

TECHNICAL UNIVERSITY OF MOLDOVA
FACULTY OF COMPUTERS, INFORMATICS, AND MICROELECTRONICS
DEPARTMENT OF SOFTWARE ENGINEERING AND AUTOMATION
SOFTWARE ENGINEERING STUDY PROGRAMME

INTERNSHIP REPORT

BlockSign - Securing Documents With Blockchain

Team No. 1

Team members:

Student 1: Alexei Pavlovschii, FAF-231 _____
Student 2: Alexandru Bujor, FAF-231 _____
Student 3: Gabriel Moraru, FAF-232 _____
Student 4: Filip Obrijan, FAF-232 _____
Student 5: Vladimir Vitcovschii, FAF-231 _____

Mentor: Andrei Poștaru _____

Submission date: 01/10/2025

Chișinău, 2025

ABSTRACT

The project titled "**BlockSign - Securing Documents With Blockchain**" was developed by students Alexei Pavlovchii, Alexandru Bujor, Gabriel Moraru, Filip Obrijan, and Vladimir Vitcovschii from the Technical University of Moldova.

This project comprises 5 chapters: Problem Framing, Domain Analysis, Solution Proposal, System Design and Practical Implementation, as well as Introduction, Conclusions and Bibliography.

It addresses the growing need for secure, transparent, and verifiable document management systems in modern organizations. Traditional approaches often rely on centralized storage and password-based authentication, which are vulnerable to tampering, unauthorized access, and human error. Our solution proposes a **blockchain-anchored mechanism** for document signing and verification, ensuring both the integrity and authenticity of documents.

The system implements a **passwordless authentication** scheme based on cryptographic key pairs, reducing risks associated with compromised credentials. Document integrity is preserved by calculating a SHA-256 hash, while signatures from all involved participants are verified using the **Ed25519 algorithm**. Once finalized, a document's hash can be anchored to a blockchain network, providing immutable proof of its existence and content at a given time.

From an architectural perspective, the back-end is developed in Node.js with Express.js and Prisma ORM on top of a PostgreSQL database. Email-based workflows, including OTP verification and document notifications, ensure usability and trust between system participants. The modular design of the application allows for future integration with cloud storage providers and expanded blockchain support.

Through this project, the students combined concepts from distributed systems, **cryptography**, and software engineering to design and implement a practical, real-world solution. The outcome is a **secure and scalable platform** that demonstrates how blockchain technology can enhance document authentication and verification processes in both academic and enterprise contexts.

Keywords: Blockchain, Cryptography, Documents, Security.

Content

INTRODUCTION	5
1 PROBLEM FRAMING	6
1.1 Problem Description	6
1.2 Problem Statement	9
2 Domain Analysis	10
2.1 Target Audience	10
2.1.1 Individual Users	10
2.1.2 Educational Institutions	10
2.1.3 Small and Medium Enterprises (SMEs)	11
2.1.4 Government Institutions	11
2.1.5 Law Firms and Notary Services	11
2.1.6 Financial and Banking Sectors	12
2.1.7 Healthcare Organizations	12
2.2 Market Size and Growth	12
2.2.1 Key Competitors and Solutions	13
2.2.2 Trends and Opportunities	14
2.2.3 Challenges and Barriers	15
2.3 Technical Research	15
2.3.1 Blockchain-Based Notarization	16
2.3.2 Electronic Signatures with Multi-Factor Authentication	17
2.3.3 Electronic & Remote Notarization	17
2.3.4 Advanced Cryptographic Techniques	18
2.3.5 Hybrid and Scalable Architectures	19
3 Solution Proposal	20
4 System Design	22
4.1 Technical Requirements	22
4.1.1 Functional Requirements	22
4.1.2 Non-Functional Requirements	24
4.2 Behavioral Modeling	25
4.2.1 Use Case Diagrams	25
4.2.2 Sequence Diagrams	28
4.3 Structural Modeling	31

4.3.1	Class Diagram	31
4.4	Figma User Interface Mockups	33
5	Practical Implementation	42
5.1	Back-end architecture	42
5.1.1	Application Layer	42
5.1.2	Database Layer	42
5.1.3	Security Measures	43
5.1.4	Authentication and Tokens	43
5.1.5	Email Service	44
5.1.6	Cryptographic Module	44
5.1.7	Document Workflow	45
5.1.8	Extensibility	45
5.2	Front-end UI	46
CONCLUSIONS		47
BIBLIOGRAPHY		48
APPENDICES		51

INTRODUCTION

In the digital era, organizations and individuals are increasingly reliant on electronic documents for communication, collaboration, and decision-making. The authenticity, integrity, and accessibility of these documents have therefore become critical factors in building trust and ensuring compliance with regulatory standards. Traditional paper-based approaches to document management are costly, time-consuming, and vulnerable to fraud or human error. At the same time, centralized digital systems often face challenges related to security, data breaches, and limited transparency.

This project addresses these challenges by designing and implementing a secure, scalable, and user-friendly system for document registration, signing, and verification. The system relies on public-key cryptography (Ed25519) to provide a passwordless authentication mechanism that ensures only authorized users can access or sign documents. A carefully designed workflow guides users through registration and approval, while administrators maintain oversight and control of pending registration requests.

The central contribution of this work is the integration of digital signatures and cryptographic payloads into the document lifecycle. Each document is uniquely identified by its SHA-256 hash, which guarantees integrity and allows participants to independently verify that the file they review is identical to the file stored in the system. By requiring each participant to sign the canonical payload, the system ensures non-repudiation and establishes a verifiable chain of consent. Once all signatures are collected, the document status transitions to signed, and participants are notified accordingly.

In addition to the cryptographic foundation, the system emphasizes practical usability. Users interact with the platform through intuitive registration and login flows, email-based verification, and role-based access controls. Administrators can approve or reject registration requests, while users can create documents, tag participants by username, and track their signature status. For future development, the platform is designed to integrate with decentralized storage or blockchain anchoring, extending its guarantees of persistence and transparency.

Overall, this project demonstrates how modern cryptographic primitives and structured workflows can be combined to deliver a robust document signing and verification solution. It lays the foundation for further research into decentralized trust, compliance with international standards, and seamless integration with existing enterprise systems.

1 PROBLEM FRAMING

1.1 Problem Description

Securing documents—whether physical or digital—remains a persistent, multi-dimensional problem that affects governments, enterprises, and individuals.

Physical Documents: Physical records (e.g., passports, certificates, contracts) have long been protected via signatures, seals, stamps, and locked storage, yet they remain vulnerable to forgery, misuse, and destruction (Figure 1.1). Law-enforcement bodies warn that advances in consumer printing and imaging have lowered the barrier to document counterfeiting [1]. Border and customs activity shows the problem is active and measurable: in one U.S. port alone, officials intercepted more than 6,800 fraudulent or stolen documents in FY2023—a 219% year-over-year increase—demonstrating both scale and growth [2]. In addition to fraud, disasters can irreparably damage archives; professional guidance exists precisely because fires, floods, and collapses have destroyed unique holdings (e.g., the 2009 Cologne City Archive collapse that obliterated a major European archive) [3], [4].



Figure 1.1 - Signature Forgery Impact on Important Processes

Digital Documents: Digitization improved accessibility and scale but introduced remote theft, silent manipulation, mass leakage, and extortion (Figure 1.2). The scale is well documented: Verizon's 2024 DBIR analyzed 30,458 incidents with 10,626 confirmed breaches, noting increased vulnerability exploitation via web applications [5]. Financial impact remains high: IBM's 2025 study reports a global average breach cost of USD 4.4M (down from USD 4.88M in 2024, still historically elevated), underscoring that document exposure is expensive even when containment improves [6], [7]. Ransomware and data-theft extortion continue to pressure organizations across critical sectors, with complaints to the FBI's

IC3 rising 9% in 2024 and losses hitting \$16.6B across cyber and scam crimes [8].

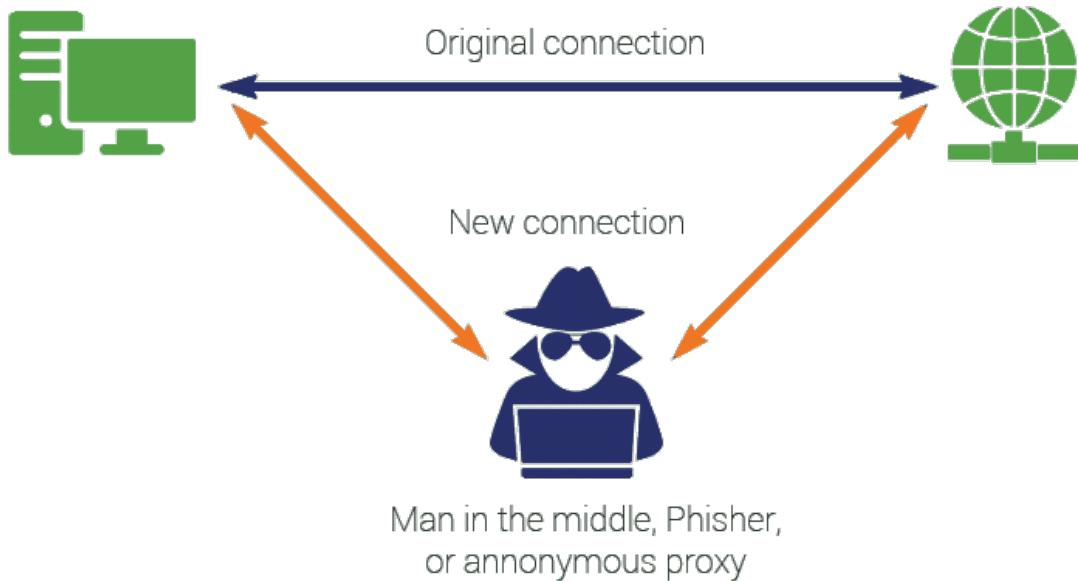


Figure 1.2 - Man In The Middle Attack

Trust and authenticity weaknesses in current ecosystems: Even when digital signatures and PKI are used, centralized trust anchors can fail. The DigiNotar breach (2011) led to hundreds of fraudulent certificates for prominent domains, breaking the authenticity guarantees expected from TLS/PKI and forcing browser vendors to distrust the CA entirely—an instructive “single point of failure” for trust [9]. The episode shows that document authenticity that depends on a compromised authority can be globally undermined.

Human and process error remain a major source of breaches: Beyond external attackers, misconfigurations, errors, and insider misuse contribute materially to breaches. Verizon’s 2024 DBIR details the role of internal actors and errors across sectors; in healthcare, for example, internal actors feature far more prominently than elsewhere, reversing earlier trends [10]. This reflects a broad, persistent problem: authorized access used improperly can compromise sensitive documents at scale.

Regulatory pressure - confidentiality, integrity, accountability: Regulatory frameworks require clear safeguards for documents that include personal data. The GDPR mandates “appropriate technical and organizational measures” and emphasizes data integrity and accountability [11]. In the EU, eIDAS sets legal scaffolding for electronic identification and trust services, defining requirements for trustworthy digital interactions (e.g., signatures, seals, timestamps) [12]. Non-compliance introduces legal and financial risks on top of the technical ones.

Common vulnerability patterns in applications that handle documents: Applications that store, view, transfer, or sign documents routinely exhibit high-impact weaknesses. The OWASP Top 10 highlights recurring problems such as Broken Access Control (ranked #1 in 2021), Cryptographic Failures, Injection, and Security Misconfiguration (Figure 1.3); notably, 94% of tested apps exhibited some form of access control weakness in the dataset behind the 2021 list [13], [14]. These patterns map directly to risks for document confidentiality, integrity, and availability.

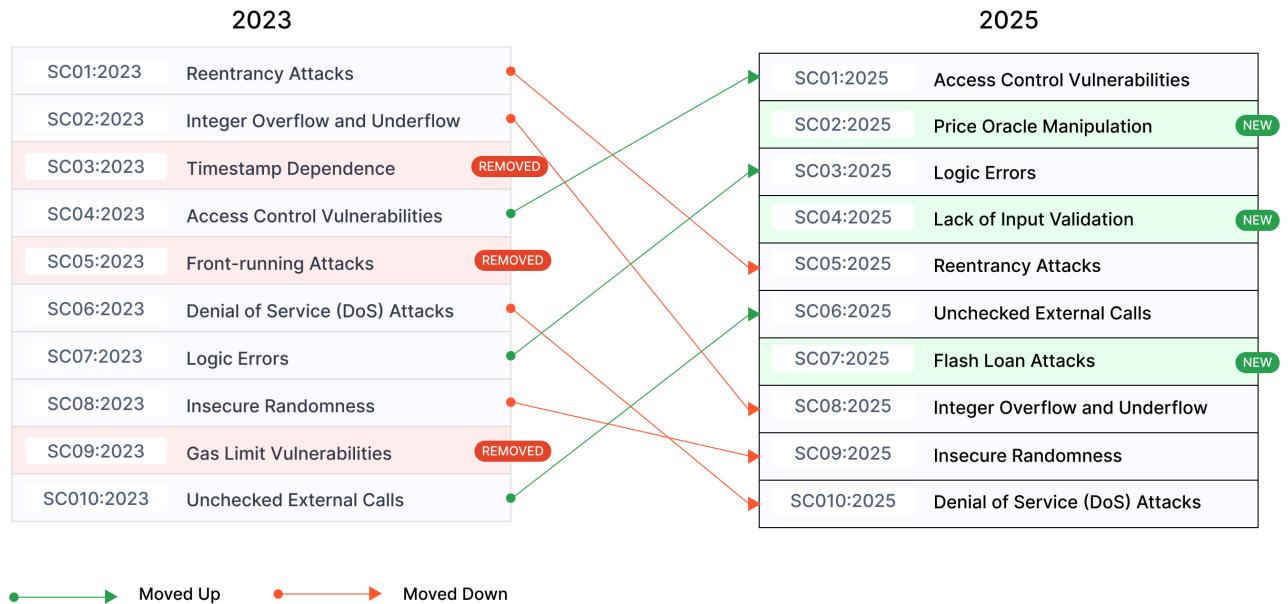


Figure 1.3 - OWASP Top 10 (2023 vs 2025)

The Core Problem: Taken together, these issues demonstrate that document security is a multi-faceted challenge:

- Physical documents face forgery and catastrophic loss risks despite traditional controls [1], [2], [3], [4].
- Digital documents face breach, extortion, and manipulation at global scale, with material financial impact [5], [6], [7], [8].
- Trust infrastructures (e.g., CAs) can become single points of failure [9].
- Human/organizational errors and app-level vulnerabilities remain prevalent [10], [13], [14].
- Regulatory frameworks demand provable safeguards and accountability [11], [12].

These facts collectively demonstrate that ensuring authenticity, integrity, confidentiality, availability, and accountability for documents is an unresolved, real-world problem spanning both physical and digital realms.

1.2 Problem Statement

Existing mechanisms for securing physical and digital documents remain vulnerable to forgery, loss, unauthorized access, manipulation, and systemic trust failures, while regulatory obligations require stronger assurance and accountability. The problem is to guarantee authenticity, integrity, confidentiality, availability, and verifiability of documents over time and across domains, despite evolving threats, human error, and infrastructural weaknesses (Figure 1.4).

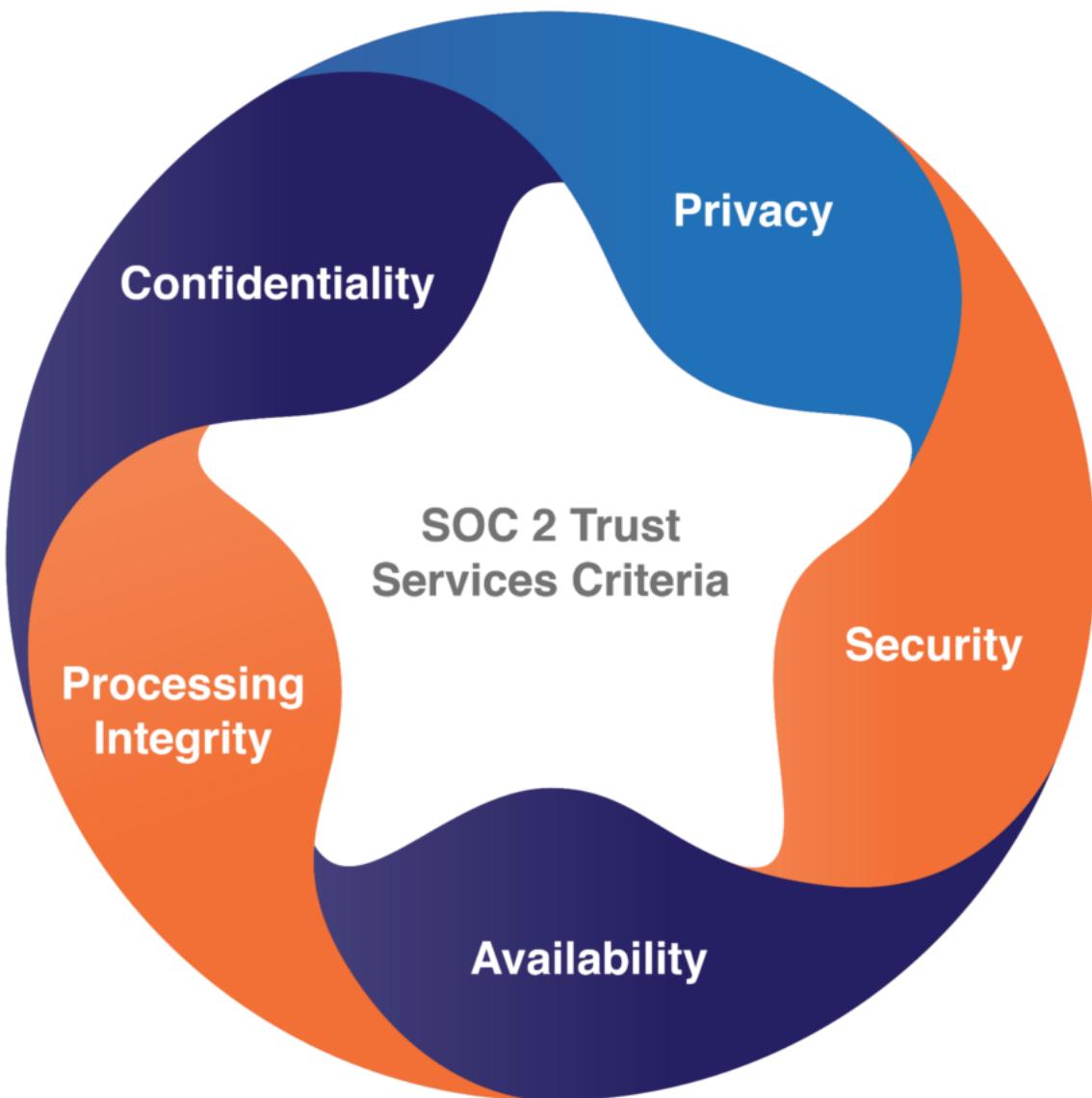


Figure 1.4 - Service Organization Controls (SOC) security principles standard

2 Domain Analysis

2.1 Target Audience

BlockSign is designed to serve a diverse range of users who require secure, verifiable, and legally recognized methods of document handling. By leveraging blockchain technology, BlockSign ensures authenticity, immutability, and compliance across various sectors. The primary audiences are described in this section.

2.1.1 Individual Users

In an era where personal data misuse and identity theft are prevalent, individuals can utilize BlockSign to notarize personal documents such as wills, rental agreements, and contracts. This ensures their documents remain immutable and verifiable over time, providing peace of mind and legal assurance [15].

2.1.2 Educational Institutions

Educational institutions require secure systems for managing sensitive records, including diplomas, transcripts, and certificates (Figure 2.1). Cases of diploma fraud have increased globally, undermining student mobility and employer trust. Blockchain notarization of educational credentials ensures their authenticity across borders, which is particularly important in student exchange programs and international hiring [16].



Figure 2.1 - Digital Certificates

2.1.3 Small and Medium Enterprises (SMEs)

SMEs often lack access to enterprise-grade solutions like DocuSign or Adobe Sign due to cost constraints. BlockSign offers a cost-effective and transparent notarization platform, enabling startups, freelancers, and growing firms to establish trust with partners, clients, and regulators without heavy infrastructure investments [17].

2.1.4 Government Institutions

Government agencies responsible for issuing and verifying official records (e.g., passports, permits, licenses) face persistent threats from forgery and manipulation of physical and digital documents (Figure 2.2). These institutions require trustworthy digital notarization solutions to comply with regulations such as the EU's eIDAS Regulation and the General Data Protection Regulation (GDPR) [18].



Figure 2.2 - Customs and Border Protection officer verifying a travel document

2.1.5 Law Firms and Notary Services

Law firms and notary services handle contracts, affidavits, and property transactions, all of which require high trust and legal enforceability. Traditional notarization can be time-consuming and limited by geographic restrictions. Remote Online Notarization (RON), already gaining traction in the United States and parts of Europe, demonstrates that secure video-based validation combined with blockchain immutability can streamline legal workflows while retaining compliance [19].

2.1.6 Financial and Banking Sectors

Financial institutions, including banks and insurance companies, must guarantee the validity of signed contracts, loan agreements, and client identities (Figure 2.3). Financial institutions are among the industries with the highest breach costs, averaging USD 4.44 million per incident [20].



Figure 2.3 - Personal Loan Agreement

2.1.7 Healthcare Organizations

The healthcare sector is increasingly dependent on electronic records and digital consent forms. The sector faces both internal and external threats: 70% of healthcare breaches involve insiders misusing access privileges [21]. For hospitals, clinics, and research institutions, BlockSign offers a mechanism to notarize patient records, safeguard sensitive data, and ensure compliance with confidentiality obligations under GDPR.

2.2 Market Size and Growth

According to industry reports, the global market for digital signatures was worth about USD 7.47 billion in 2023, and it's expected to soar to around USD 37.79 billion by 2029, expanding at an annual growth rate of 31%.

Other estimates are even more bullish: one study puts the 2023 market at USD 4.6 billion with a forecast to USD 43.5 billion by 2030, representing a 37.9% CAGR between 2023 and 2030 (Figure 2.4) [22]. Another source projects growth from USD 3.2 billion in 2021 to USD 48.4 billion by 2028, at

35.4% CAGR (Figure 2.5) [23]. Despite slight variations in numbers, the consensus is clear: the market is booming.

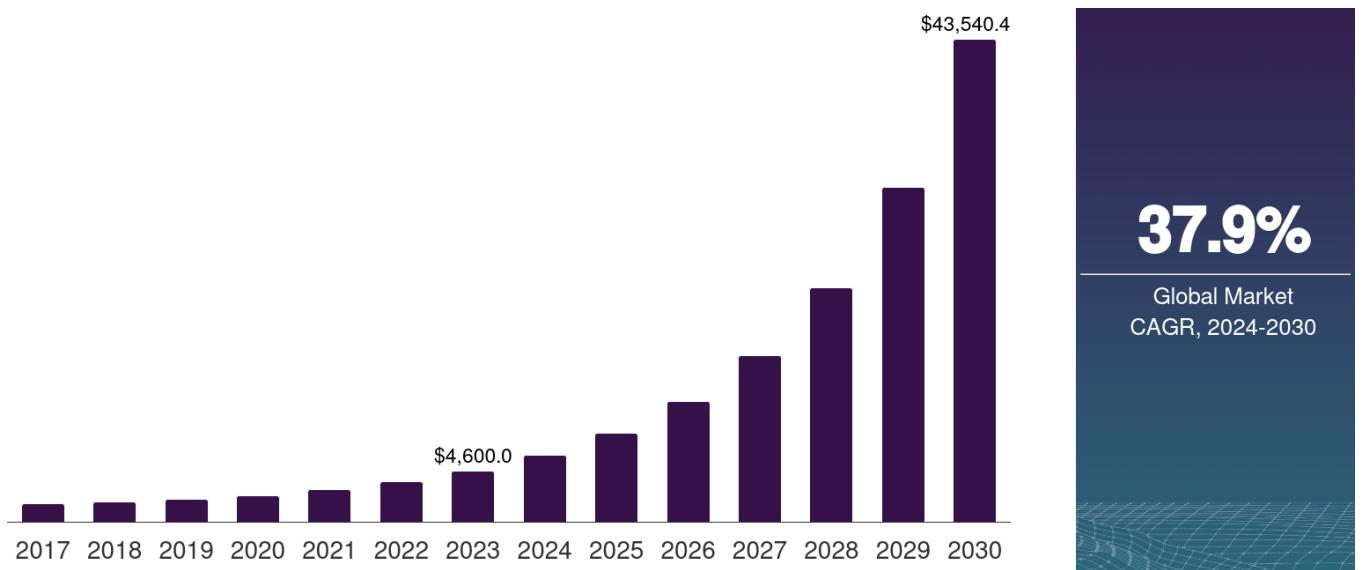


Figure 2.4 - Global Digital Signature Market Size 2017-2030 (Horizon)

Blockchain-related identity services and notarization tools are also on the rise, particularly in industries where trust, compliance, and speed are critical: banking, finance, legal, and healthcare. These solutions help reduce fraud, accelerate cross-border processes, and ensure compliance with regulations like GDPR, eIDAS in Europe, or ESIGN and UETA in the United States.

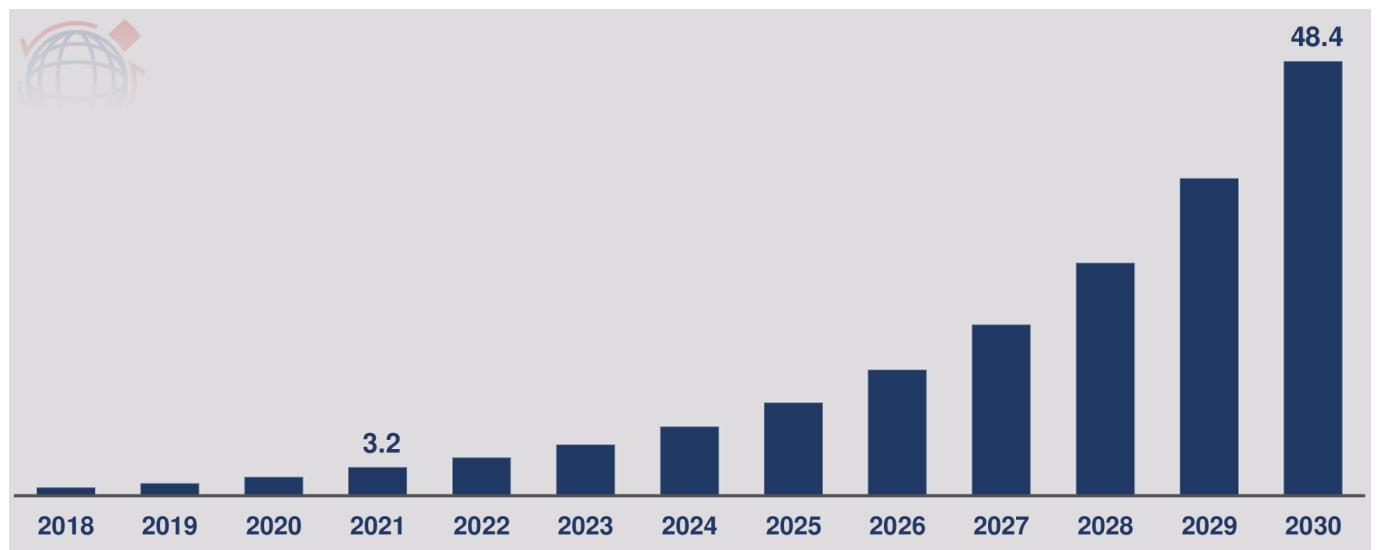


Figure 2.5 - Digital Signature Market 2018-2030 (Acumen)

2.2.1 Key Competitors and Solutions

Several big players are driving the digital signature space:

- **DocuSign** and **Adobe Sign** are trusted and widely used, especially by enterprises, but still rely on

centralized infrastructure.

- **Notarize**, **NotaryCam**, and **SignNow** specialize in Remote Online Notarization (RON), often using video identity checks to meet legal and compliance needs.
- On the blockchain side, platforms like **DoxyChain** and **Blocknotary** offer immutable timestamping and decentralized storage.
- Emerging frameworks like **KILT Protocol** and **Concordium** support decentralized identity and can integrate into notarization workflows.

These players show how mature the e-signature market is becoming—and how blockchain is carving out its place as a serious value-add technology (Figure 2.6) [24].

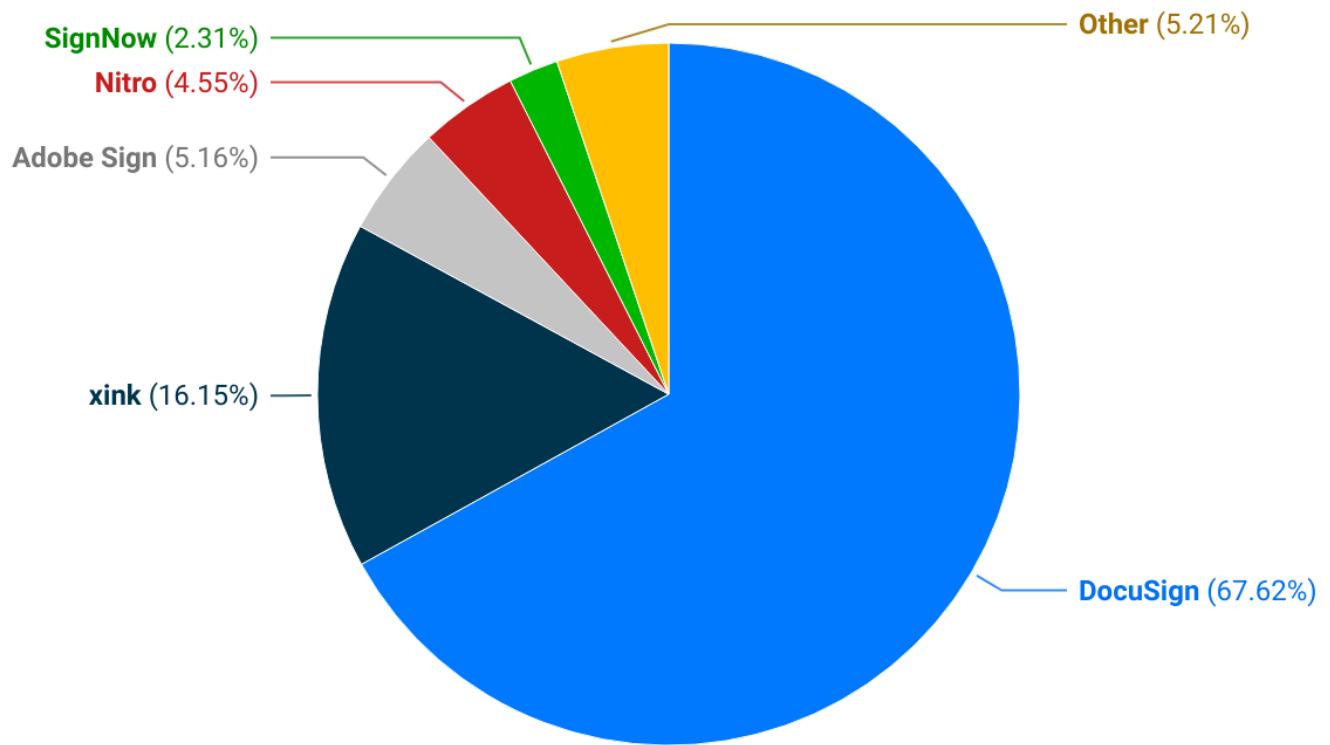


Figure 2.6 - Market Share of Leading Electronic Signature Companies

2.2.2 Trends and Opportunities

A few clear trends are shaping the future of digital signatures:

1. **Trustless, decentralized verification** – Blockchain-based notarization helps remove single points of failure tied to central Certificate Authorities (CAs).
2. **Remote and cross-border notarization** – With more people working globally, demand increases for legally recognized remote notarization systems.
3. **AI and automation integration** – Automated document checks, fraud detection, and smart contract workflows are on the rise.
4. **Quantum-safe cryptography** – Some platforms are starting to prepare for future cryptographic threats

to ensure long-term document integrity.

5. **Hybrid architectures** – Combining public and permissioned blockchains helps balance trust, scalability, and cost-efficiency.

These trends create fertile ground for innovation, especially for solutions that balance security, legal compliance, and user-friendliness (Figure 2.7).



Figure 2.7 - Benefits of Digital Signatures

2.2.3 Challenges and Barriers

However, adoption still faces some challenges:

- Legal frameworks vary widely across countries, slowing global standardization and interoperability.
- Many institutions remain comfortable with traditional notarization; change can feel risky.
- Balancing high security with simplicity is tough—systems that are too complex won't encourage adoption.
- Public blockchains can struggle with scalability and can be costly for frequent use.

2.3 Technical Research

This section describes core technologies potentially applicable for implementing the secure document notarization idea. For each, it will be described how it operates, its benefits, and real-world usage.

2.3.1 Blockchain-Based Notarization

Document notarization on blockchain typically involves computing a cryptographic hash of the file and storing it timestamped on a decentralized ledger. Anyone can later rehash the document to verify integrity without revealing the document's content [25]. Some valuable benefits of this approach are:

- **Immutability and transparency:** Hash entries cannot be altered after being written to the chain and are visible across the network (Figure 2.8).
- **No central point of failure:** Decentralized consensus removes reliance on a single trusted authority [26].
- **Timeproof:** Timestamps on transactions provide verifiable evidence of document existence at a given time [25].

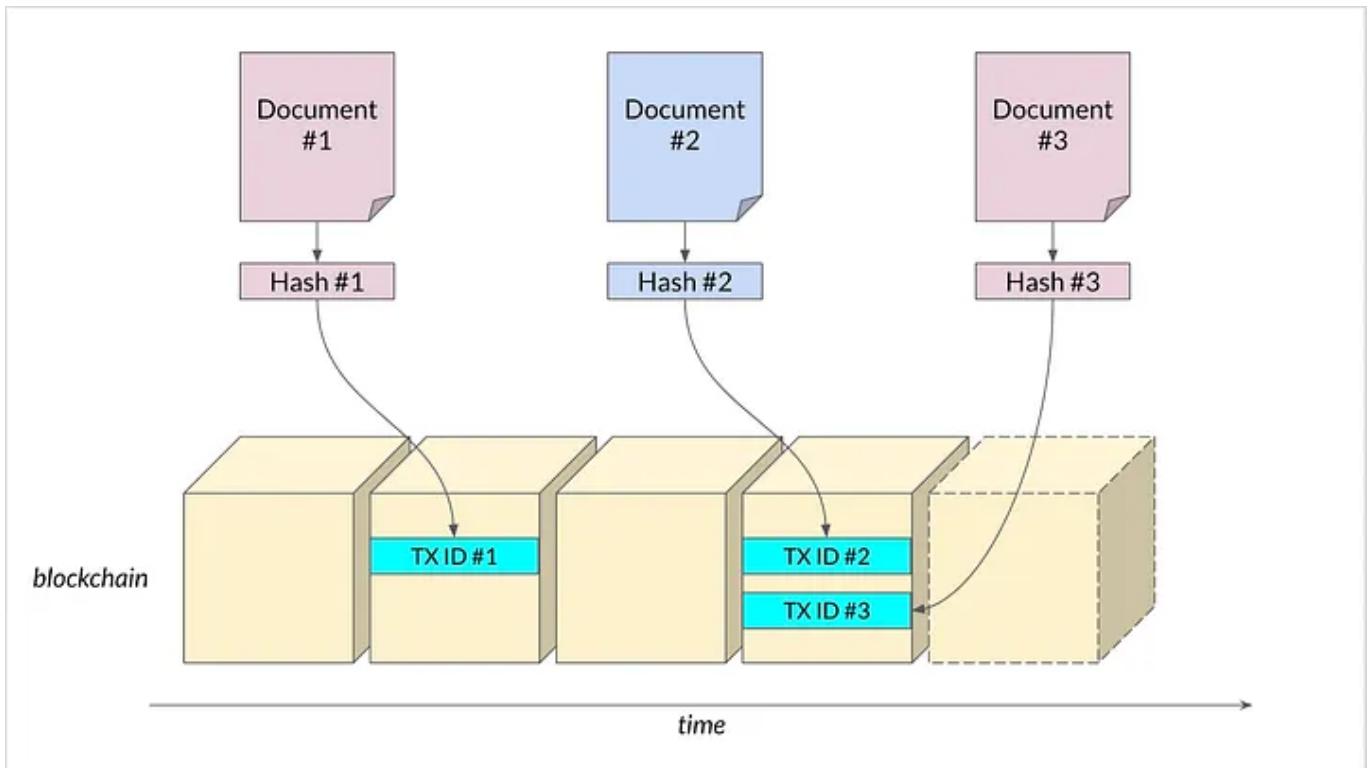


Figure 2.8 - Blockchain Notarization

Recent academic research explores moving from simple “proof of existence” to full document validation, integrating smart contracts, Zero-Knowledge Proofs (ZKPs), AI-based content analysis, and quantum-resistant cryptography—to ensure privacy, detect fraud, and future-proof security [27]. Hybrid blockchain architectures are also being proposed to improve scalability and cost-efficiency, balancing public and permissioned ledger benefits [28].

2.3.2 Electronic Signatures with Multi-Factor Authentication

Combining digital signatures with MFA requires users to authenticate via multiple channels—e.g., password plus a one-time code or biometric—before signing or notarizing a document (Figure 2.9) [29]. Several useful features and benefits are:

- **Significantly enhanced security:** Microsoft reports that MFA can block 99.2% of account compromise attacks [30].
- **Fraud reduction:** Additional authentication steps make forging or stealing identities substantially harder [29], [31].
- **Regulatory compliance:** MFA aids in meeting stringent identity verification requirements in sectors like finance and legal services [29].



Figure 2.9 - Multi-Factor Authentication

Remote Online Notarization (RON) platforms integrate MFA to verify signer identity and prevent unauthorized access—combining this with tamper-evident seals and audit trails strengthens legal validity and trust [32].

2.3.3 Electronic & Remote Notarization

E-Notary systems use digital signatures, cryptographic seals, and a public key infrastructure (PKI) to notarize documents electronically. Remote Online Notarization (RON) adds a layer of video verification and identity validation via secure video + digital credentialing (Figure 2.9) [33]. The benefits include:

- **Tamper-evident documents:** Digital signatures and seals prevent unnoticed alterations.
- **Cost savings and efficiency:** Eliminates paper handling and on-site meetings; notarizations can be completed online, rapidly.

- **Audit trails:** Many systems log each step of the notarization process, boosting transparency and legal compliance.



Figure 2.10 - Remote Notarization

For example, Notario.org offers an online notarization platform supporting identity verification via video, digital certificates, and legal compliance across several countries (Spain, USA, Germany, etc.) [34].

2.3.4 Advanced Cryptographic Techniques

Zero-Knowledge Proofs (ZKPs) enable one party to prove a statement is true without revealing the underlying data. In blockchain notarization, ZKPs can allow verification of document integrity or content compliance without exposing sensitive data (Figure 2.9) [35]. The two benefits of this technique are:

- **Privacy preservation:** Keeps personal or confidential document content hidden while still proving authenticity.
- **Regulatory advantages:** Complies with data protection regulations by limiting exposure of sensitive data.

Zero Knowledge Proofs



Figure 2.11 - Zero-Knowledge Proof Mechanism

With the potential arrival of quantum computing, future document notarization systems must adopt quantum-safe cryptographic algorithms to remain secure long-term. Research highlights this as an evolving domain in notarization systems to guard against future computational threats.

2.3.5 Hybrid and Scalable Architectures

To address limitations of public blockchains (e.g., transaction fees, latency) and private blockchains (e.g., trust, centralization), hybrid DLT (Distributed Ledger Technology) designs are emerging. They combine local/private storage for efficiency with public chains for decentralization and transparency. Benefits include:

- **Cost optimization:** Keeps frequent notarizations low-cost by batching hashing operations off-chain while anchoring checkpoints on-chain.
- **Scalability:** Manages large volumes efficiently while maintaining tamper evidence and verifiability.

3 Solution Proposal

Based on defined problems and domain research, it is evident that existing document management approaches face serious limitations. Physical records remain vulnerable to forgery, loss, and destruction, while digital records suffer from risks such as unauthorized modification, cyberattacks, and dependence on centralized authorities. Current protections, including digital signatures and certificate-based systems, mitigate some threats but are not sufficient to guarantee authenticity, long-term verifiability, and compliance with modern security standards. At the same time, regulatory frameworks such as GDPR and eIDAS demand solutions that ensure confidentiality, integrity, and accountability. These findings highlight the need for a system that not only secures documents but also provides transparency, privacy, and user trust.

The proposed solution is a blockchain-based notarization platform that enables the creation, signing, and verification of documents in a secure and transparent manner. The platform leverages blockchain to store only the cryptographic hash of documents, ensuring immutability and tamper resistance without exposing sensitive content. This approach allows users to instantly verify document authenticity by comparing a locally computed hash with the one recorded on the blockchain, making the verification process fast, reliable, and independent of intermediaries.

The architecture of the system is structured around four main components:

1. **Client Applications (Web and Mobile)** – provide users with an accessible interface to create, sign, and verify documents. Both platforms support multilingual functionality (English, Russian, Romanian) and integrate usability features such as search, filtering, and history tracking.
2. **Authentication and Identity Management** – user authentication is handled through Google OAuth2 and local registration flows, with strong password policies and multi-factor authentication (MFA) applied during sensitive operations such as signing. Identity verification relies on a one-time check of personal identifiers (e.g., IDNP), which are not stored long term, ensuring compliance with privacy regulations. Session management is secured with JWT tokens.
3. **Application Server** – coordinates document workflows, including creation, pending approvals, and signature collection. The server computes document hashes, manages participant approvals, and interacts with both the blockchain network and the database. It also enforces security controls such as input validation, secure APIs, and proper session handling.
4. **Blockchain and Database Layer** – the blockchain serves as a public, immutable ledger for document hashes, timestamps, and participant references, ensuring integrity and transparency. The database stores only operational metadata and user account information, excluding sensitive identity data. Together, these layers guarantee both system efficiency and data protection.

Functionally, the platform supports a full document lifecycle: registration and identity verification, creation and upload of documents, participant assignment, approval workflows, signing, and final notarization on the blockchain (Figure 3.1). Each step is backed by security controls, ensuring that fraudulent activity, tampering, or unauthorized access is either prevented or immediately detectable.

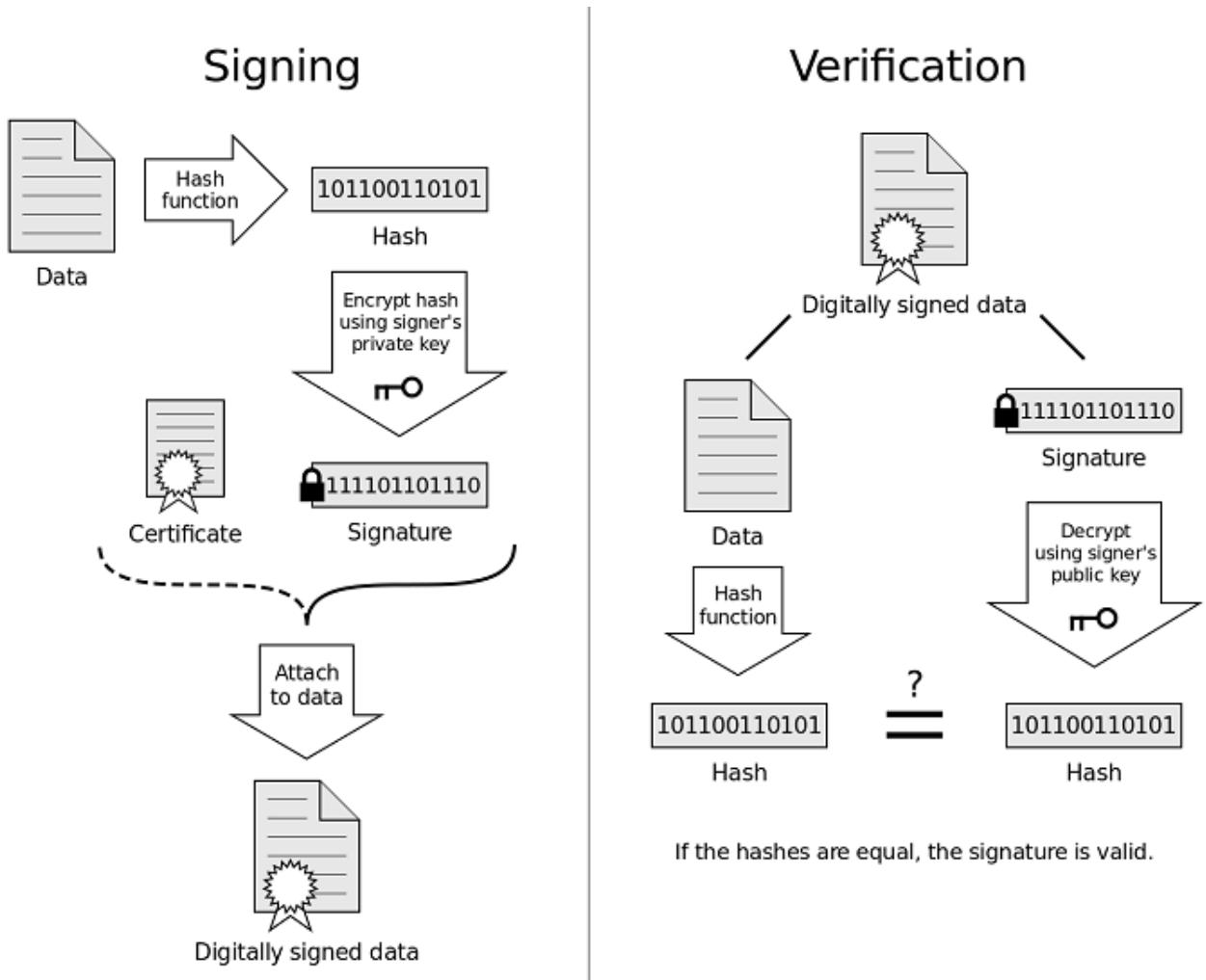


Figure 3.1 - Core Signing and Verifying Logic

By combining usability, regulatory compliance, and cryptographic trust mechanisms, the solution directly addresses the shortcomings identified in traditional document management. It provides a system that ensures authenticity, integrity, transparency, and privacy, offering users a verifiable and tamper-proof method of managing critical documents.

4 System Design

4.1 Technical Requirements

This section describes the architectural backbone of the project, mainly Functional and Non Functional requirements. It describes key actors, functionalities accessed by them, as well as other technical specifications which will be considered in the project practical implementation part (Figure 4.1).

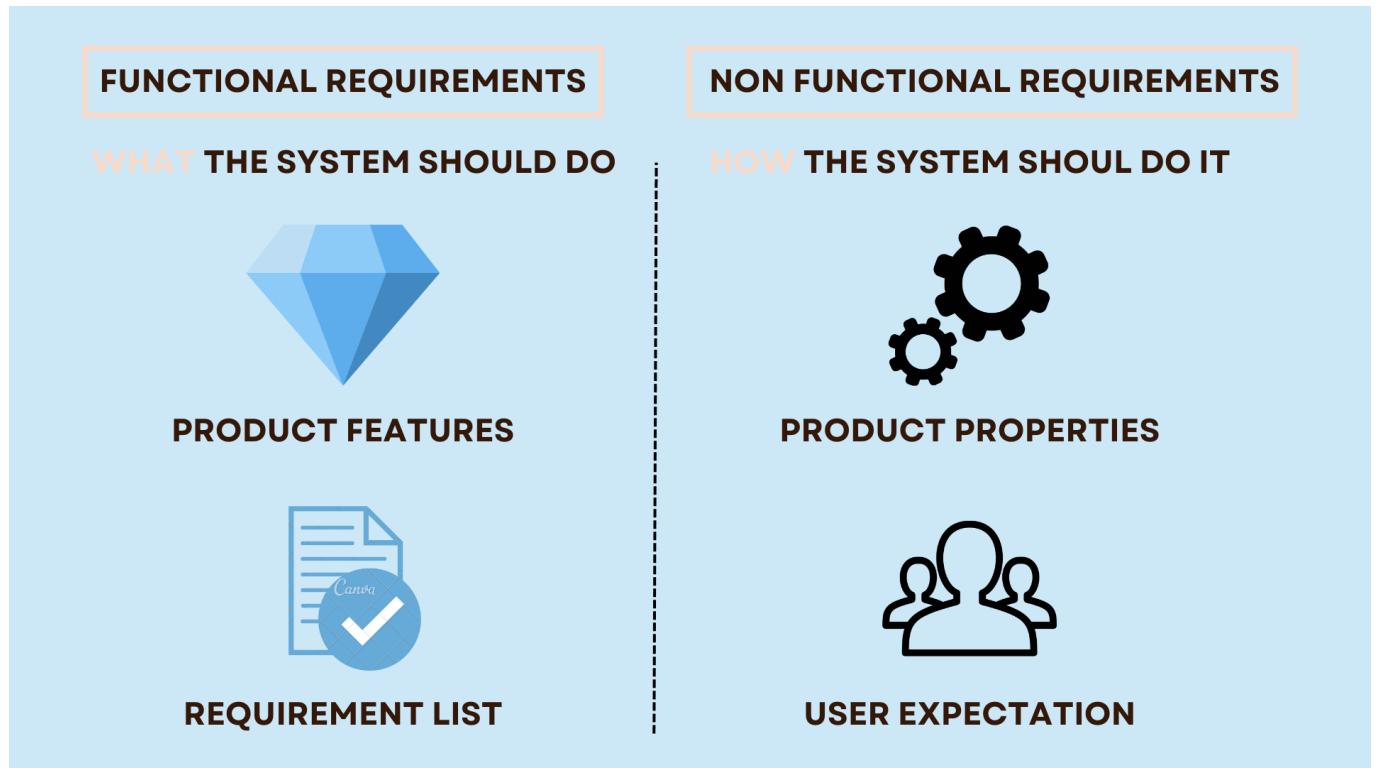


Figure 4.1 - Functional And Non-Functional Requirements

4.1.1 Functional Requirements

The application is designed around three primary user roles:

1. **Unauthorized users**, who may access only the main page and perform registration or login.
2. **Authorized users**, who gain full access to document-related services such as creation, signing, verification, and account management.
3. **Administrators**, who are responsible for managing the user database and can access limited user information when necessary.

The system incorporates a wide set of functions to support these roles. First, it provides multilingual support, ensuring that the entire interface is available in English, Russian, and Romanian. The main page allows navigation to registration, login, and account pages, as well as a mail integration for sending quick requests to support.

On the documents page, authorized users may create new documents by uploading files through a drag-and-drop interface, specifying the parties involved, and submitting them for signing. Pending documents appear in the personal cabinet of each participant until all signatures are collected. At the same time, users can verify documents by uploading a file, generating its hash, and comparing it with blockchain records. If no match is found, a notification is displayed.

The account page contains a full history of signed and pending documents. Each entry provides a preview, the date, file size, hash, status, and the option to download. Account management includes editing personal details, changing passwords, enabling multi-factor authentication, verifying a phone number, and connecting an authenticator app.

Additional functionality is provided through search and filters, which allow users to locate documents based on keywords, sides, or metadata. Pending documents can be opened in a PDF viewer for review and signed electronically. Once the final party signs, the system hashes the document and records it immutably on the blockchain.

Finally, the system enforces secure authorization and registration flows. Users may authenticate through Google OAuth 2.0 or via local registration (Figure 4.2).

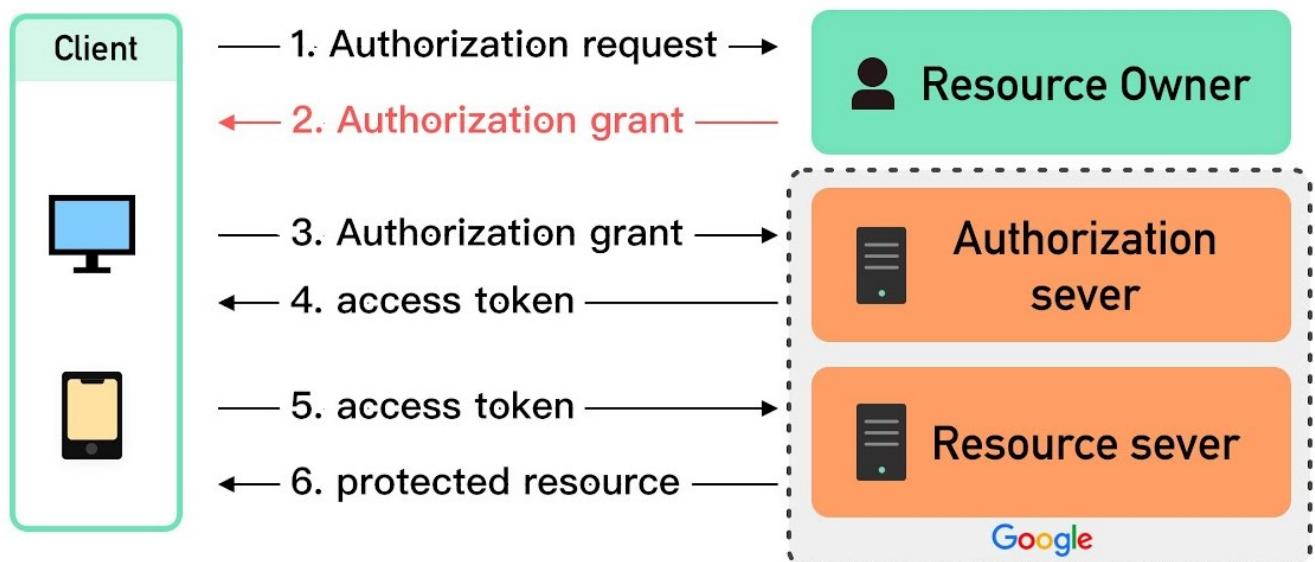


Figure 4.2 - OAuth Mechanism Description

Registration follows a structured, multi-step process: (1) account creation with password and phone validation, (2) email verification through a six-digit code, and (3) submission of identity data (IDNP, birth date, selfie) for administrative approval. A password recovery mechanism is also implemented, allowing users to initiate a reset request by email, verify the reset code, and set a new password meeting complexity requirements .

4.1.2 Non-Functional Requirements

Beyond functionality, the application is governed by several non-functional requirements that ensure its performance, usability, and security.

From a performance perspective, documents themselves are never stored on the blockchain. Instead, only their final cryptographic hash is recorded. This guarantees integrity verification without exposing sensitive content or overloading the ledger.

Regarding usability, the system is designed as both a web application and a mobile application, ensuring broad accessibility. To support a diverse user base, the entire interface is available in three languages: English, Russian, and Romanian.

In terms of security, the platform adopts multiple protective measures:

1. **Sensitive data minimization** – personal identifiers such as IDNP are used solely during registration for verification and are not retained long-term.
2. **Multi-factor authentication (MFA)** – required for signing documents, adding an extra layer of identity assurance.
3. **JWT tokens** – used to secure session management and provide controlled access to the personal cabinet (Figure 4.3).

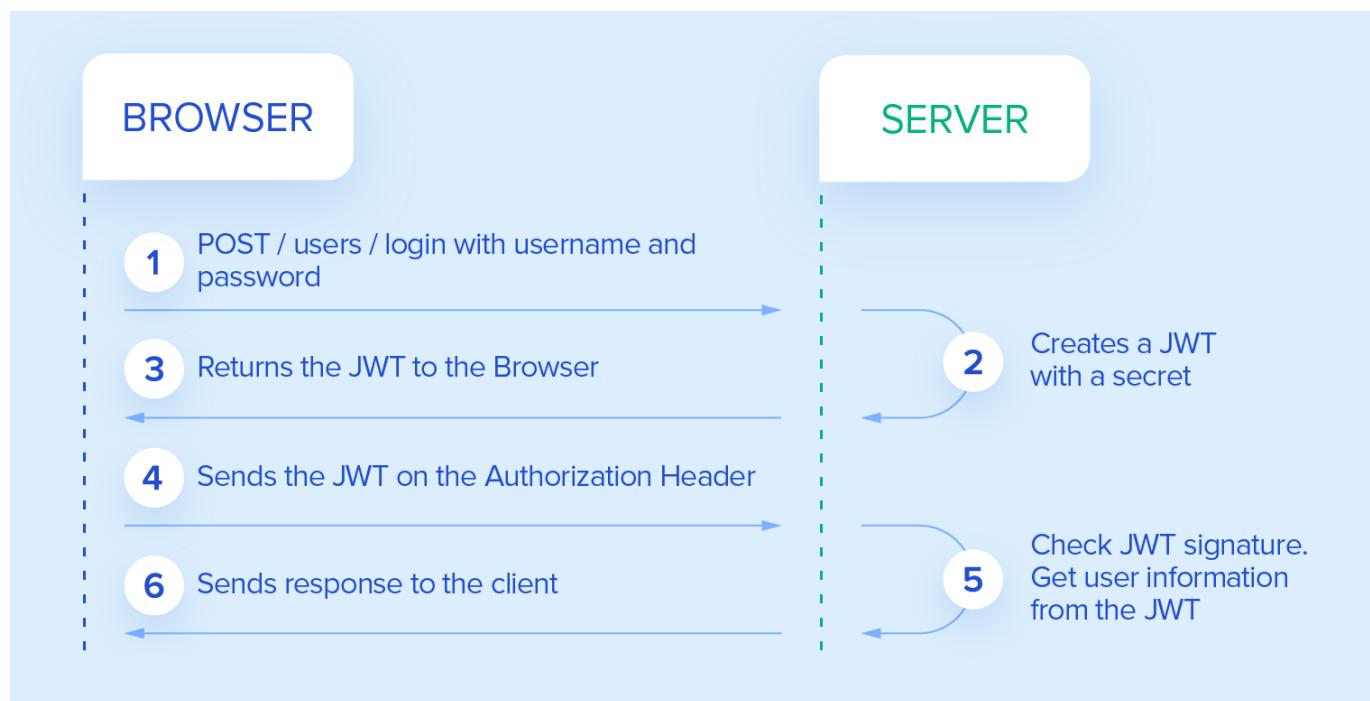


Figure 4.3 - JWT Token Usage Mechanism

Finally, the system adheres to privacy and compliance standards. The blockchain stores only document hashes, with no personal data or file content, ensuring confidentiality and compliance with data protection principles.

4.2 Behavioral Modeling

To capture the dynamic aspects of the system and illustrate how users and components interact, several UML diagrams were created. These diagrams help visualize workflows, user interactions, and message flows between system elements, making the architecture more comprehensible and easier to validate against requirements.

4.2.1 Use Case Diagrams

The use case diagrams represent the primary interactions between different user roles and the system, highlighting the functionalities available to each category of user. There are four main use cases described:

1. **Registration process:** The Figure 4.4 illustrates the registration process for an unauthenticated user.

The actor initiates the flow by selecting the option to register into the system. The process includes several mandatory steps such as filling in registration data, providing personal information, verifying the email, and awaiting administrator approval. An optional extension allows the user to authenticate through Google OAuth as part of the email verification step. The diagram highlights the dependencies between activities using «include» and «extend» relationships, showing that registration is a structured, multi-step procedure designed to ensure security and identity verification.

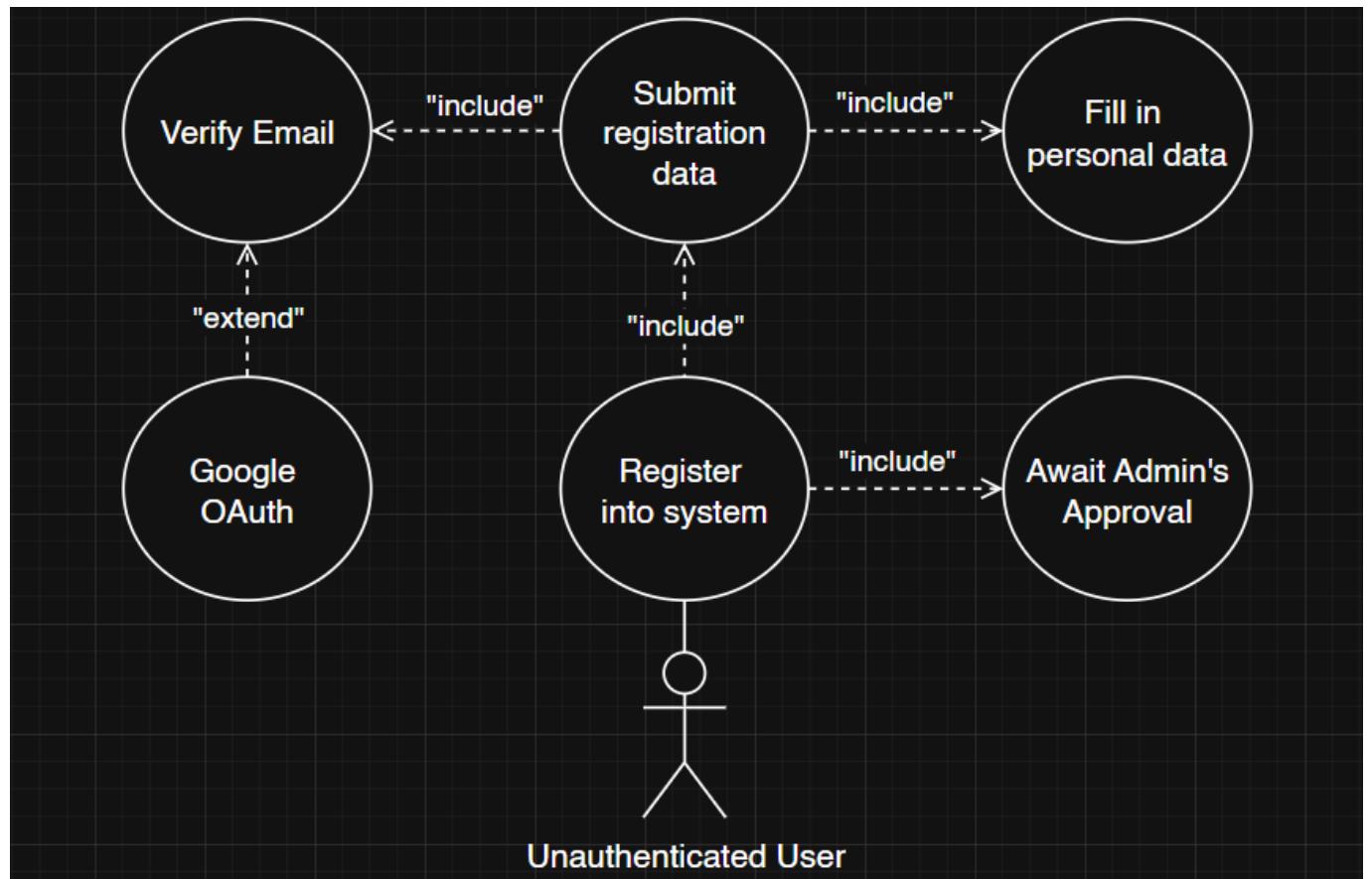


Figure 4.4 - UML Registration Use Case

2. **Document Creation:** The Figure 4.5 represents the process of creating a document within the system by an authenticated user. The actor begins by initiating document creation, which includes multiple dependent steps. The user must upload the document, after which the system checks whether it already exists on the blockchain. The process requires the creator's approval, the specification of participant IDs, and the subsequent approval of all tagged participants. Once these steps are completed, the creation is confirmed, finalizing the process and preparing the document for secure handling. The diagram emphasizes the structured and multi-party approval workflow that ensures document authenticity and prevents duplication.

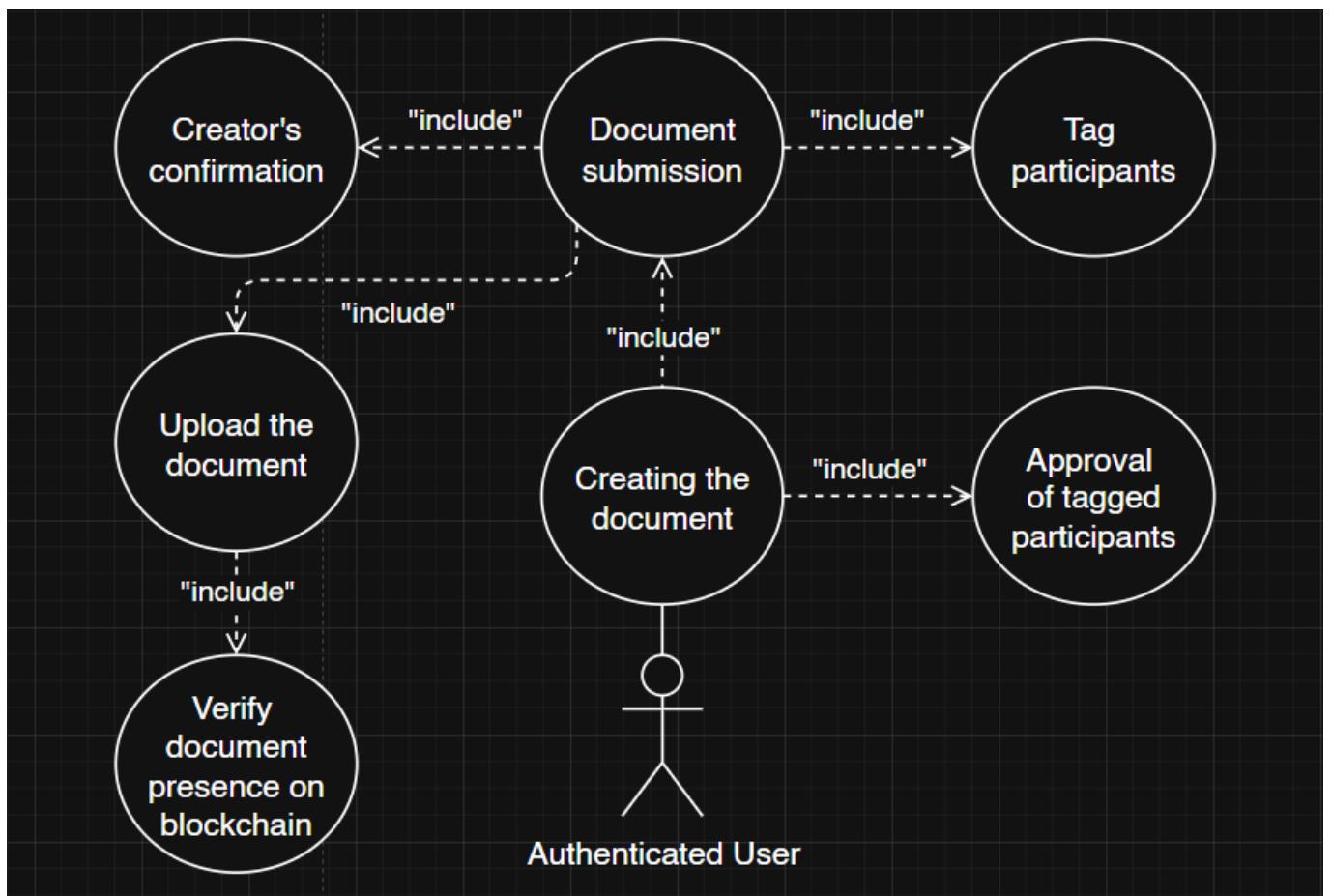


Figure 4.5 - UML Document Creation Use Case

3. **Document Verification:** The Figure 4.6 depicts the process of verifying a document by an authenticated user. The actor initiates the verification by uploading the document and providing the participants' identifiers. The system then calculates the cryptographic hash of the uploaded file and performs a check against existing blockchain records. If a corresponding hash is found, the document is confirmed as authentic and unaltered; otherwise, the system indicates that no match exists. This diagram highlights the structured verification workflow, where hashing and blockchain lookups ensure document integrity and transparency in the verification process.

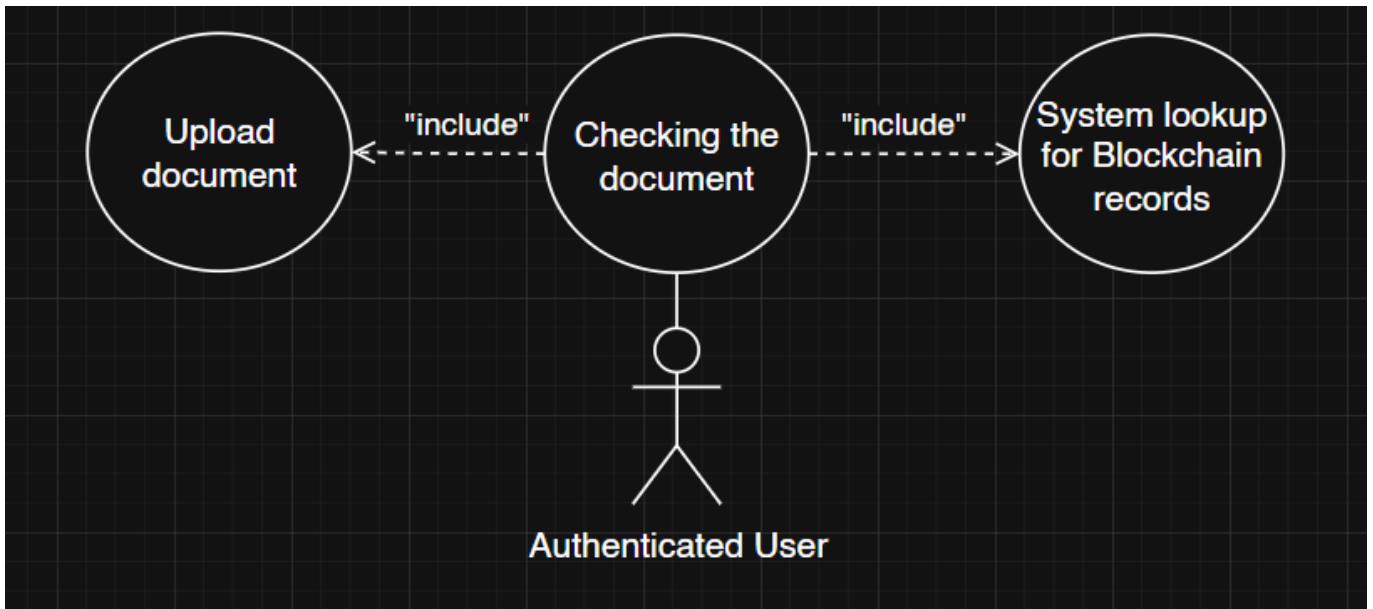


Figure 4.6 - UML Document Verification Use Case

4. **Account Approval:** The Figure 4.7 models the administrator's role in approving user registration. The administrator actor is responsible for validating new accounts by checking the uniqueness of the user and comparing the submitted registration data against records provided by the identity provider (IDP). The process also includes requesting personal data through the IDP to confirm authenticity before final approval. This ensures that only legitimate users, whose identities can be verified and who have not previously registered, are granted access to the system. The diagram emphasizes the administrator's critical role in safeguarding trust, preventing duplicate accounts, and maintaining the integrity of the registration process.

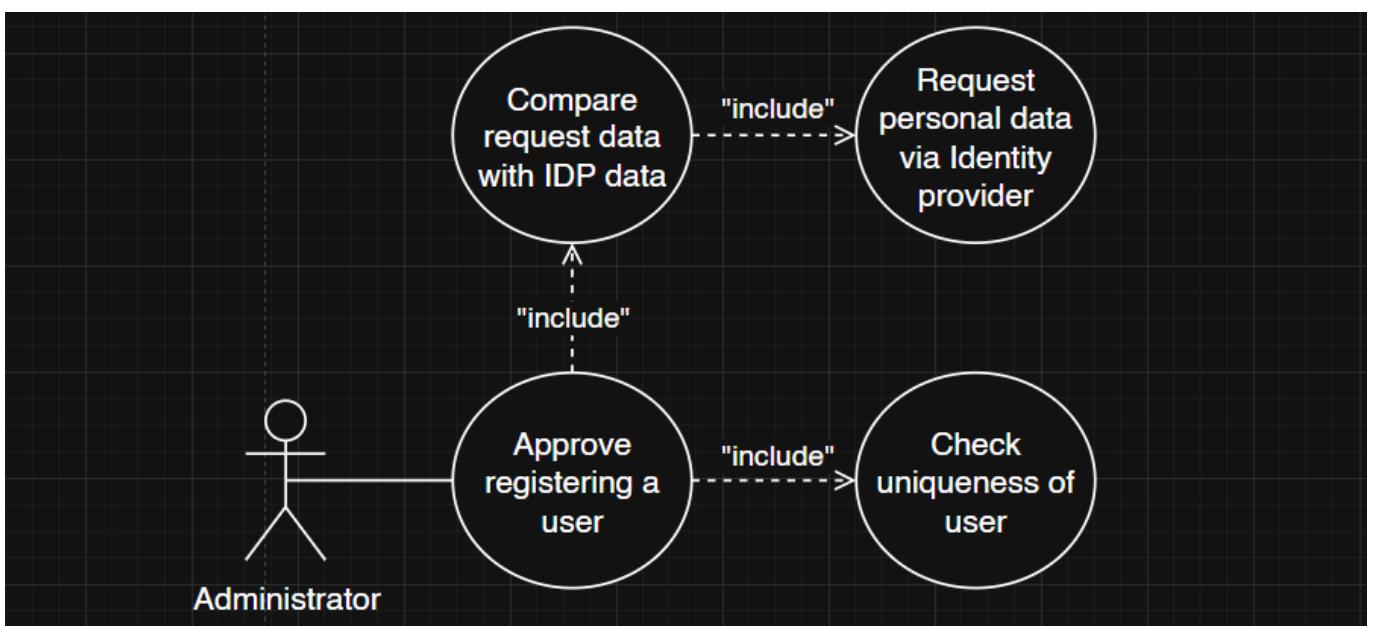


Figure 4.7 - UML Account Approval Use Case

4.2.2 Sequence Diagrams

The sequence diagrams illustrate the chronological flow of actions and messages for key scenarios, showing how the system components collaborate to achieve the intended operations.

- Registration process:** The Figure 4.8 illustrates the registration workflow for an unauthenticated user. The process begins when the user initiates registration, which triggers the client interface to start the registration procedure and confirm the initiation with the server. The client then renders the registration window where the user provides personal data. At this point, the server initiates an email verification by sending a code to the user's email account. The client displays this code input field, and the user submits the verification code to confirm the email. The server validates the code and returns a response, which the client displays as a status message. Once verified, the user submits the full registration data, and the server saves the request, confirms the creation, and the client interface updates the UI to reflect successful registration. This sequence diagram emphasizes the interaction between the user, client UI, server, and email service to ensure secure and validated registration.

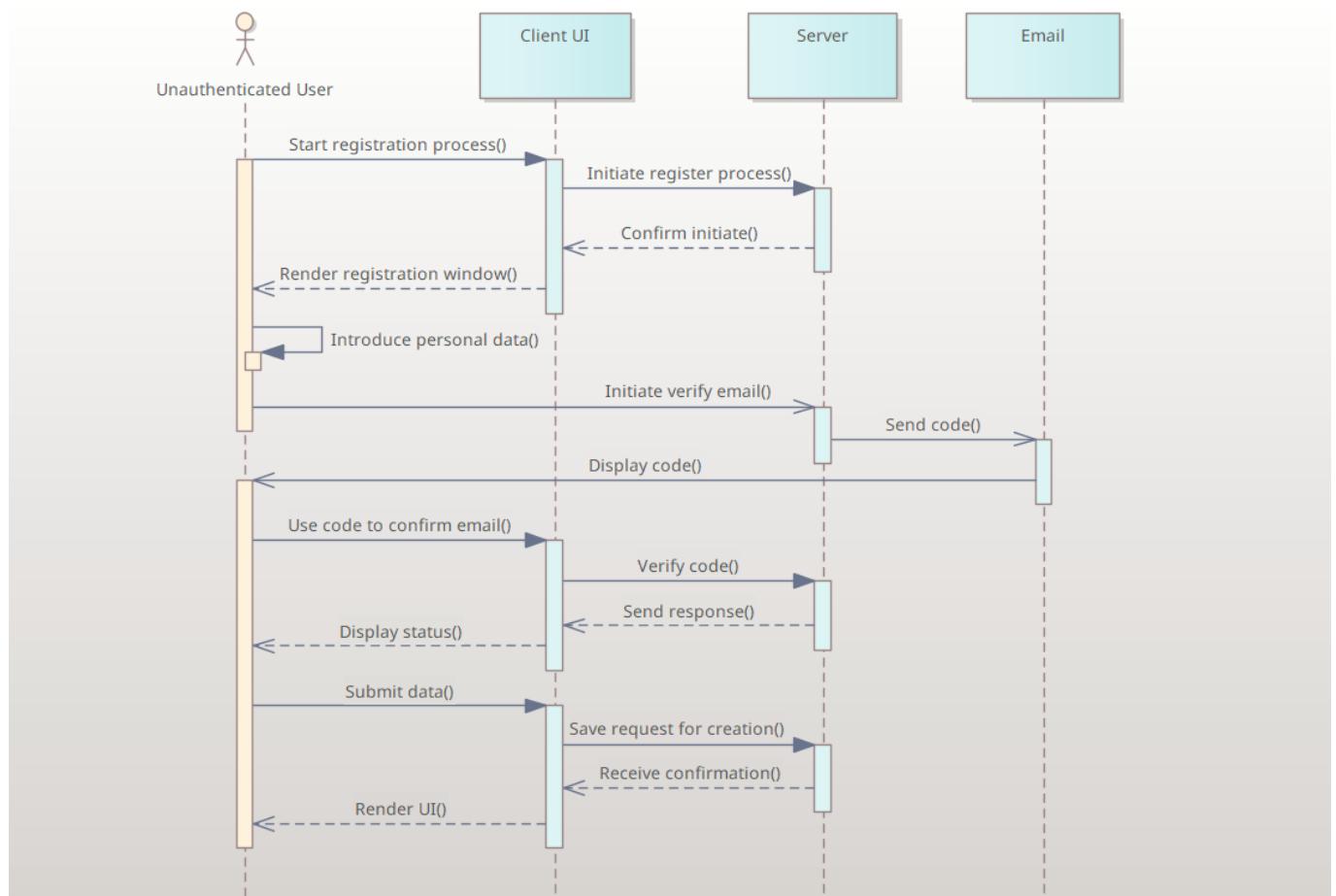


Figure 4.8 - UML Registration Sequence

- Document Creation:** The Figure 4.5 describes the process of document creation by an authorized user. The workflow starts when the user initiates the creation process through the client, which renders

the UI. The user uploads the document, provides the participants' IDs, and confirms the action. The client then sends a request for document creation to the server, which computes the hash of the file and checks the blockchain for existing records. If no duplicate is found, the server proceeds by distributing the document to all listed participants for approval. Once the approvals are collected, the server creates a new immutable record on the blockchain and confirms its creation. At the same time, a reference to the new document is stored in the database, linking it to the user's account. Finally, the confirmation is returned to the client, which updates the user interface with the new document's details. This sequence diagram highlights the coordinated interaction between client, server, blockchain, and database to ensure document integrity, approval, and traceability.

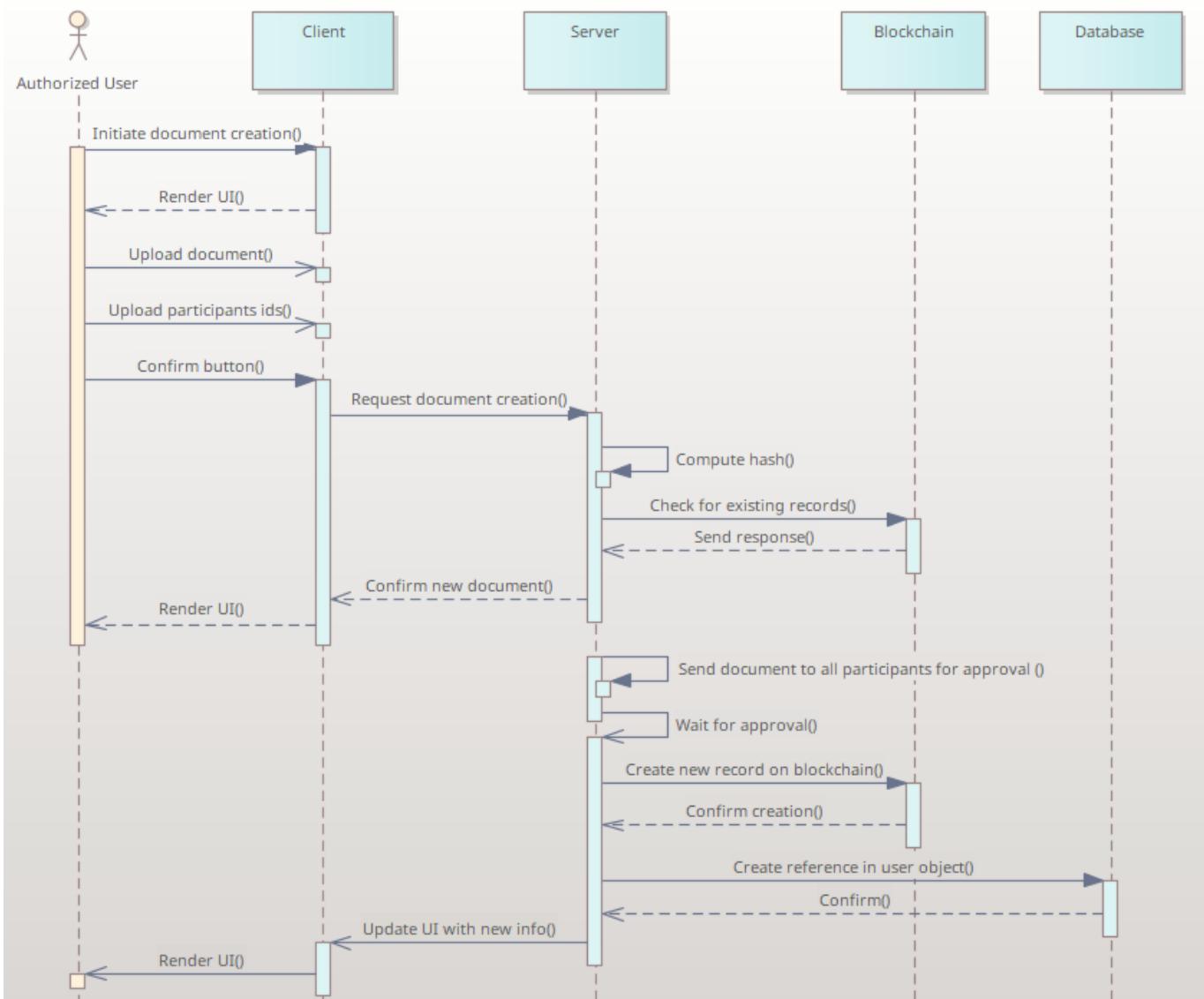


Figure 4.9 - UML Document Creation Sequence

3. Document Verification: The Figure 4.10 shows the workflow for document verification by an authorized user. The process begins when the user initiates the verification through the client interface,

which renders the UI. The user uploads the document and enters the participants' IDs before confirming the action. The client then sends a verification request to the server. The server computes a cryptographic hash of the uploaded file and queries the blockchain to check whether a matching record already exists. The blockchain responds with the result of the lookup, which the server forwards back to the client. Finally, the client displays the verification outcome to the user. This diagram highlights the critical interaction between user actions, system components, and blockchain infrastructure to ensure document authenticity and integrity.

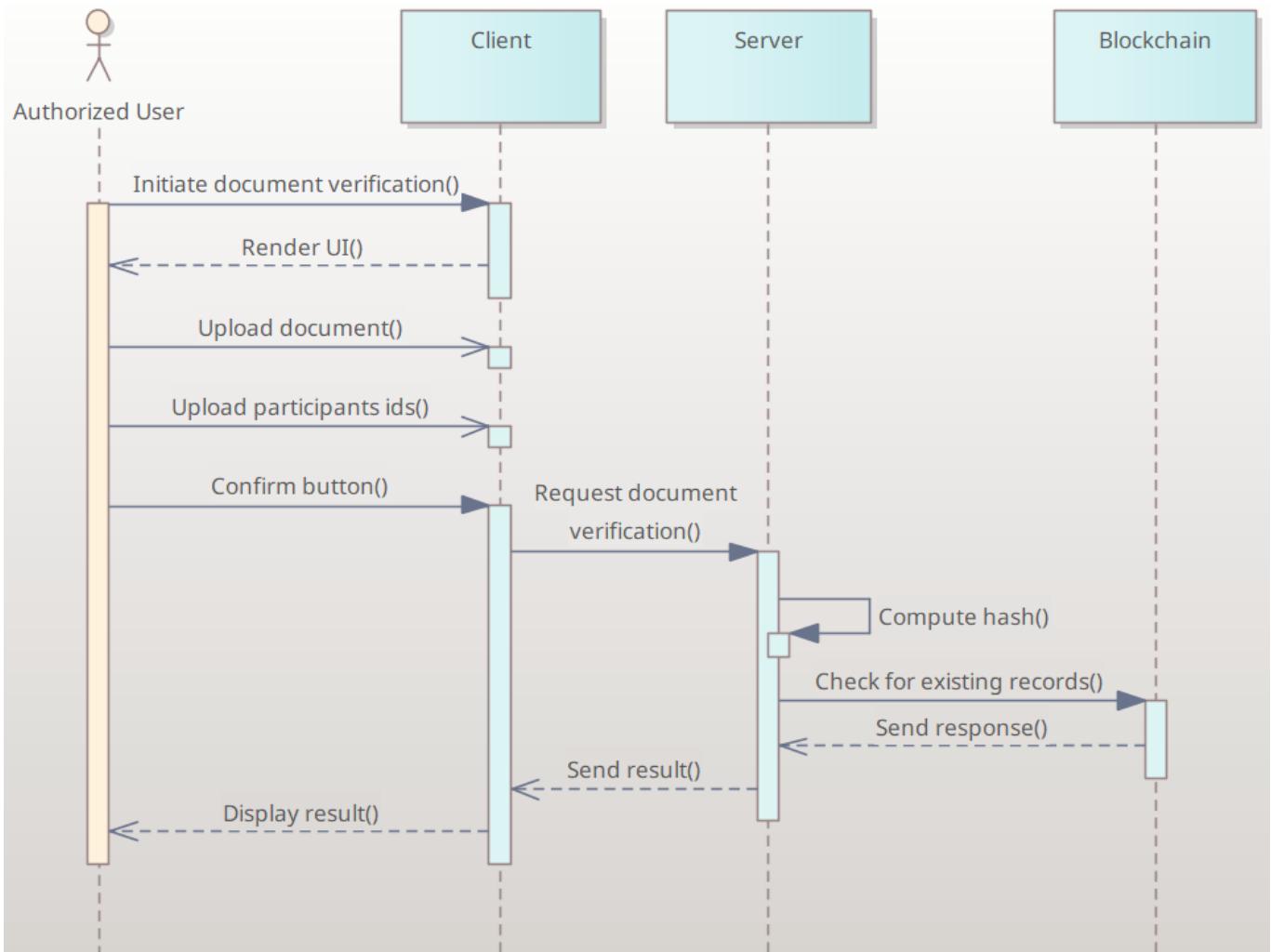


Figure 4.10 - UML Document Verification Sequence

4. Account Approval: The Figure 4.11 illustrates the user account approval process managed by the administrator. The flow begins when the administrator requests pending registration data for review, which the server provides to the admin panel. To validate the registration, the server queries the Identity Provider (IDP) for personal data associated with the submitted IDNP and returns the response. The administrator then compares the provided information against the IDP data. If the data is valid, the administrator approves the account creation. The server processes this approval by generating a new

user object in the database, after which a confirmation of account creation is returned to the administrator. This diagram highlights the administrator's critical role in ensuring user identity verification and the coordinated interaction between the server, identity provider, and database during registration approval.

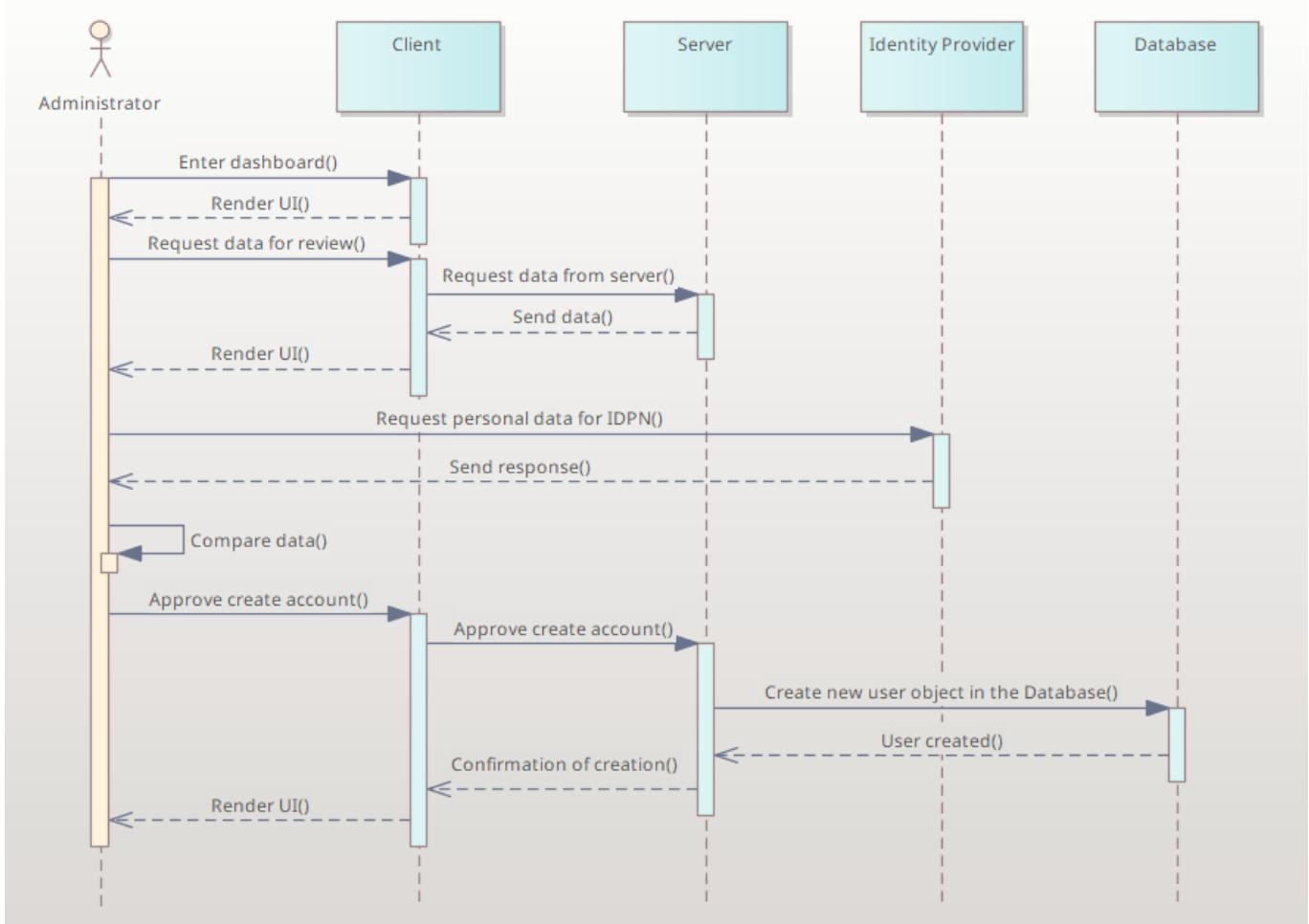


Figure 4.11 - UML Account Approval Sequence

4.3 Structural Modeling

This section presents the structural view of the system, focusing on the static aspects of its architecture. Structural modeling helps define the main components, their responsibilities, and the relationships between them.

4.3.1 Class Diagram

The Figure 4.12 models the core entities and relationships within the document notarization system. At the center is the User class, which contains attributes such as ID, full name, email, phone, status, role, and timestamps, alongside methods for document creation, signing, declining, and verification. Each user is assigned a Role, which defines permissions and enforces access control.

The Document class represents notarized files with properties like ID, title, owner, status, storage

reference, size, and creation details. Its methods manage the signing workflow, including adding participants, submitting for signing, and finalizing signatures. A document is linked to multiple Participants, each of whom has a role, status, and the ability to either sign or decline. These actions generate corresponding Signatures, which record details such as participant ID, signature type, reference, and timestamp.

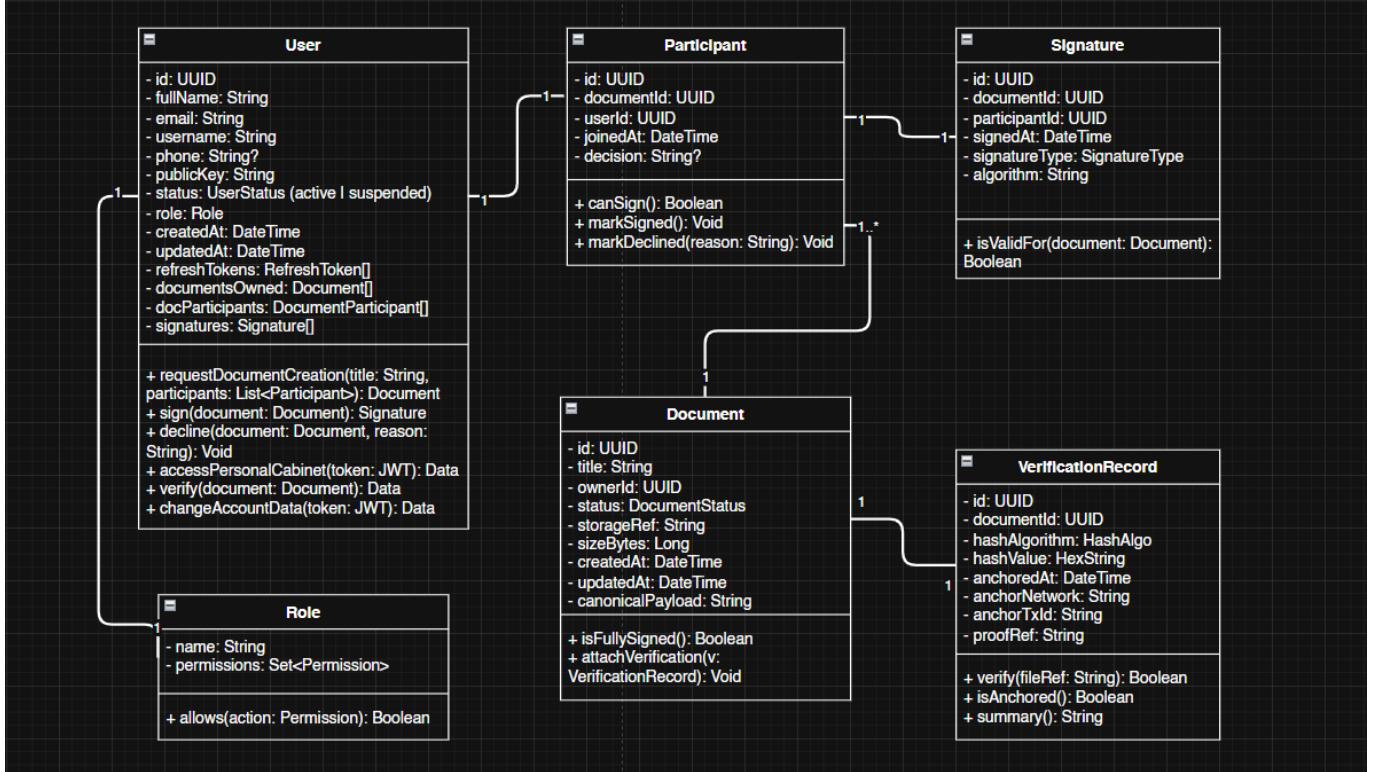


Figure 4.12 - UML Core Domain Class Model

Additionally, the system maintains VerificationRecords, which store blockchain-related data like hash values, algorithms, anchoring timestamps, and network references. These records provide functions to verify integrity, check anchoring, and generate summaries.

Altogether, this diagram highlights how users, roles, documents, participants, signatures, and verification records interact. It reflects a cohesive domain model where documents are securely managed, signed by multiple parties, and validated against blockchain anchors to ensure integrity and trustworthiness.

4.4 Figma User Interface Mockups

The landing page (Figure 4.13) is the first page seen by the user when entering the site, so it gives the user a clear description of the functionality the service provides.

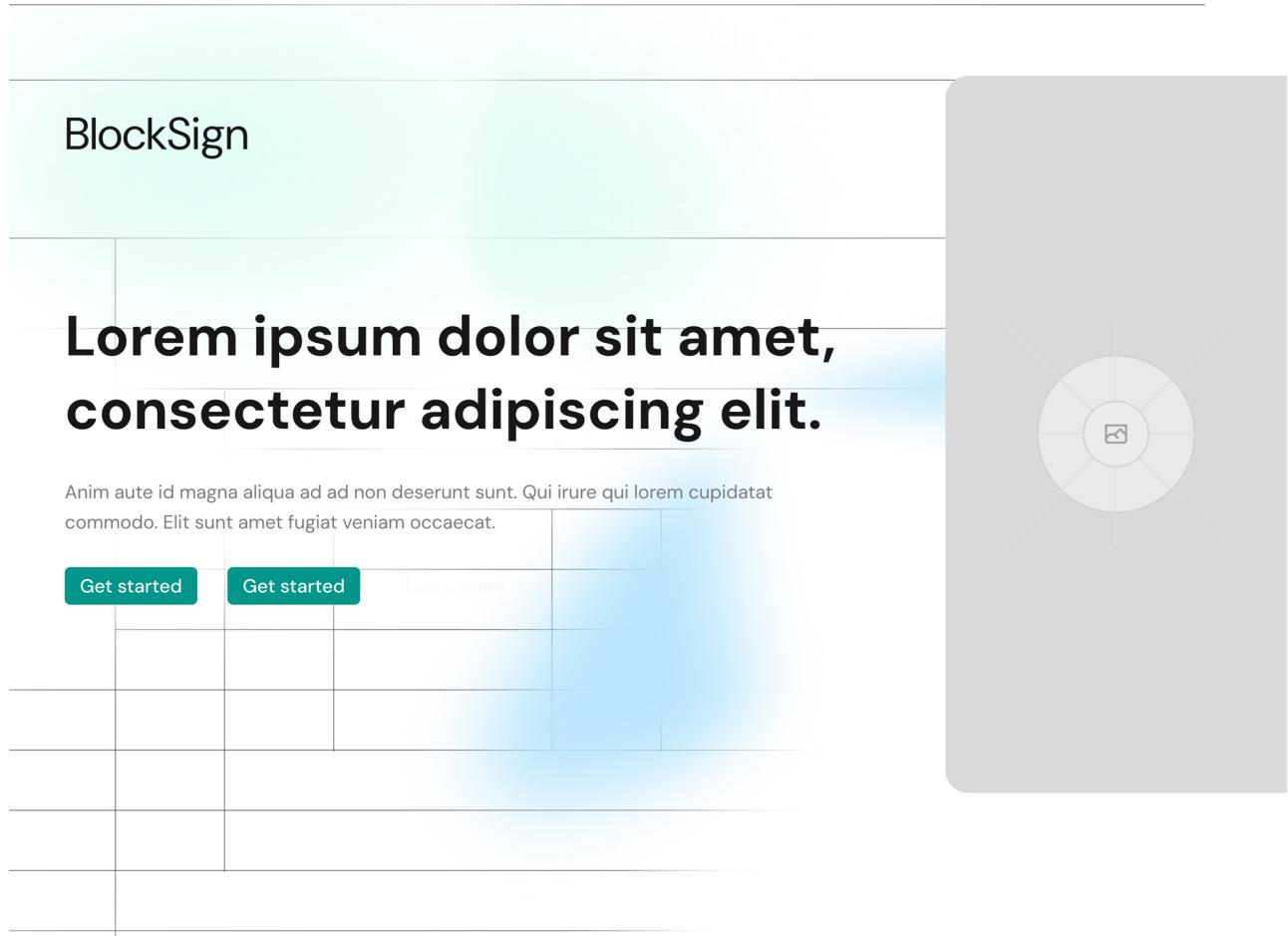


Figure 4.13 - Landing page

The login page (Figure 4.14) has the possibility of entering via email and password, as well as entering through existing accounts in services such as Google.

Log in to your design account

[!\[\]\(d57a1b197a027a7530b400fe9672ef3c_img.jpg\) Continue with Facebook](#)[!\[\]\(6757e27931db5677f6c2ef135ef81205_img.jpg\) Continue with Google](#)[!\[\]\(d199f757b38d3e8181a4276a315aabb8_img.jpg\) Continue with Apple](#)

OR

Email address

Your password
 

[Forgot your password?](#)

Keep me signed in until I sign out

Log in

Don't have an account?

Sign up

Figure 4.14 - Login page

The registration page (Figure 4.15) provides the user with the possibility to create an account in the service and lets the use of other services such as Google to provide the information needed to service.

Create an account

Already have an account? [Log in](#)

Full name

Email address

Phone number

Create a password
 weak
Use 8 or more characters with a mix of letters, numbers & symbols

Confirm password
 weak

By creating an account, you agree to the [Terms of use](#) and [Privacy Policy](#).

Sign up

OR Continue with

 Continue with Facebook

 Continue with Google

 Continue with Apple

Figure 4.15 - Register page - User info

The second step of registration (Figure 4.16) is a confirmation of the user's email.

The screenshot shows the 'Confirm email' step of the registration process. At the top, there is a navigation bar with the 'BlockSign' logo, a 'Register' button, and a 'Sign In' button. Below the navigation bar, the title 'Confirm email' is centered. A sub-instruction reads: 'To finish the first step registration write the code sent to email <email@example.com>'. Below this, there is a row of three sets of two empty boxes each, followed by a 'Confirm' button. The main content area contains the 'BlockSign' logo again, followed by four sections: 'Lorem ipsum dolor mego asdasdasdasdasdasdasd asdasdasdasdasdasd asdasdasd' (under 'About us'), 'Lorem ipsum' (under 'Information'), and 'Smth' (under 'Smth'). Below these sections is a 'Contact us' section with icons for email and phone.

Figure 4.16 - Register - Verifying the email

The third step of registration (Figure 4.17) is a confirmation of identity using sensitive personal data that is not stored or used after verification.

The screenshot shows the 'Confirm the identity' step of the registration process. The title 'Confirm the identity' is at the top. Below it are three input fields: 'IDNP' with the value '12366127364', 'Birth Date' with a date picker, and 'Selfie' with a file input field ('File name.file') and a 'Select file' button. A note below the selfie field states: 'Accepts only jpeg, jpg, png, pdf, bmp, svg'. At the bottom, a note says: 'The credentials are only used to verify the identity, then they are deleted'. A large green 'Confirm' button is at the bottom.

Figure 4.17 - Register - Confirming the identity

Then the user sees the successful finish (Figure 4.19) screen and is redirected to his account.

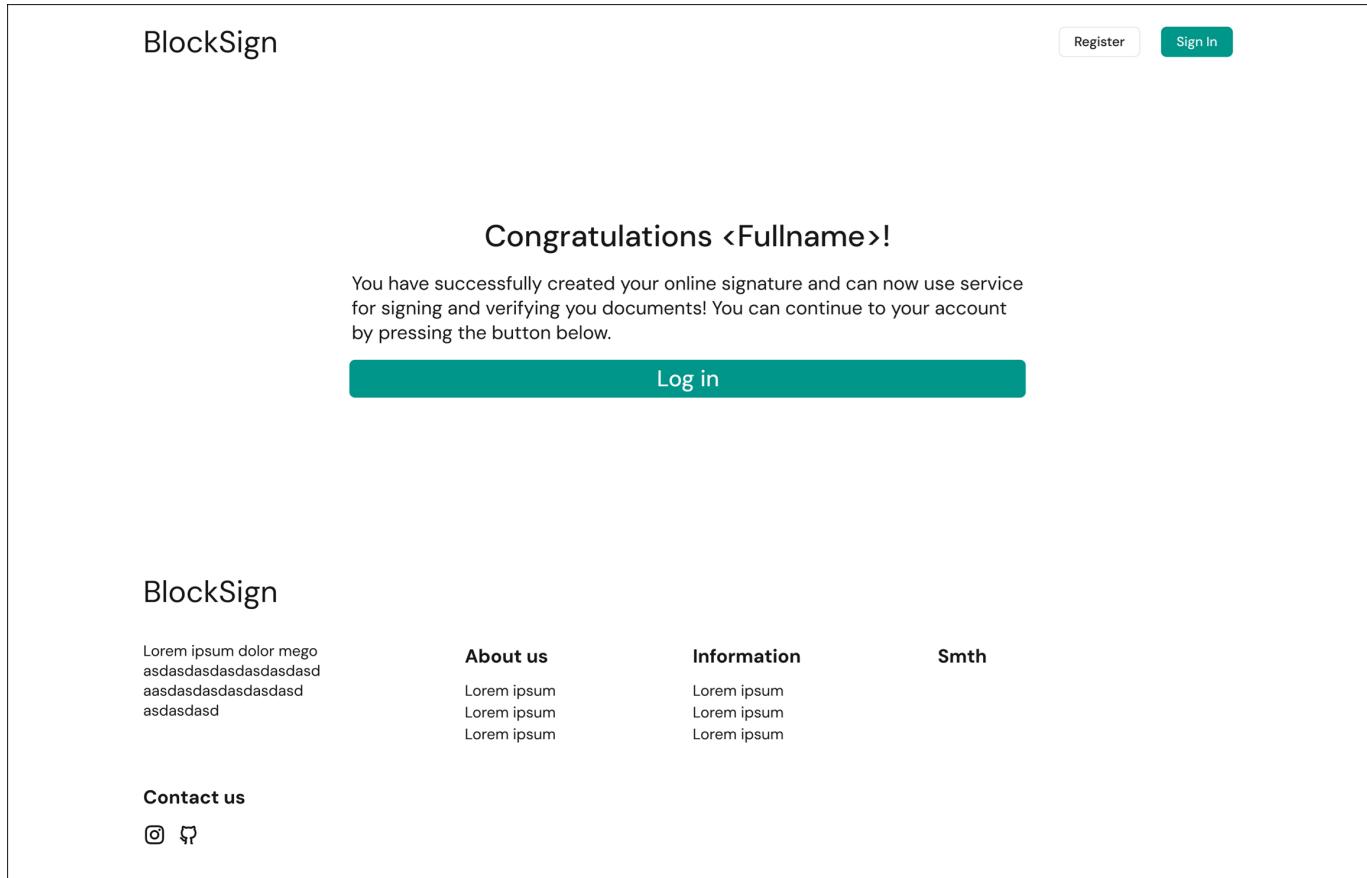


Figure 4.18 - Register - Successful finish

When authorized user gets access to the pages: documents(Figures 4.19, 4.22), account (Figures 4.23, 4.24, 4.25)

The documents page has 2 main functionalities - uploading (Figure 4.19) and creating a session of signing the document, and second - verifying (Figure 4.22) if the file with the given users was ever signed.

The screenshot shows a web interface for verifying a document. At the top, there are two buttons: 'Upload' (in a teal bar) and 'Verify'. Below these are two input fields for file upload, each with a dashed blue border and a small cloud icon. The first field contains the text 'Format: .pdf & Max file size: 100 MB'. A 'Browse files' button is located below the first field. Below the input fields is a section for adding collaborators. It includes two dropdown menus labeled 'Name of collaborator' and a red 'X' icon. A green button labeled '+ Add collaborator' is positioned between the dropdowns. At the bottom right is a teal 'Submit' button.

Figure 4.19 - Documents page - Verify an existing document

The results of verifying might be only exists (Figure 4.20) or does not exist (Figure 4.21).

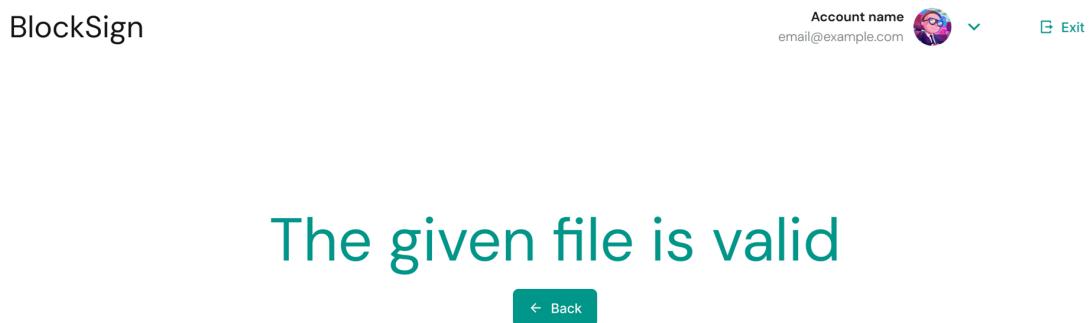


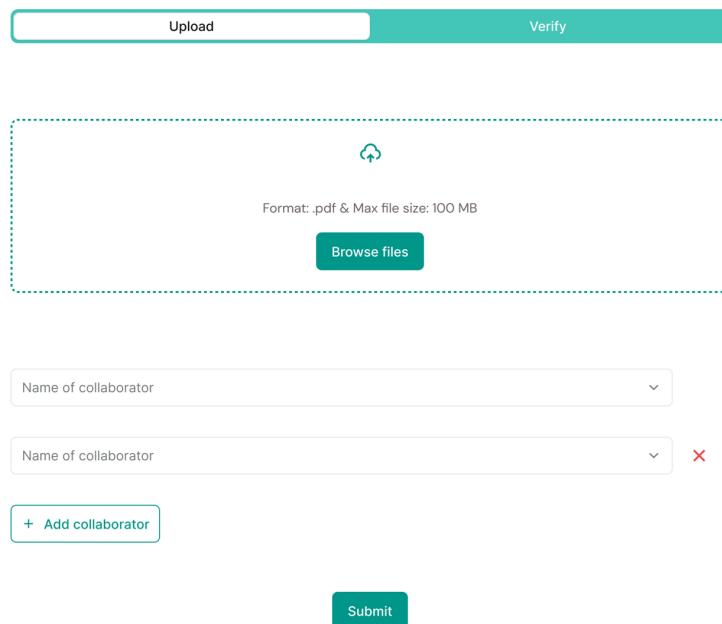
Figure 4.20 - Documents page - Existing instance of document

The document does not exist or you filled wrong information

 Back

Figure 4.21 - Documents page - Not existing instance of document

On the upload option (Figure 4.22) the session of the signing the document is created by adding the sides of the signing via account name/id.

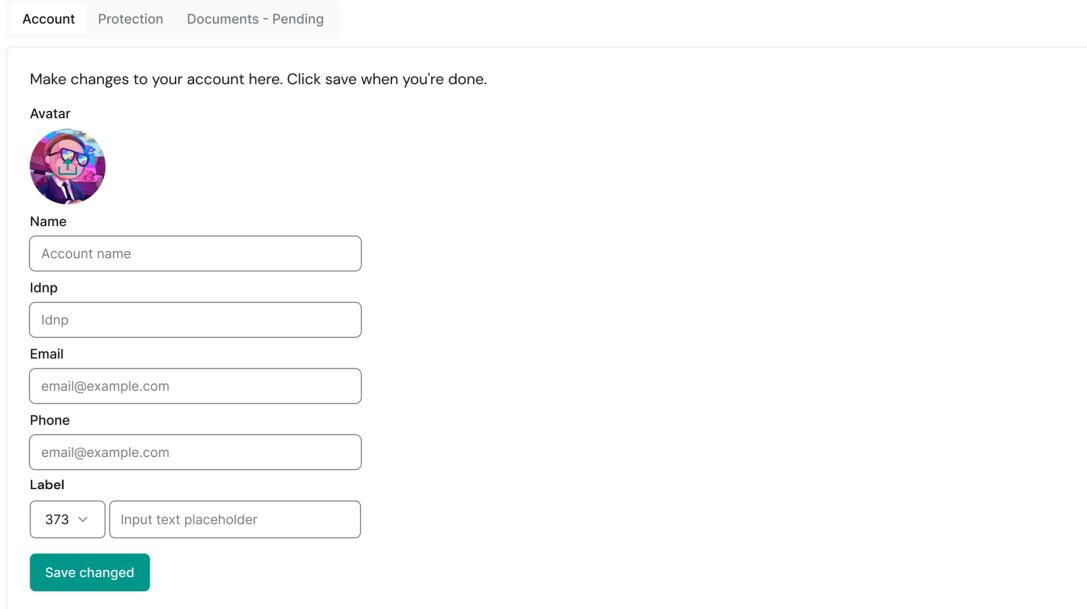


The screenshot shows the 'Documents' page of the BlockSign application. At the top, there are two buttons: 'Upload' on the left and 'Verify' on the right. Below these buttons is a large dashed rectangular area with a central cloud icon and the text 'Format: .pdf & Max file size: 100 MB'. A 'Browse files' button is located within this area. Below this section, there are two input fields for 'Name of collaborator', each with a dropdown arrow. The first field contains the text 'Name of collaborator'. The second field has a red 'X' icon to its right. At the bottom of the page is a 'Submit' button.

Figure 4.22 - Documents page - Upload and sign the document

The account page gives the ability to manipulate the user account(Figure 4.23) and protection(Figure 4.24) as well as view and sign the documents(Figure 4.25).

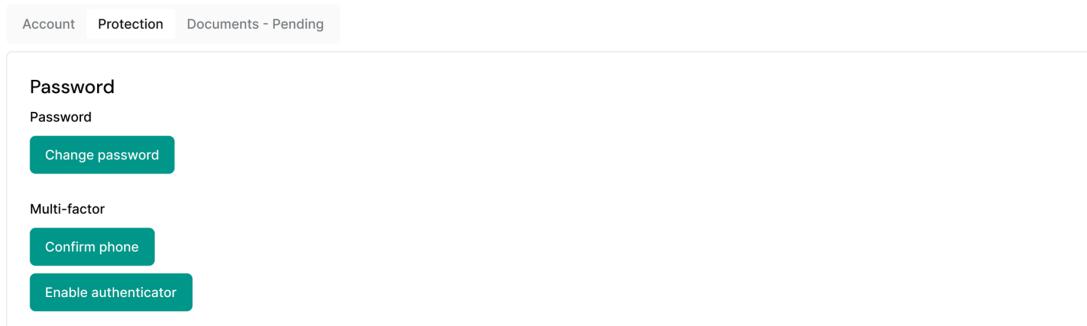
The account tab (Figure 4.23) has the customization of the previously introduced info.



The screenshot shows the 'Account' tab selected in the top navigation bar. Below it, a message says 'Make changes to your account here. Click save when you're done.' There are several input fields: 'Avatar' with a placeholder image, 'Name' with 'Account name' as the placeholder, 'Idnp' with 'Idnp' as the placeholder, 'Email' with 'email@example.com' as the placeholder, 'Phone' with 'email@example.com' as the placeholder, 'Label' with a dropdown menu showing '373' and a text input field 'Input text placeholder', and a 'Save changed' button at the bottom.

Figure 4.23 - Account page - Possibility to modify personal info

The protection tab (Figure 4.24) provides the possibility to change password and enable multi-factor authentication.



The screenshot shows the 'Protection' tab selected in the top navigation bar. It contains three main sections: 'Password' with a 'Change password' button, 'Multi-factor' with 'Confirm phone' and 'Enable authenticator' buttons, and a 'Documents - Pending' section which is currently empty.

Figure 4.24 - Account page - Possibility to modify the protection methods

The documents tab (Figure 4.25) gives the user list of the documents and pending.

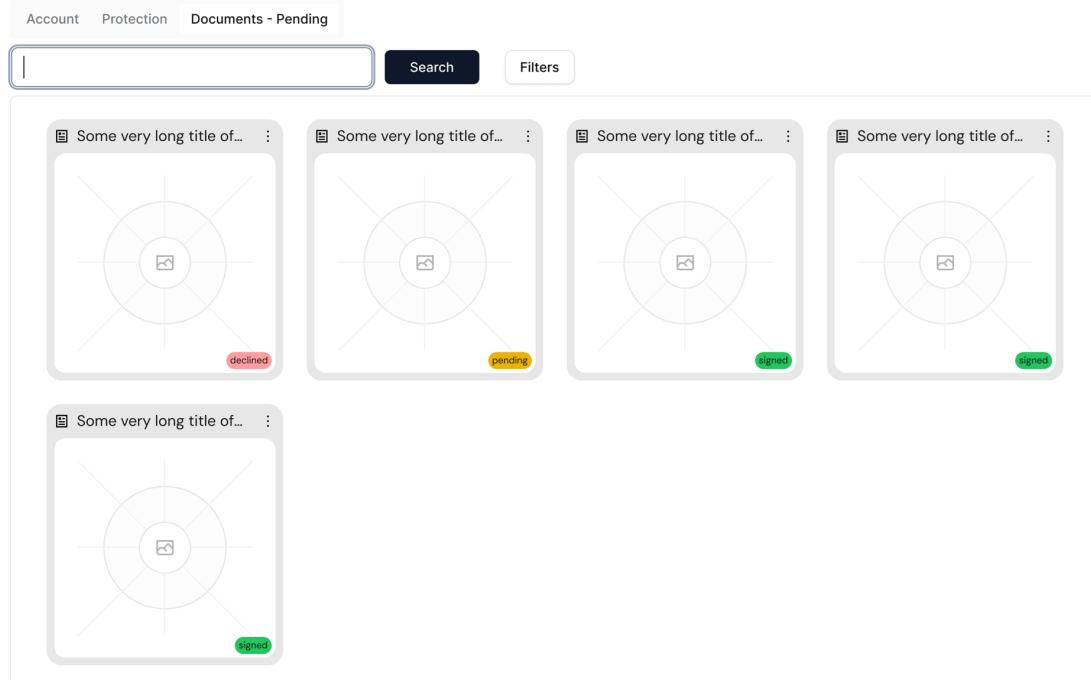


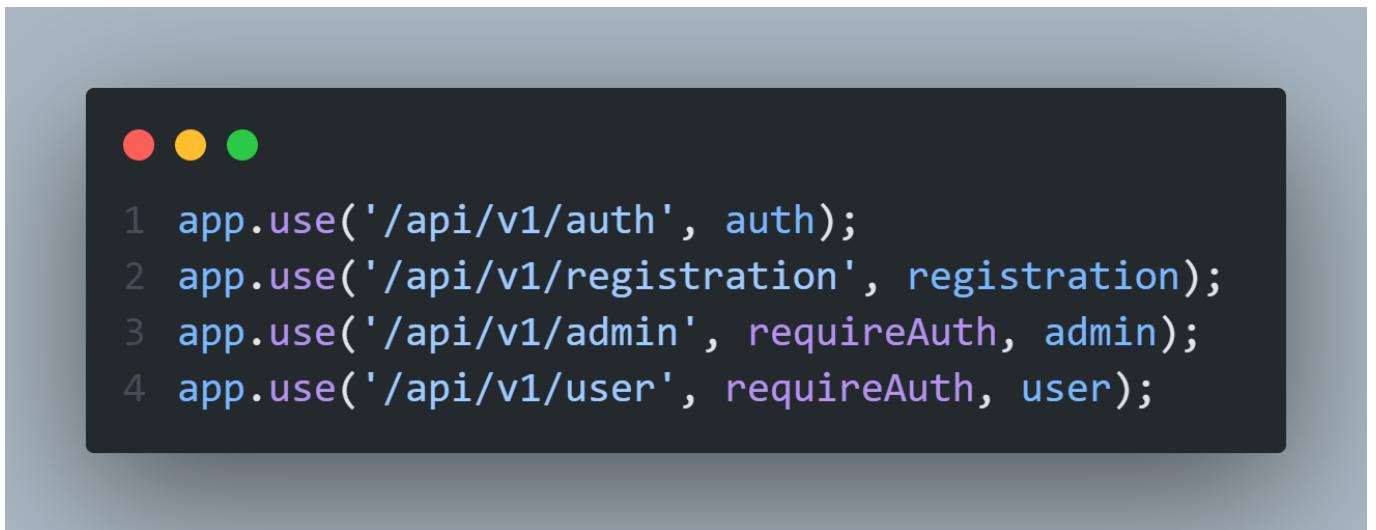
Figure 4.25 - Account page - View of the documents

5 Practical Implementation

The Project repositories are hosted on GitHub, are public and can be accessed by following these references: Back-end Core Logic[36] and Front-end User Interface[37].

5.1 Back-end architecture

The back-end of the system has been developed with a focus on scalability, modularity, and security. Its purpose is to provide all the critical functionality required for user registration, authentication, document management, and secure verification of signatures (Figure 5.1).



```
1 app.use('/api/v1/auth', auth);
2 app.use('/api/v1/registration', registration);
3 app.use('/api/v1/admin', requireAuth, admin);
4 app.use('/api/v1/user', requireAuth, user);
```

Figure 5.1 - Main Project Routers

The implementation relies on Node.js with the Express.js framework, while data persistence is handled by PostgreSQL through the Prisma ORM.

5.1.1 Application Layer

The server is structured around separate route modules, each of which is responsible for a specific part of the functionality. For example, the auth.routes.ts file manages the passwordless login process using challenge-response verification, while registration.routes.ts covers the steps of email OTP verification, registration requests, and account completion with a public key. The administrator's responsibilities, such as reviewing and approving registration requests, are implemented in admin.registration.routes.ts. Finally, user-oriented functionality, including profile management and document operations, is centralized in user.routes.ts. This modular design improves maintainability and makes it easier to extend the system in the future.

5.1.2 Database Layer

The database schema is implemented using Prisma ORM on top of PostgreSQL. Entities such as User, RegistrationRequest, Document, DocumentParticipant and Signature are modeled explicitly with for-

eign keys and unique constraints to guarantee consistency (Figure 5.2).



The screenshot shows a code editor window with a dark theme. At the top left are three colored circular icons: red, yellow, and green. The main content is a Prisma schema for a 'User' model. The code is as follows:

```
1 model User {
2   id          String      @id @default(uuid())
3   email       String      @unique
4   fullName    String
5   username    String      @unique
6   publicKeyEd25519 String?
7   keyCreatedAt DateTime?
8   phone       String?    @db.VarChar(32)
9   role        UserRole   @default(USER)
10  status      UserStatus @default(ACTIVE)
11  createdAt   DateTime   @default(now())
12  updatedAt   DateTime   @updatedAt
13
14  refreshTokens RefreshToken[]      @relation("UserRefreshTokens")
15  documentsOwned Document[]        @relation("UserDocumentsOwned")
16  docParticipants DocumentParticipant[] @relation("UserDocumentParticipants")
17  signatures    Signature[]       @relation("UserSignatures")
18
19  createdFromRequestId String?
20 }
```

Figure 5.2 - User Database Model

The use of Prisma Client enables type-safe queries and simplifies operations like migrations, seeding, and testing.

5.1.3 Security Measures

The architecture incorporates several security mechanisms. Authentication challenges are valid only for five minutes and become invalid once used. Refresh tokens are stored in secure cookies to reduce exposure. The use of Ed25519 ensures modern cryptographic security, while SHA-256 guarantees the integrity of documents. Finally, file validation ensures that only PDF documents are accepted.

5.1.4 Authentication and Tokens

Authentication in the system is fully passwordless and relies on public/private key pairs. Users prove their identity by signing challenges provided by the server. Successful verification grants them access tokens and refresh tokens in the form of JWTs.

Access tokens are short-lived and returned in the response body, while refresh tokens are long-lived and stored securely in HTTP-only cookies. Middleware functions such as requireUser and requireAdmin check the validity of tokens and enforce role-based access control.

5.1.5 Email Service

The system integrates Nodemailer as an email delivery mechanism configured with SMTP credentials for the project's domain. Emails are used in two important contexts. First, during registration, users receive a six-digit OTP code for email validation. Second, during document workflows, participants receive notifications when they are asked to review and sign a document, and again when the document has been finalized (Figure 5.3).

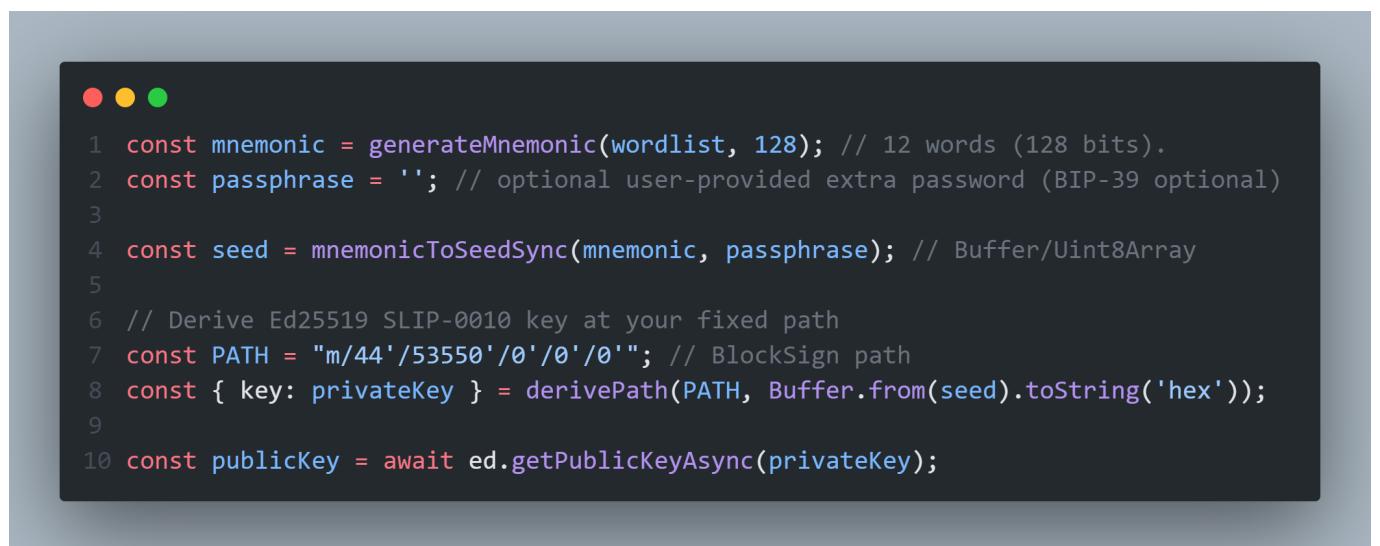


```
● ● ●
1 await sendEmail(recipients.join(','), 
2   `Document to review & sign: ${doc.title}`,
3   `<p>You have a new document to review and sign: <b>${doc.title}</b>.</p>
4   <p>Verify its SHA-256 hash matches the payload shown in the app before signing.</p>`,
5   { attachments: [{ filename: `${doc.title}.pdf`, content: req.file.buffer, contentType: 'application/pdf' }] }
6 );
```

Figure 5.3 - Email Sending Mechanism

5.1.6 Cryptographic Module

Security of authentication and documents is achieved with the Ed25519 digital signature scheme, implemented via the @noble/ed25519 library (Figure 5.4).



```
● ● ●
1 const mnemonic = generateMnemonic(wordlist, 128); // 12 words (128 bits).
2 const passphrase = ''; // optional user-provided extra password (BIP-39 optional)
3
4 const seed = mnemonicToSeedSync(mnemonic, passphrase); // Buffer/Uint8Array
5
6 // Derive Ed25519 SLIP-0010 key at your fixed path
7 const PATH = "m/44'/53550'/0'/0'/0'"; // BlockSign path
8 const { key: privateKey } = derivePath(PATH, Buffer.from(seed).toString('hex'));
9
10 const publicKey = await ed.getPublicKeyAsync(privateKey);
```

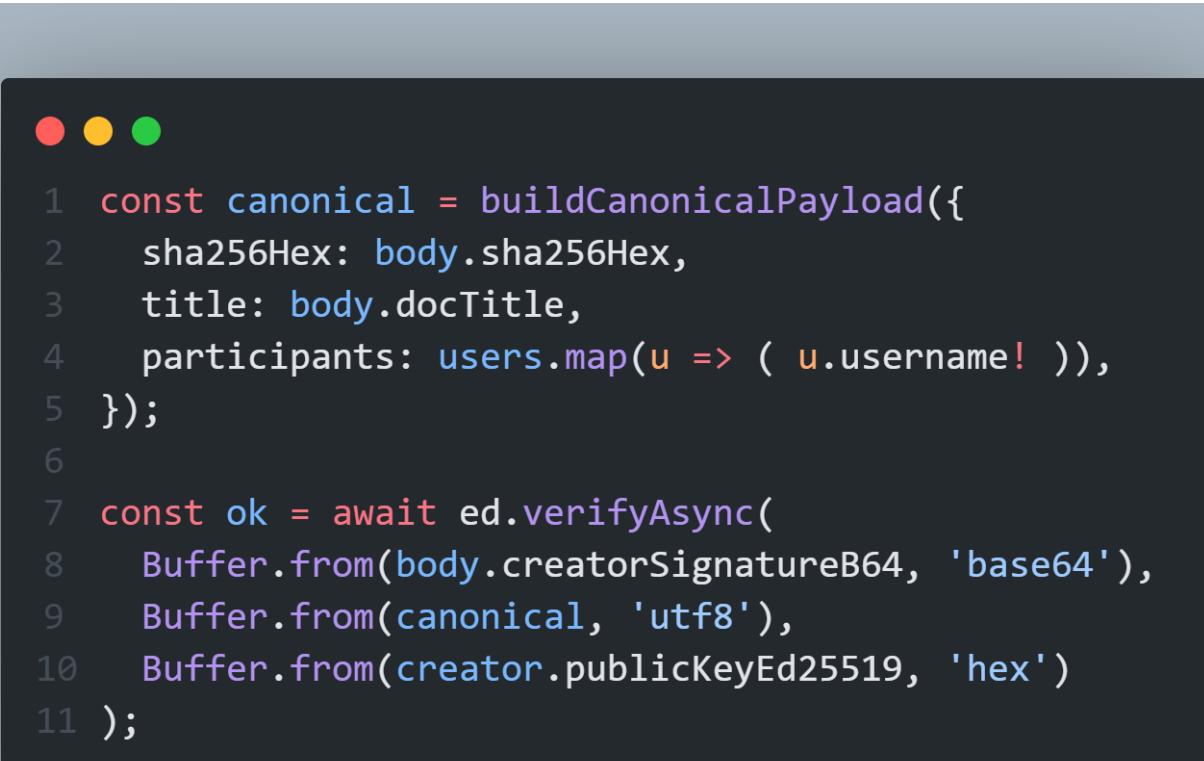
Figure 5.4 - Key Pairs Generation Mechanism

A dedicated crypto utility handles key pair generation, signing, and verification of messages. In addition, SHA-256 is used for hashing documents, ensuring their integrity before they are accepted or signed.

5.1.7 Document Workflow

The MVP implementation of the document signing process follows a well-defined lifecycle. When a user creates a document, they upload the file, calculate its SHA-256 hash, and sign a canonical payload. The payload and initial signature are stored in the database.

Participants selected by the creator receive an email with the PDF attached and the corresponding hash. Each participant is expected to calculate the hash independently, compare it with the payload, and if it matches, sign the document (Figure 5.5).



```
1 const canonical = buildCanonicalPayload({
2   sha256Hex: body.sha256Hex,
3   title: body.docTitle,
4   participants: users.map(u => ( u.username! )),
5 });
6
7 const ok = await ed.verifyAsync(
8   Buffer.from(body.creatorSignatureB64, 'base64'),
9   Buffer.from(canonical, 'utf8'),
10  Buffer.from(creator.publicKeyEd25519, 'hex')
11 );
```

Figure 5.5 - Build Paylaod and Verify Signature

Their signatures are then added to the database. Once all required signatures are collected, the document status changes to signed, and a notification is sent to all involved parties.

5.1.8 Extensibility

The modular design of the back-end makes it adaptable to future improvements. Currently, documents are distributed as email attachments, but the system is ready for integration with external storage providers such as AWS S3. The ChainAnchor entity in the future versions of database will anticipate the anchoring of finalized document hashes on blockchain networks. Similarly, while usernames are currently used to tag participants, the design leaves room for later integration with decentralized identity systems.

5.2 Front-end UI

Aa

CONCLUSIONS

The work carried out in this project demonstrates that secure, scalable, and verifiable document management can be achieved through the careful integration of modern cryptographic techniques, structured workflows, and practical user interfaces. By replacing traditional password-based authentication with Ed25519 key pairs and challenge-response mechanisms, the system eliminates a major vulnerability of centralized platforms while improving usability and security.

The design of the registration process, supported by email-based verification and administrative approval, ensures that only legitimate users gain access to the platform. At the same time, the introduction of digital signatures over canonical payloads provides a strong guarantee of document integrity and participant accountability. Each document is uniquely identified by its cryptographic hash, which allows all stakeholders to independently verify its authenticity.

From a functional perspective, the project delivers the core features of a minimum viable product (MVP): user registration, authentication, document creation, participant tagging, and the collection of signatures. Notifications via email strengthen the user experience by ensuring that participants remain informed throughout the signing process. Once all participants have provided their signatures, the system automatically transitions the document to a signed state, establishing a clear and auditable completion of the workflow.

The results confirm the feasibility of using lightweight cryptographic libraries and structured database schemas to implement secure document workflows without excessive infrastructure requirements. While the current MVP uses email for distribution of documents and notifications, the architecture is prepared for future integration with decentralized storage systems or blockchain anchoring, which would provide long-term transparency and persistence.

In conclusion, this project achieves its primary objective of creating a secure system for passwordless user authentication and document signing. It demonstrates the viability of combining cryptographic security with practical user workflows, and it establishes a foundation for further research and development. Future improvements may include integration with external identity providers, support for blockchain-based anchoring, advanced role-based permissions, and the addition of seed-phrase-based account recovery mechanisms on the client side. These directions would enhance resilience, usability, and trust in the system, preparing it for deployment in real-world organizational contexts.

BIBLIOGRAPHY

- [1] INTERPOL, *Identity and travel document fraud*. [Online]. Available: <https://www.interpol.int/en/Crimes/Counterfeit-currency-and-security-documents/Identity-and-travel-document-fraud>
- [2] U.S. Customs and Border Protection, *Cincinnati CBP intercepts thousands of fraudulent and counterfeit documents during FY2023*. [Online]. Available: <https://www.cbp.gov/newsroom/local-media-release/cincinnati-cbp-intercepts-thousands-fraudulent-and-counterfeit>
- [3] International Council on Archives, *Emergency management and disaster preparedness: A manual for protecting archives* (2024). [Online]. Available: https://www.ica.org/app/uploads/2024/10/Emergency-Management-and-Disaster-Preparedness-Manual_FINAL_VERSION_PDFA.pdf?utm_source=chatgpt.com
- [4] Geoengineer.org, *Cologne archive collapse: How a 0.6m void led to germany's costliest construction failure* (2025). [Online]. Available: <https://www.geoengineer.org/news/cologne-archive-collapse-how-a-06m-void-led-to-germanys-costliest-construction-failure>
- [5] Verizon, *2024 data breach investigations report (DBIR)*. [Online]. Available: <https://www.verizon.com/business/resources/reports/2024-dbir-data-breach-investigations-report.pdf>
- [6] IBM, *Cost of a data breach 2025 (live report page)*. [Online]. Available: <https://www.ibm.com/reports/data-breach>
- [7] IBM, *Cost of a data breach 2024*. [Online]. Available: <https://www.ibm.com/think/insights/cost-of-a-data-breach-2024-financial-industry>
- [8] Reuters — FBI, *Complaints about ransomware attacks on u.s. infrastructure rose 9% in 2024*. [Online]. Available: <https://www.reuters.com/world/us/complaints-about-ransomware-attacks-us-infrastructure-rise-9-fbi-says-2025-04-23/>
- [9] WIRED, *DigiNotar files for bankruptcy in wake of devastating hack*. [Online]. Available: <https://www.wired.com/2011/09/diginotar-bankruptcy/>
- [10] HIPAA Journal, *Verizon 2024 DBIR: 70% of healthcare breaches involved internal actors (sector-specific summary)*. [Online]. Available: <https://www.hipaajournal.com/verizon-2024-data-breach-investigations-report/>
- [11] EUR-Lex, *GDPR (regulation (EU) 2016/679) official text*. [Online]. Available: <https://eur-lex.europa.eu/eli/reg/2016/679/oj/eng>

- [12] EUR-Lex, *eIDAS (regulation (EU) no 910/2014) consolidated*. [Online]. Available: <https://eur-lex.europa.eu/eli/reg/2014/910/2024-10-18/eng>
- [13] OWASP, *Top 10 (2021)*. [Online]. Available: <https://owasp.org/Top10/>
- [14] OWASP, *A01: Broken access control (2021)*. [Online]. Available: https://owasp.org/Top10/A01_2021-Broken_Access_Control/
- [15] World Economic Forum, *Global risks report 2023*. [Online]. Available: <https://www.weforum.org/publications/global-risks-report-2023>
- [16] UNESCO, *Credentials fraud now a global threat for universities*. [Online]. Available: <https://etico.iiep.unesco.org/en/credentials-fraud-now-global-threat-universities>
- [17] European Comission, *Digital transformation of SMEs*. [Online]. Available: https://commission.europa.eu/projects/digital-transformation-smes_en
- [18] European Comission, *eIDAS regulation*. [Online]. Available: <https://digital-strategy.ec.europa.eu/en/policies/eidas-regulation>
- [19] NCFA Canada, *The future of remote online notarization: Advancements in security and efficiency*. [Online]. Available: <https://ncfacanada.org/the-future-of-remote-online-notarization-advancements-in-security-and-efficiency>
- [20] ACCENTURE, *State of cybersecurity resilience 2023*. [Online]. Available: <https://www.accenture.com/us-en/insights/security/state-cybersecurity>
- [21] Kadir Canoz, *Use of electronic medical records in the digital healthcare system and its role in communication and medical information sharing among healthcare professionals*. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S2352914823002198>
- [22] Grand View Horizon, *Global digital signature market size & outlook, 2024-2030*. [Online]. Available: <https://www.grandviewresearch.com/horizon/outlook/digital-signature-market-size/global>
- [23] Acumen, *Digital signature market size growing at 35.4% CAGR*. [Online]. Available: <https://www.globenewswire.com/news-release/2023/01/30/2598004/0/en/Digital-Signature-Market-Size-Growing-at-35-4-CAGR-Set-to-Reach-USD-48-4-Billion-by-2030.html>
- [24] Electro IQ, *E-signature and digital document statistics*. [Online]. Available: <https://electroiq.com/stats/e-signature-and-digital-document-statistics>
- [25] DoxyChain, *The power of blockchain notarization*. [Online]. Available: <https://www.doxychain.com/blog/the-power-of-blockchain-notarization-securing-digital-assets-against-deepfakes-and-fraud>
- [26] Deeksha Uikey, *A blockchain-based digital notary system provides reliable and tamper-proof times-tamping and verification services for digital documents: A review*. [Online]. Available: <https://>

- pdfs.semanticscholar.org/c1d0/ee0aa761ba214d5c4c899147aab358eace25.pdf] [<https://powerpatent.com/blog/blockchain-for-document-verification-and-notarization>
- [27] Tejas Chandrakant Mhapankar, *Future trends in blockchain-based notarization: From proof of existence to full document validation*. [Online]. Available: <https://harbinengineeringjournal.com/index.php/journal/article/download/4322/2423/6793>
- [28] Domenico Tortola, *Scalable data notarization leveraging hybrid DLTs*. [Online]. Available: <https://arxiv.org/abs/2501.04571>
- [29] SutiSoft, *Role of multi-factor authentication in eSignatures for advanced security*. [Online]. Available: <https://www.sutisoft.com/blog/esignature-multifactor-authentication-security/>
- [30] PingIdentity, *Eight benefits of multi-factor authentication (MFA)*. [Online]. Available: <https://www.pingidentity.com/en/resources/blog/post/eight-benefits-mfa.html>
- [31] Uplevel Systems, *Top 10 benefits of implementing multi-factor authentication (MFA) for small businesses*. [Online]. Available: <https://www.uplevelsystems.com/blog/top-10-benefits-of-implementing-mfa-for-small-businesses>
- [32] ProNotary, *How law firms are using remote online notarization to increase client satisfaction*. [Online]. Available: <https://pronotary.com/blog/how-law-firms-are-using-remote-online-notarization-to-increase-client-satisfaction>
- [33] Wikipedia, *ENotary*. [Online]. Available: <https://en.wikipedia.org/wiki/ENotary>
- [34] Wikipedia, *Notario (firm)*. [Online]. Available: [https://en.wikipedia.org/wiki/Notario_\(firm\)](https://en.wikipedia.org/wiki/Notario_(firm))
- [35] Wikipedia, *Privacy and blockchain*. [Online]. Available: https://en.wikipedia.org/wiki/Privacy_and_blockchain
- [36] Alexei Pavlovschii, *Blocksign server*. [Online]. Available: <https://github.com/AlexDandy77/BlockSign-Server>
- [37] Vladimir Vitcovschii, *Blocksign front-end*. [Online]. Available: <https://github.com/NeValetik/BlockSign-FrontEnd>