterPropertyTransferPanelView presents a GUI (Graphical User Interface) (FIGURE 64) for the REGISTRY OFFICE to transfer ownership of the property from the PROPERTY OWNER to the PROPERTY BUYER. This operation is executed by registering a Property Transfer inscription on the Bitcoin Blockchain as a "child" of the "parent" Property Registry inscription that was negotiated in the signed Public Deed of Sale and Purchase.

The fields "Contract Inscription ID", "Transaction ID of Signed Contract Sent to Registry Office Address", and "Transaction ID of Payment Sent to Owner Address" filled out by the REGISTRY OFFICE on RegisterPropertyTransferPanelView form are used to retrieve data of inscriptions and Bitcoin transactions during the Property Transfer process. The retrieved data are saved on the Property Transfer inscription. The field Property Inscription ID filled out by the REGISTRY OFFICE on RegisterPropertyTransferPanelView form is used to link the "parent" Property Registry inscription to a child Property Transfer inscription on the Bitcoin Blockchain.

When the REGISTRY OFFICE presses the Register Button on View Class RegisterPropertyTransferPanelView, this process of transferring the property from the PROPERTY OWNER to the PROPERTY BUYER is triggered through several method calls on Control class RegistryServiceControl.

"Contract Inscription ID", which is obtained after executing the REGISTER CONTRACT OPERATION, is used to retrieve and save data from the Public Deed of Sale and Purchase to the Property Transfer inscription. The View Class RegisterPropertyTransferPanelView calls method

[59]The source code of Model Class GetRawTransactionModel can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/model/GetRawTransactionModel.java

[60]The source code of Model Class OrdInscribedDataModel can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/model/OrdInscribedDataModel.java

[61]The source code of Model Class GetBlockModel can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/model/GetBlockModel.java

[62]The source code of Model Class InscriptionModel can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/model/InscriptionModel.java

[63]The source code of Model Class RegistryModel can be accessed on: https://github.com/ybatinga/solution/blob/main/src/solution/model/RegistryModel.java

“RegistryServiceControl.getInscriptionData” that retrieves the “Contract Inscription ID” on the “ord” inscription index database (Ordinal Theory Handbook, 2023c), which returns Model Class InscriptionModel containing data of the Public Deed of Sale and Purchase that was registered on the Bitcoin Blockchain. The Public Deed of Sale and Purchase data is saved on a Model Class RegistryModel object.

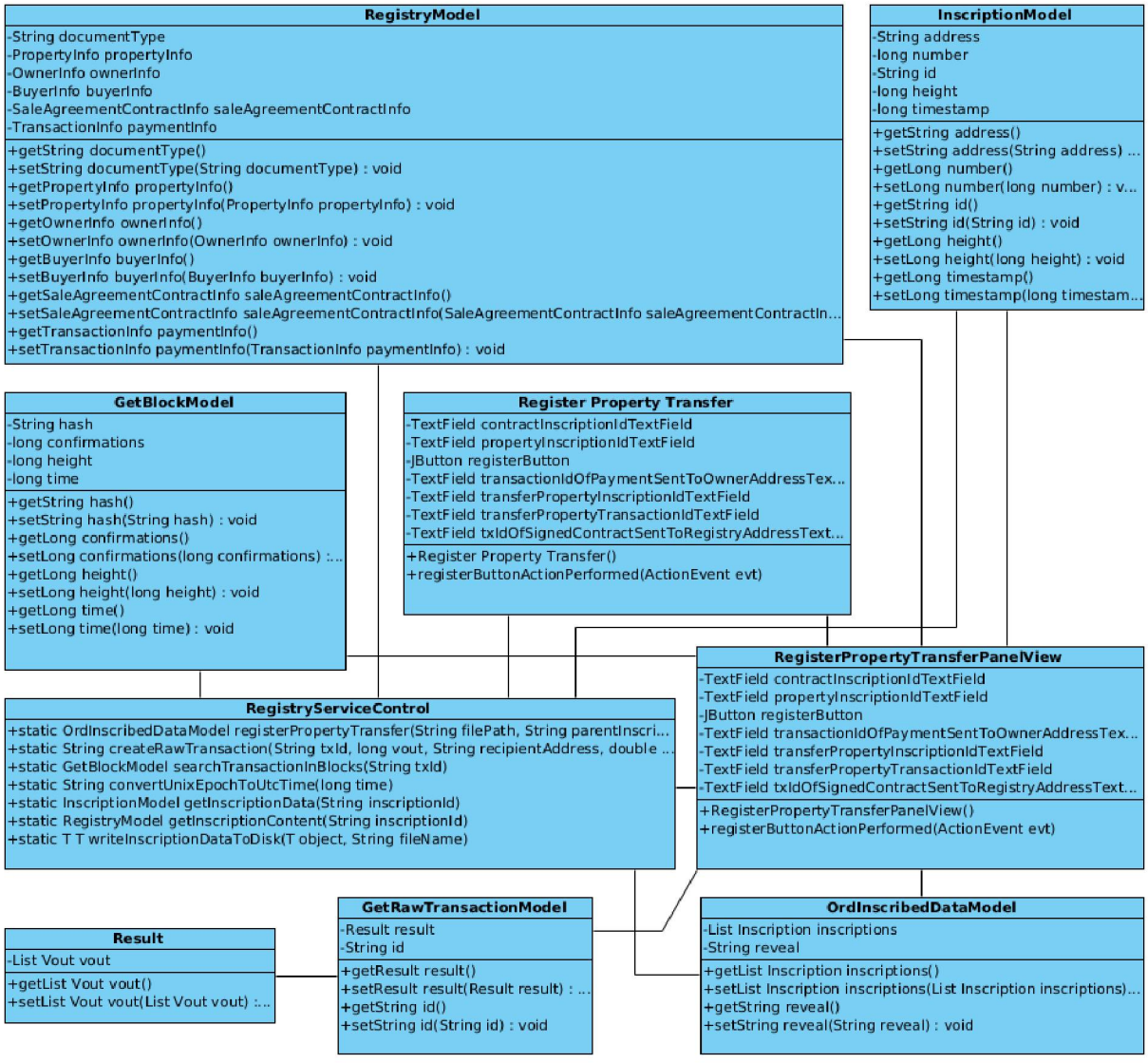
“Transaction ID of Signed Contract Sent to Registry Office Address”, which is obtained after executing the SEND SIGNED CONTRACT TO REGISTRY OPERATION, is used to retrieve and save data from the Multisig transaction that was signed by the PROPERTY OWNER to the PROPERTY BUYER. The View Class RegisterPropertyTransferPanelView calls method “RegistryServiceControl.searchTransactionInBlocks” to search for a block on the Bitcoin blockchain that contains registration of the “Transaction ID of Signed Contract Sent to Registry Office Address”, which returns a Model Class GetBlockModel containing data of the Multisig transaction. The Multisig transaction data is saved on the Model Class RegistryModel object.

“Transaction ID of Payment Sent to Owner Address”, which is obtained after executing the SEND PAYMENT OPERATION, is used to retrieve and save data from the payment transaction sent the in amount agreed in the Public Deed of Sale and Purchase from the PROPERTY BUYER to the PROPERTY OWNER's Bitcoin wallet address. The View Class RegisterPropertyTransferPanelView calls method “RegistryServiceControl.searchTransactionInBlocks” to search for a block on the Bitcoin blockchain that contains registration of the “Transaction ID of Payment Sent to Owner Address”, which returns a Model Class GetBlockModel containing data of the Payment transaction. The Payment transaction data is saved on the Model Class RegistryModel object.

Property Inscription ID, which is obtained after executing the REGISTER NEW PROPERTY OPERATION, is used to link the Property Registry inscription as “parent” of a “child” Property Transfer inscription. This establishes provenance of “children” Property Transfer inscriptions as having been registered/inscribed by the REGISTRY OFFICE to provide history of ownership of a “parent” Property Registry. To make the Property Transfer inscription a “child” of the Property Registry inscription, the "parent" Property Registry inscription has to be registered in the REGISTRY OFFICE's Bitcoin wallet (Ordinal Theory

Handbook, 2025a). Since the REGISTRY OFFICE controls the wallet that contains the Property Registry inscription, it can create as many “child” Property Transfer registries, trustlessly establishing the provenance of the “children's” Property Transfers registered on the Bitcoin Blockchain, as proof of having been created by the REGISTRY OFFICE. (Ordinal Theory Handbook, 2025b).

FIGURE 68 – REGISTER PROPERTY TRANSFER CLASS DIAGRAM



SOURCE: AUTHOR (2025).

The View Class RegisterPropertyTransferPanelView calls method “RegistryServiceControl.registerPropertyTransfer” to get data stored in the RegistryModel

object to register the property Property Transfer inscription as a “child” of the Property Registry inscription on the Bitcoin Blockchain, by executing the “ord” (Ordinal Software Utility) on the Linux Server node shell. Finally, “ord” returns Model Class OrdInscribedDataModel that stores “Transfer Property Transaction ID” and Transfer Property Inscription ID which are shown on the RegisterContractPanelView GUI. The “Transfer Property Transaction ID” is used to retrieve the Property Transfer transaction on the Bitcoin Blockchain. And Transfer Property Inscription ID is used to retrieve the Property Transfer inscription the “ord” index database explorer.

4 RESULTS AND DISCUSSIONS

This section compares this research project's proposed Solution Concept to other systems in terms of scalability, transparency, decentralization, cost, data immutability, and transfer of ownership methods.

4.1 SCALABILITY: LIMITATIONS AND CHALLENGES OF THE SOLUTION CONCEPT[64]

Regarding limitations and challenges, implementation of the Solution Concept endured delayed confirmation times of payment and registry transactions on the Testnet3 Network, even though the Bitcoin Blockchain on the Testnet3 Network is set to confirm transactions faster than on the Mainnet Network (Franzoni; Abellan; Daza, 2020, p. 4). However, regardless of whether utilizing the Bitcoin Blockchain on Mainnet Network or Testnet3 Network delayed confirmation times are frequent nowadays, which may be caused by high traffic or transactions sent with low fees (Blockstream, 2025).

There was no data available regarding the average confirmation time of transactions on the Testnet3 Network since it is 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, 2024d). However, on the Mainnet Network, there is data provided by Blockchain.com, 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: Transaction Rate, Average Confirmation Time, and Average Number of Transactions per Block. The Transaction Rate chart is used as a performance measurement to compare the Solution Concept's Bitcoin Blockchain with other platforms such as Notarchain's Hyperledger Fabric Blockchain, Ethereum Blockchain, Solana Blockchain, and Visa Payment Card Services. Additionally, a more in-depth performance measurement compares the Solution Concept's Bitcoin Blockchain and

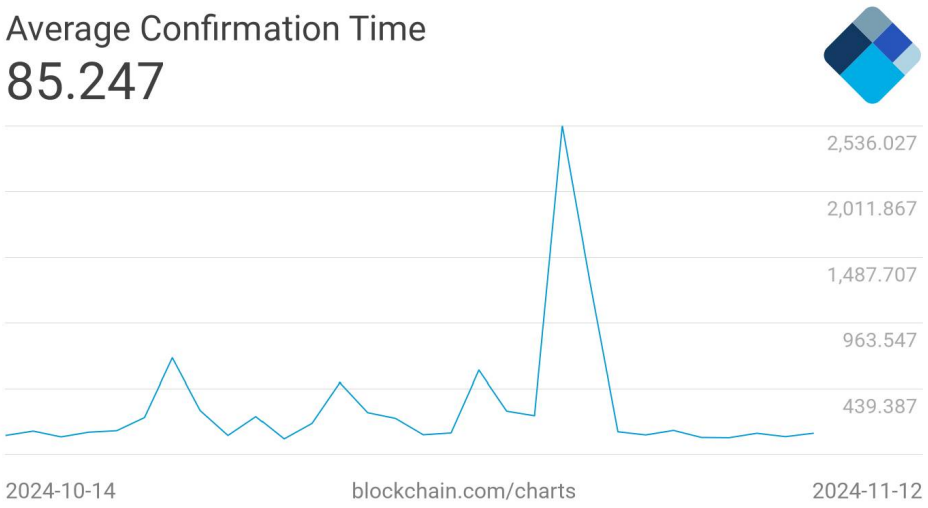
[64]SECTION "4.1 SCALABILITY: LIMITATIONS AND CHALLENGES OF THE SOLUTION CONCEPT" contains text from SECTION "4.2. Limitations and Challenges of the Solution Concept" of the published article at the following reference: SASAKI, E. E., GROSSMANN, D., WILDAUER, E. W. **Implementing UML Models, Principles 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.** Advances on Knowledge Representation, vol. 1, no. 1, p. 137-168, 2025. DOI: 10.5281/zenodo.15041980. Available in: https://periodicos.ufmg.br/index.php/advances-kr/article/view/53994/47843.

the Notarchain's Hyperledger Fabric Blockchain using the Transaction Rate, Average Confirmation Time, and Average Number of Transactions per Block charts. Next, these results are used to analyze the realm of the Blockchain Trilemma (Section 2.6) to comprehend the Bitcoin Blockchain's scalability issue in comparison with the Hyperledger Fabric Blockchain.

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 69). 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 85.247 minutes (FIGURE 69) 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, 2025).

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, this may be contributing "to clog the [Mainnet] network, raising confirmation time and costs for regular Bitcoin transactions" (Vardai, 2023). Likewise, the popularity of the Ordinal Theory Protocol may also increase the use by "application developers or bitcoin testers to experiment" (Bitcoin Wiki, 2024d) on the Testnet3 Network, which may also explain why transaction confirmation time is delayed on the Testnet3 Network.

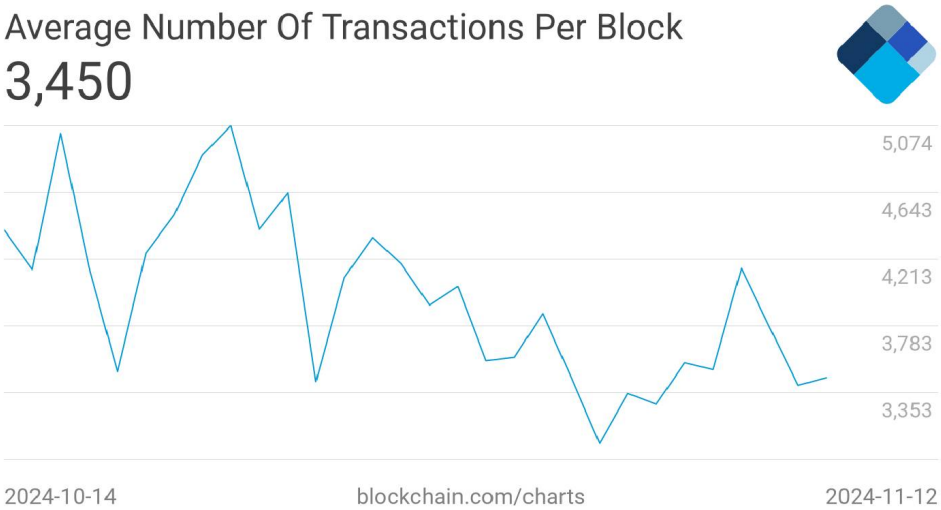
FIGURE 69 – AVERAGE CONFIRMATION TIME FROM OCTOBER 14TH, 2024 TO NOVEMBER 12TH, 2024 (Blockchain.com, 2024d)



SOURCE: 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 70).

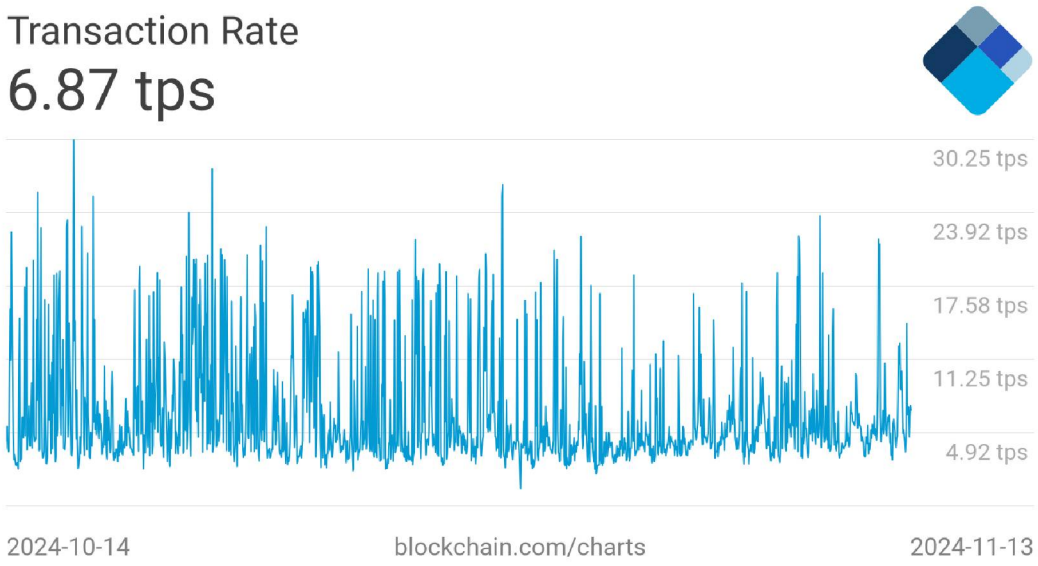
FIGURE 70 – AVERAGE NUMBER OF TRANSACTIONS PER BLOCK FROM OCTOBER 14TH, 2024 TO NOVEMBER 12TH, 2024 (Blockchain.com, 2024c)



SOURCE: BLOCKCHAIN.COM (2024c).

During the 30 days from October 14th, 2024 to November 13th, 2024, Bitcoin's Transaction Rate per Second (TPS) was 6.87 (FIGURE 71). On the Bitcoin Blockchain, TPS is “the number of transactions added to the mempool per second” (Blockchain.com, 2024e). “A mempool (a contraction of memory and pool) is a cryptocurrency node’s mechanism for storing information on unconfirmed transactions. It acts as a sort of waiting room for transactions that have not yet been included in a block” (Binance Academy, 2025).

FIGURE 71 – TRANSACTION RATE FROM OCTOBER 14TH, 2024 TO NOVEMBER 13TH, 2024 (Blockchain.com, 2024e)



SOURCE: BLOCKCHAIN.COM (2024e).

4.2 SCALABILITY: TRANSACTION RATE COMPARISON BETWEEN BITCOIN BLOCKCHAIN AND HYPERLEDGER FABRIC BLOCKCHAIN, ETHEREUM BLOCKCHAIN, SOLANA BLOCKCHAIN, AND VISA PAYMENT CARD SERVICES

Considering the Bitcoin Blockchain's Transaction Rate performance measurement of 6.87 TPS (Figure 13), the Ethereum Blockchain (Bedawala; Wijeyekoon, 2023) is 1.75 times (12÷6.87) faster than the Bitcoin Blockchain, the Hyperledger Fabric Blockchain (SECTION “2.8 RELATED WORKS”) is 320.23 times (2200÷6.87) faster than the Bitcoin

Blockchain, the Solana Blockchain is 582.24 times (~4000÷6.87) faster than the Bitcoin Blockchain, as informed on April 15th, 2025 on Solana Explorer (2025), and the Visa Payment Card Services (Bedawala; Wijeyekoon, 2023) is 9461.43 times (65000÷6.87) faster than the Bitcoin Blockchain, as shown in TABLE 3:

TABLE 3 – TRANSACTION RATES

Platform	Transaction Per Second (TPS)	Comparison with Bitcoin
Bitcoin Blockchain	6.87 (Blockchain.com, 2024e)	
Ethereum Blockchain	12 (Bedawala; Wijeyekoon, 2023)	1.75x faster
Hyperledger Fabric Blockchain	2.2k (Nakaike et al., 2020, p. 1)	320x faster
Solana Blockchain	~4k (Solana Explorer (2025)	582x faster
Visa Payment Card Services	65k (Bedawala; Wijeyekoon, 2023)	9461x faster

SOURCE: AUTHOR (2025).

4.3 SCALABILITY COMPARISON BETWEEN SOLUTION CONCEPT'S BITCOIN BLOCKCHAIN VS. NOTARCHAIN'S HYPERLEDGER FABRIC BLOCKCHAIN

In comparing the Solution Concept's Bitcoin Blockchain with Notarchain's Hyperledger Fabric Blockchain (HFB) (SECTION "2.8 RELATED WORKS"), it should be considered the fact that HFB has a different type of architecture than the public Bitcoin Blockchain since HFB is a private blockchain which its performance can be optimized (Nakaike et al., 2020, p. 2) with different implementations (Arnabkaycee, 2018). Nakaike et al. (2020, p. 2), in an article entitled "Hyperledger Fabric Performance Characterization and Optimization Using GoLevelDB Benchmark", obtained 2.2k Transactions per Second (TPS) on HFB "on the commit phase instead of the consensus phase (i.e., ordering phase in Hyperledger Fabric)" (Nakaike et al., 2020, p. 2).

The "commit phase" on HFB may be compared with Bitcoin Blockchain's Average Confirmation Time (FIGURE 69) "for a transaction with miner fees to be included in a mined block and added to the public ledger" (Blockchain.com, 2024f). Comparing HFB with the Bitcoin Blockchain considering the Average Confirmation Time (FIGURE 69), HFB's 2.2k Transactions per Second (TPS) is a lot faster than the Bitcoin Blockchain's 3.45k Transactions (FIGURE 70) per 85.247 Minutes/Block (FIGURE 69). The proportion number of transactions that the HFB would confirm considering a Rule of Three calculation

on Bitcoin Blockchain's Average Confirmation Time of 85.247 minutes (FIGURE 69), would be 11,256,168 million transactions, where:

- Rule of Three: x = (b × c) ÷ a (Rule of Three Calculator, 2025)
- a: 1 second
- b: 2.2k transactions
- c: 5116.44 seconds (85.247 minutes * 60)
- x = (2200 x 5116.44) ÷ 1 = 11,256,168

4.4 INFORMATION SECURITY[65]

Information Security principles, being confidentiality, integrity, availability, authenticity, immutability, identity, legality, and non-repudiation, are analyzed in the context of the service provided by the Solution Concept, which provides a method for signing Public Deeds of Sale and Purchase and registering Property Purchase Payments and Property Registries on the Bitcoin Blockchain.

In regard to confidentiality, the Solution Concept does not provide confidentiality of personal data, registered on Property Registries, Property Transfers and Public Deeds of Sale and Purchase, since "the [Brazilian] Real Estate Registry [System] is governed by the principle of publicity, the law determines that information must be provided to any citizen who requests it, which implies that some data cannot be deleted, anonymized or rectified without due legal process" (Registro De Imóveis do Brasil, 2025). As a result, as informed in Article 33 of Provimento nº 134/2022 (Corregedora Nacional De Justiça, 2022), "in the notarial act, the following will be included in the qualification of the subjects: the full name of all parties; the identification document, or, in its absence, the filiation; the CPF number; the nationality; the marital status; the existence of a stable union; the profession and the domicile, with the inclusion of an electronic address and telephone number being waived". Additionally, the Solution Concept provides low confidentiality of Property Purchase Payments registered on the Bitcoin Blockchain since it "requires transaction data to be visible and verifiable" (Abasi, 2022).

[65]The definitions of the Information Security Principles presented in this SECTION "4.5 INFORMATION SECURITY" can be found in SECTION "2.7 INFORMATION SECURITY" of the thesis by this same author at the following reference: SASAKI, E. E. **Use of Blockchain Timestamping and Digital Certificates Based on ICP-BRASIL Standards to Provide Authenticity of Documents.** Advisor: Egon Walter Wildauer. 2020. Thesis (Master's in Information Management) – Universidade Federal do Paraná. Curitiba, 2020. Available in: https://acervodigital.ufpr.br/handle/1884/68798?show=full.

Regarding integrity and immutability in the context of the Solution Concept, integrity and immutability of data registered/inscribed and timestamped on the Bitcoin Blockchain is maintained “due [to] the existence of a long chain of blocks [that] makes the blockchain’s deep history immutable, a key feature of bitcoin’s security” (Antonopoulos, 2010, p. 164). “Bitcoin utilises the SHA-256 algorithm to secure the integrity of the blockchain by creating a digital fingerprint for transactions and blocks. This feature makes it computationally impractical to overwrite or change stored data, making it resistant to tampering. Any node or user can authenticate the integrity of the data by using the Merkle proof of a transaction” (Sprick, 2023). Additionally, the immutability of Bitcoin Ordinal inscriptions is discussed in SECTION “4.8 DATA IMMUTABILITY”.

With reference to authenticity in the context of the Solution Concept, authenticity is ensured through the mechanics of the Ordinal Theory Protocol, which involves two key components (Trust Wallet, 2024):

- **“Ordinal assignments:** Each satoshi is given a unique ordinal number based on its mining sequence. The ordinal number enables users to identify and track individual satoshis”. (Trust Wallet, 2024).
- **“Inscriptions:** Users can inscribe data onto these numbered satoshis” (Trust Wallet, 2024).

“This combination enables users to create unique digital assets that inherit the security and immutability of the Bitcoin blockchain. Once inscribed, an ordinal cannot be altered or removed, ensuring its authenticity and permanence.” (Trust Wallet, 2024).

With respect to availability in the context of the Solution Concept, “since a distributed [Bitcoin Network] architecture is used, a full copy of the data resides across several nodes. This provides a high level of Availability” (Abasi, 2022).

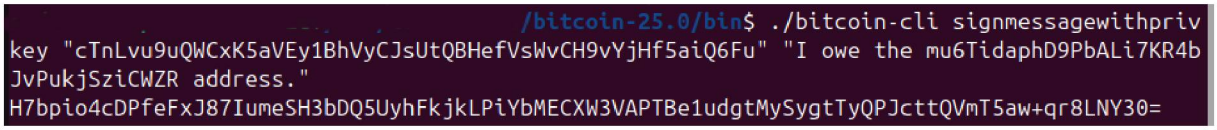
Regarding identity in the context of the Solution Concept, as delimited in SECTION “3.2 DELIMITATION”, it is assumed that identity has been verified by the REGISTRY OFFICE in step “1) GATHERING OF DOCUMENTS AND CERTIFICATES”, that is described in SECTION “2.7 REAL ESTATE REGISTRY SYSTEM IN BRAZIL”. Moreover, it is assumed that the REGISTRY OFFICE has linked the PROPERTY OWNER and PROPERTY BUYER’s identities to their respective Bitcoin Wallet Addresses. Thus, Bitcoin Wallet Addresses act as a Digital Identity Certificates in the Solution Concept that are required to perform the twelve operations described in SECTION “3.4 SOLUTION CONCEPT DEVELOPMENT”.

One possible way that the REGISTRY OFFICE could link identities to Bitcion Wallet Addresses is to have the PROPERTY OWNER and PROPERTY BUYER sign a message with the private keys associated with their respective Bitcion Wallet Addresses. It could be done by using the "*signmessagewithprivkey*" (Bitcoin Developer, 2025l) command on Bitcoin Core (SECTION "3.3.1.1 Linux Server Node").

In the Bitcoin Blockchain Network, message signing "is the action of signing a cryptographic message using a private key and its associated address, to prove that you have access to the address. These messages can be verified by wallets by checking the signature against the address to see if they correspond to each other. The result of message signing is often called a signed message." (Bitcoin Wiki, 2024e).

To exemplify how message signing works on Bitcoin Core, the REGISTRY OFFICE asks the PROPERTY OWNER to sign the message: "I owe the mu6TidaphD9PbALi7KR4bJvPukjSziCWZR address.". Consequently, the PROPERTY OWNER signs the message with the private key associated with the Bitcoin Wallet Address "mu6TidaphD9PbALi7KR4bJvPukjSziCWZR", as shown in Figure 72.

FIGURE 72 – MESSAGE SIGNING TO PROVE ACCESS TO BITCOIN WALLET ADDRESS



SOURCE: AUTHOR (2025).

Once the message is signed, the PROPERTY OWNER obtains the signature "H7bpio4cDPfeFxJ87IumeSH3bDQ5UyhFkjkLPiYbMECXW3VAPTBe1udgtMySygtTyQPJcttQVmT5aw+qr8LNY30=". Finally, the REGISTRY OFFICE verifies the signature against the PROPERTY OWNER's address and the signed message using the "*verifymessage*" command (Bitcoin Developer, 2025m) on Bitcoin Core, as shown in Figure 73.

If the "*verifymessage*" command returns "*true*" (Figure 73), it proves that the PROPERTY OWNER has access to the Bitcoin Wallet Address "mu6TidaphD9PbALi7KR4bJvPukjSziCWZR".

FIGURE 73 – SIGNATURE CHECKING TO PROVE ACCESS TO BITCOIN WALLET ADDRESS

```
                                    /bitcoin-25.0/bin$ ./bitcoin-cli verifymessage "mu6T
idaphD9PbALi7KR4bJvPukjSziCWZR" "H7bpio4cDPfeFxJ87IumeSH3bDQ5UyhFkjkLPiYbMECXW3VAPTBe1udgtM
ySygtTyQPJcttQVmT5aw+qr8LNY30=" "I owe the mu6TidaphD9PbALi7KR4bJvPukjSziCWZR address."
true
```

SOURCE: AUTHOR (2025).

Respecting non-repudiation in the context of the Solution Concept, a document signed with a Digital Identity Certificate that was certified by a Registry Office “offers non-repudiation: signatory cannot claim later that he did not create the signature, because he is the only one who has access to the private key and signature cannot be created without it, hence he must have made it” (Ponka, 2000, p. 9).

Regarding legality in the context of the Solution Concept, a Public Deed of Sale and Purchase signed with the PROPERTY OWNER and PROPERTY BUYER’s Digital Identity Certificates (Bitcoin Wallet Addresses) would have legal validity according to paragraph 2 of Provisional Measure 2.200-2/2001, which states that “the provisions of this Provisional Measure do not preclude the use of any other means of proving the authorship and integrity of documents in electronic form, including those that use certificates not issued by ICP-Brasil, as long as admitted by the parties as valid or accepted” (Brasil, 2001).

4.5 TRANSPARENCY: TRADITIONAL BRAZILIAN REAL ESTATE REGISTRY SYSTEM VS. SOLUTION CONCEPT BASED ON BITCOIN BLOCKCHAIN TECHNOLOGY

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 “3.2 DELIMITATION”) 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 PROPERTY BUYER and the PROPERTY 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.[66]

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 Real Estate a “Double Sale Scam” or “False Owner Scam”. The “Double Sale Scam” occurs when the PROPERTY OWNER sells the property to more than one Buyer before the Public Deed of Sale and Purchase is taken to the Real Estate Registry Office for the definitive transfer of the property to a PROPERTY BUYER. (Neto, 2022, Unio Imóveis, 2025).[67]

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. Taking advantage of the PROPERTY BUYER's naivety, the person [PROPERTY BUYER] makes a down payment or deposit [or one-time full upfront payment], and the scammer simply disappears with the money” (Neto, 2022).[68]

On the other hand, as proposed in SECTION “3.3 SOLUTION CONCEPT REQUIREMENTS” and SECTION “3.4 SOLUTION CONCEPT DEVELOPMENT”, 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

[66]SASAKI, E. E., GROSSMANN, D., WILDAUER, E. W. **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.** Advances on Knowledge Representation, vol. 1, no. 1, p. 137-168, 2025. DOI: 10.5281/zenodo.15041980. Available in: https://periodicos.ufmg.br/index.php/advances-kr/article/view/53994/47843.

[67]SASAKI, E. E., GROSSMANN, D., WILDAUER, E. W. **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.** Advances on Knowledge Representation, vol. 1, no. 1, p. 137-168, 2025. DOI: 10.5281/zenodo.15041980. Available in: https://periodicos.ufmg.br/index.php/advances-kr/article/view/53994/47843.

[68]Ibid.

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.[69]

Regarding payments and registries of property ownership and transfer, this project's Solution Concept uses the Bitcoin Blockchain to provide provenance, and a digital thread of payments and registries. Provenance is provided through "the history of the ownership" (Provenance, 2025) 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 "3.4.12 Register Property Transfer Operation") of the Ordinal Theory (SECTION "2.5 NON-FUNGIBLE-TOKENS (NFTS) ON THE BITCOIN BLOKCHAIN THROUGH ORDINAL THEORY INSCRIPTIONS") by registering Property Transfer inscriptions as "children" of a "parent" Property Registry inscription on the Bitcoin Blockchain.[70]

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 an *inscriptionID* IRI (Internationalized Resource Identifiers) key-value (Section "3.4. Knowledge Representation").

4.6 DECENTRALIZATION: BLOCKCHAIN TRILEMMA ANALYSIS OF SOLUTION CONCEPT AND NOTARCHAIN

[69]Ibid.

[70]SASAKI, E. E., GROSSMANN, D., WILDAUER, E. W. **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.** Advances on Knowledge Representation, vol. 1, no. 1, p. 137-168, 2025. DOI: 10.5281/zenodo.15041980. Available in: https://periodicos.ufmg.br/index.php/advances-kr/article/view/53994/47843.

In regard to the realm of the Blockchain Trilemma (Section 2.6), by comparing the Solution Concept's Bitcoin Blockchain with the Notarchain's Hyperledger Fabric Blockchain (SECTION "2.8 RELATED WORKS"), Bitcoin Blockchain's lower Transaction Rate of 6.87 TPS (FIGURE 71) and long Average Block Confirmation Times of 3,45k Transactions (FIGURE 70) per 85.247 Minutes/Block (FIGURE 69) 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 (Nakaike et al., 2020, p. 1) is due to its private network design that prioritizes security and scalability over decentralization.[71]

4.7 DECENTRALIZATION AND COST: PERMISSIONLESS BLOCKCHAIN VS. PERMISSIONED BLOCKCHAIN

Considering the flowchart in FIGURE 74 "to determine whether a blockchain is the appropriate technical solution to solve a problem" (Wüst; Gervais, 2018), it indicates that a Permissionless Blockchain, such as the Solution Concept's Bitcoin Blockchain, is an appropriate technical solution to solve the problem of transparency in the Brazilian Real Estate Registry System. Permissionless Blockchains are open and decentralized; on the other hand, Permissioned Blockchains, only authorize a limited set of readers and writers (nodes) (Wüst; Gervais, 2018).

As for the Notarchain's Hyperledger Fabric Blockchain (SECTION "2.8 RELATED WORKS"), it indicates that a Blockchain, such as Notarchain's Hyperledger Fabric Blockchain (SECTION "2.8 RELATED WORKS"), may not be an appropriate technical solution to be used in the used in the Brazilian Notary System.

With reference to the Solution Concept, the flowchart (FIGURE 74) leads to determining that a Permissionless Blockchain is an appropriate technical solution by following the steps described below:

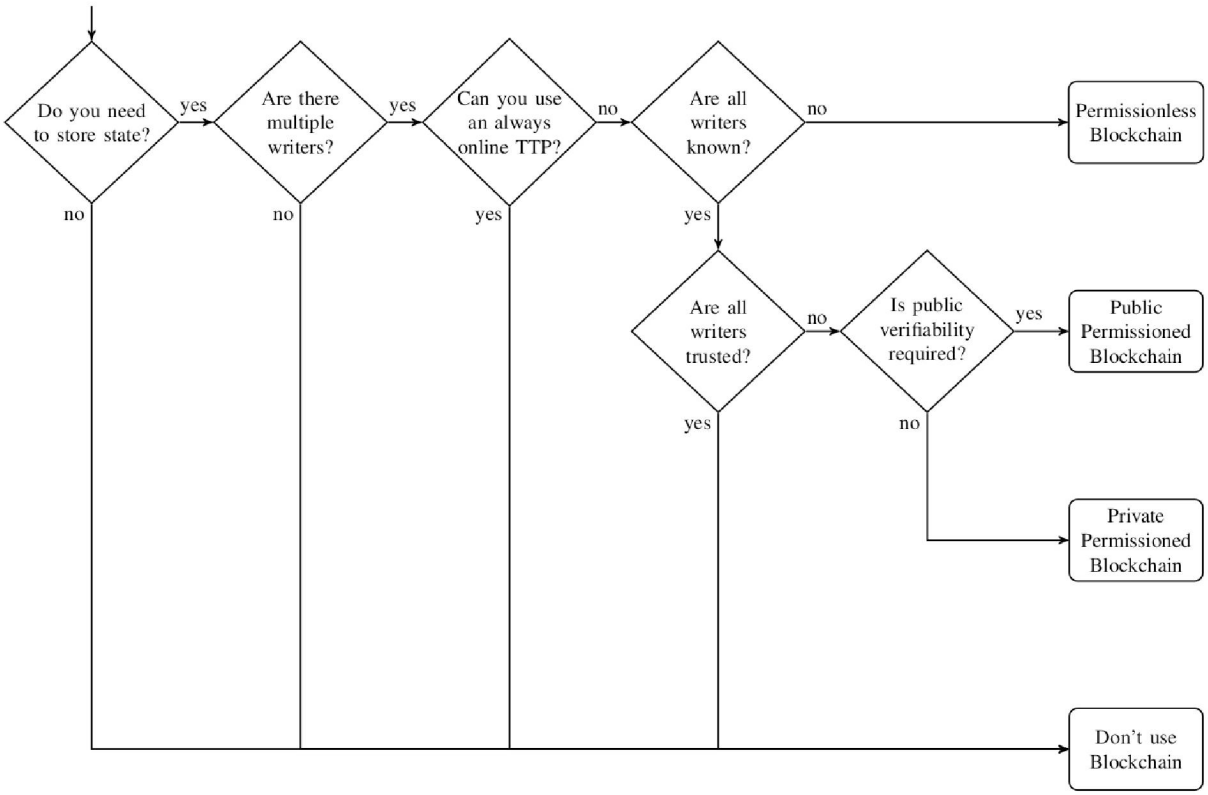
- **Do you need to store data?** Answer: **Yes**.
- **Are there multiple writers?** Answer: **Yes**, there are multiple writers in the Bitcoin Blockchain network. A writer is "any entity which writes state to the database"

[71]SASAKI, E. E., GROSSMANN, D., WILDAUER, E. W. **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.** Advances on Knowledge Representation, vol. 1, no. 1, p. 137-168, 2025. DOI: 10.5281/zenodo.15041980. Available in: https://periodicos.ufmg.br/index.php/advances-kr/article/view/53994/47843.

(Wüst; Gervais, 2018). Moreover, a writer is a node, where each node competes to add blocks and shares a copy of the blockchain (Antonopoulos, 2010, p. xviii; Köhler; Pizzol, 2019, p. 13598).

- **Can you use an always online TTP?** Answer: **No**, there is “no intervention of a trusted third party [TTP], such as such as a central bank or financial institution” (Prasad, 2021) on the Bitcoin Blockchain.
- **Are all writers known?** Answer: **No**, because an unknown writer (node) can participate in the Bitcoin Blockchain peer-to-peer network without asking for permission to join the network.
- **Decision**: **Permissionless Blockchain**.

FIGURE 74 – “FLOW CHART TO DETERMINE WHETHER A BLOCKCHAIN IS THE APPROPRIATE TECHNICAL SOLUTION TO SOLVE A PROBLEM” (WÜST; GERVAIS, 2018)



(Wüst; Gervais, 2018).

With reference to the Notarchain, the flowchart leads to determining that a Blockchain, such as the Hyperledger Fabric Blockchain, may not be an appropriate technical solution by following the steps described below:

- **Do you need to store data?** Answer: **Yes**.
- **Are there multiple writers (nodes)?** Answer: **Yes**, there are multiple writers (nodes) in the Notarchain network. “Each notary is one of the supporting nodes” (e-Notariado, 2025) of the Notarchain network.
- **Can you use an always online TTP?** Answer: **No**, there is “no intervention of a trusted third party [TTP], such as such as a central bank or financial institution” (Prasad, 2021) on the Notarchain’s Hyperledger Fabric Blockchain.
- **Are all writers known?** Answer: **Yes**, because only writers (nodes) operated by notaries can participate in Notarchain’s Hyperledger Fabric Blockchain network. “If the writers all mutually trust each other, i.e. they assume that no participant is malicious, a database with shared write access is likely the best solution” (Wüst; Gervais, 2018).
- **Decision**: **Don’t use Blockchain**.

Considering the above analysis on Notarchain that leads to not using a blockchain as a technical solution, it indicates that a central database would be more cost-efficient since a private Hyperledger Fabric Blockchain adds extra cost for maintaining each notary as a node (writer) in the Notarchain system. Hence, in a centralized system such as Notarchain, data redundancy could be “achieved through replication on different physical servers and through backups” (Wüst; Gervais, 2018). Additionally, in a centralized system, “the performance in terms of latency and throughput is generally much better than in blockchain systems, as blockchains add additional complexity through their consensus mechanism” (Wüst; Gervais, 2018).

Concerning the use of a Permissionless Blockchain, since the Solution Concept uses the open and decentralized Bitcoin Blockchain as a technical solution, the cost involves paying 1500 sats, or 1.28 USD[72], as miner fees to sign and register Public Deeds of Sale and Purchase, and register Property Payments, Property Registries (Ownership), and Property Transfer Registries on the Bitcoin Blockchain. Registering/inscribing data on the Bitcoin Blockchain “are included in transactions, so the larger the content, the higher the fee that the inscription transaction must pay” (Ordinal Theory Handbook, 2025a). Since the size of JSON files registered/inscribed through the Solution Concept as Property

[72]CoinCodex. **SATS to USD.** Available in: https://coincodex.com/convert/satoshi-sats/usd/1500/. Accessed on: 20 Mar. 2025.

Registries (Ownership) and Property Transfer Registries on the Bitcoin Blockchain are at most 713 Bytes, the 1500 sats is enough to pay for transactions as miner fees.

4.8 DATA IMMUTABILITY

A major difference between Bitcoin Ordinal Theory (SECTION 2.5) and traditional Ethereum NFTs (SECTION 2.3), as described in TABLE 4, is that Bitcoin inscriptions are immutable. On Ethereum, an NFT ID is stored on-chain (i.e., stored on the Ethereum blockchain). The media file and the metadata file that contains information that links the media file to its associated NFT ID are stored off-chain, usually on decentralized storage such as Interplanetary File System (IPFS) (SECTION 2.4) or centralized storage such as data server. Since both the metadata and media files are stored off-chain, they can be updated or deleted at any time. (Dalton, 2023; Eshghi, 2023).

TABLE 4 – DIFFERENCE BETWEEN NFTS AND BITCOIN ORDINALS

(Ordzaar, 2023).

On Bitcoin, the “broken link problem” or “link rot” discussed in SECTION “2.4 DECENTRALIZED STORAGE: INTERPLANETARY FILE SYSTEM (IPFS)” is solved since the media is stored on-chain with a direct link to its NFT ID (satoshi number). As a result, there is no need to create a metadata file that informs the existence of a link between the NFT ID the media file. “Ordinals or digital artifacts are directly inscribed into the satoshi and preserved on-chain. This implies that they are authenticated in blocks and stored

perpetually in the distributed ledger of the network, essentially carving out a permanent niche on the blockchain" (Ordzaar, 2023).

Comparing the Solution Concept's Real Estate Registry System to e-Notariado's (SECTION 2.8) Notary System (TABLE 5), the Solution Concept registers Property Purchase Payments, Property Registries, and Public Deeds of Sale and Purchase on the immutable Bitcoin Blockchain through the Ordinal Theory Protocol. Notarchain registers on the HFB (Hyperledger Fabric Blockchain) the "[cryptographic] hashes, signatures and dates of documents. The [document] content does not need to be registered on this platform [Notarchain], because it is already in the virtual space of each notary's office" (Martini, 2020). The "virtual space" that Martini (2020) may refer to is e-Notariado's "Cloud Backup solution for data storage" (Colégio Notarial do Brasil, 2025), which is one the technologies of the e-Notariado platform.

TABLE 5 – DIFFERENCE BETWEEN NOTARCHAIN AND SOLUTION CONCEPT

DIFFERENCE BETWEEN NOTARCHAIN AND SOLUTION CONCEPT		
	NOTARCHAIN	**SOLUTION CONCEPT**
STORAGE	Off-Chain	On-Chain
IMMUTABILITY	No	Yes
PAYMENTS	No	Yes

SOURCE: AUTHOR (2025).

4.9 TRANSFER OF OWNERSHIP METHODS

Comparing transfer of ownership methods between the Ordinal Marketplaces and the Solution Concept, as described in TABLE 6, Ordinal Marketplaces, such as Magic Eden (Magic Eden, 2025), Gamma (Gamma, 2025a), and Ordinals Wallet (Ordinals Wallet, 2025), are Bitcoin Ordinal marketplaces which allow "users to explore, sell, buy and trade Ordinals [inscriptions], directly on the Bitcoin blockchain" (Gamma, 2025b). Each of these Ordinal Marketplaces transfers ownership of a sat (satoshi), the smallest unit of a bitcoin (BTC) (SECTION 2.5), that is inscribed with media by sending it to a buyer's wallet.

TABLE 6 – DIFFERENCE BETWEEN ORDINAL MARKETPLACES AND SOLUTION CONCEPT

DIFFERENCE BETWEEN ORDINAL MARKETPLACES AND SOLUTION CONCEPT		
	ORDINAL MARKETPLACES	**SOLUTION CONCEPT**
TRANSFER OF OWNERSHIP METHOD	Send sat (satoshi) containing media	Register Property Transfer inscription as child of parent Property Registry inscription

SOURCE: AUTHOR (2025).

The Solution Concept uses the provenance method (ORDINAL THEORY HANDBOOK, 2025b) of the Ordinal Theory Protocol (SECTION “2.5 NON-FUNGIBLE-TOKENS (NFTS) ON THE BITCOIN BLOKCHAIN THROUGH ORDINAL THEORY INSCRIPTIONS”) to transfer ownership of Property Registries. The provenance method is implemented by registering/inscribing a Property Transfer as a “child” of a “parent” Property Registry (SECTION “3.4.12 Register Property Transfer Operation”). This establishes the provenance of “children” Property Transfer inscriptions as having been registered/inscribed by the REGISTRY OFFICE to provide a history of ownership of a “parent” Property Registry (Ordinal Theory Handbook, 2025b).

Even in case the REGISTRY OFFICE mistakenly sends an inscription of a Property Registry, Property Transfer, or Public Deed of Sale and Purchase as a transaction fee to a miner, an inscription will always maintain the same Inscription ID. As a result, by recording all Inscriptions IDs that are registered by the REGISTRY OFFICEs in a centralized database, it may be possible to maintain a Brazilian Real Estate System transparently on the Bitcoin Blockchain.

5 CONCLUSIONS[73]

This research project's Solution Concept develops a method to aid in solving the problem of transparency, uncertainty, and insecurity in the Brazilian Real Estate Registry System by signing and registering Public Deeds of Sale and Purchase and registering Property Payments, Property Registries (Ownership), and Property Transfers on the public, traceable, and immutable Bitcoin Blockchain (Bitcoin.org, 2024d), which assures information security principles such as integrity, authenticity, availability, identity, legality, and non-repudiation. Considering the realm of the Blockchain Trilemma, the limitations and challenges related to delayed confirmation of payment and registry transactions on the Bitcoin Blockchain are justified by Bitcoin's public network design that prioritizes decentralization and security over scalability.

In comparison with e-Notariado's digital certificate platform, which is currently used by the Brazilian Real Estate Registry System to validate electronic documents through its Notarchain solution (Colégio Notarial do Brasil, 2025), the TPS (Transaction Per Second) rate of Notarchain's Hyperledger Fabric Blockchain (HBF) is 320.23 times faster than the Solution Concept's Bitcoin Blockchain. However, Notarchain does not provide on-chain utilities presented by the Solution Concept, such as storing documents, signing Public Deeds of Sale and Purchase, and paying for properties on the Bitcoin Blockchain.

On the Notarchain, "hashes, signatures and dates of documents" are registered on the HBF (Martini, 2020), but the documents' contents are stored on a Cloud Backup solution for data storage (Colégio Notarial do Brasil, 2025). On the Solution Concept, documents, such as Property Registry, Property Transfer, or Public Deed of Sale and Purchase, are stored directly on the Bitcoin Blockchain via the Ordinal Software Utility of the Ordinal Theory. Additionally, the Solution Concept provides a method for signing Public Deeds of Sale and Purchase on the Bitcoin Blockchain by combining Bitcoin multi-signature transactions and Ordinal Theory.

Furthermore, Property Payments are sent in bitcoin on the Solution Concept, which enables a REGISTRY OFFICE to verify Property Payments transparently on the

[73]SECTION " CONCLUSIONS" contains text from SECTION "5. Conclusion" of the published article at the following reference: SASAKI, E. E., GROSSMANN, D., WILDAUER, E. W. **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.** Advances on Knowledge Representation, vol. 1, no. 1, p. 137-168, 2025. DOI: 10.5281/zenodo.15041980. Available in: https://periodicos.ufmg.br/index.php/advances-kr/article/view/53994/47843.

Bitcoin Blockchain, no longer requiring proof of Property Payment from a PROPERTY BUYER. This may eliminate uncertainty and insecurity from the PROPERTY BUYER for falling for a “Double Sale Scam” or “False Owner Scam”, by permitting the PROPERTY BUYER to send a Property Payment to a PROPERTY OWNER only after both, the PROPERTY BUYER and the PROPERTY OWNER, have signed a Public Deed of Sale and Purchase. As a result of which, upon verification of the Property Payment on the Bitcoin Blockchain, the REGISTRY OFFICE subsequently transfers the property to the PROPERTY BUYER.

Finally, payments and registries of property ownership and transfer on the Bitcoin Blockchain provide provenances and a digital thread of payments and registries. The "Parent-Child” functionality of the Ordinal Theory results in a complete and transparent view of the Property Registry history. Even in case a REGISTRY OFFICE mistakenly sends an inscription of a Property Registry, Property Transfer, or Public Deed of Sale and Purchase as a transaction fee to a miner, an inscription will always maintain the same Inscription ID. Additionally, the Property Transfers registered on the Bitcoin Blockchain implement principles of Knowledge Representation (KR) that allows for making the RDF (Resource Description Framework) statements (FIGURE 65) for “AI [Artificial Intelligence] by promising to bring the possibility of automatic inferences to the web” (Almeida, 2013, p. 1687).

6 RECOMMENDATIONS FOR FUTURE WORK

The following recommendations for future work are presented to add functionalities and research to the Solution Concept:

- Develop a tool to add digital identity certificates (Bitcoin Wallet Addresses) to the Solution Concept through message signing (Bitcoin Developer, 2025l) and message verification (Bitcoin Developer, 2025m) on Bitcoin Core (SECTION “3.3.1.1Linux Server Node”) as described in SECTION “4.4 INFORMATION SECURITY”.
- Explore the possibility of adding more IRIs (Internationalized Resource Identifiers) key-values (SECTION “2.10 Application of Knowledge Representation (KR)”) such as “sibling” Property Transfer IDs to JSON format files registered/inscribed as Property Transfers on the Bitcoin Blockchain. “Siblling” Property Transfer IDs would add more RDF (Resource Description Framework) statement (FIGURE 65) possibilities.
- Explore the possibility of making recursive “Parent-Child” functionality by making a new Property Transfer inscription ID a “child” of another Property Transfer inscription ID in which the have the same root “parent” Property Registry linkage.
- Develop a database to record Inscriptions IDs of Property Registries, Property Transfers, and Public Deeds of Sale and Purchase registered on the Bitcoin Blockchain by REGISTRY OFFICEs through the Solution Concept for Knowledge Representation data analysis (SECTION “2.10 KNOWLEDGE REPRESENTATION (KR)”).
- Research other Blockchain projects that may offer better scalability performance as the Bitcoin Blockchain (SECTION “4.2 SCALABILITY: TRANSACTION RATE COMPARISON BETWEEN BITCOIN BLOCKCHAIN AND HYPERLEDGER FABRIC BLOCKCHAIN, ETHEREUM BLOCKCHAIN, SOLANA BLOCKCHAIN, AND VISA PAYMENT CARD SERVICES”), while simultaneously, offering equivalent on-chain storage of media as the Bitcoin Blockchain Ordinal Theory Protocol (SECTION “2.5 NON-FUNGIBLE-TOKENS (NFTS) ON THE BITCOIN BLOKCHAIN THROUGH ORDINAL THEORY INSCRIPTIONS”).
- Propose simulated case studies with notary offices to assess adoption and operational impacts.

- Analyze economic impact of payment and transaction cost considering Bitcoin price fluctuations and network congestion.

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