**Research Project**
**FAPESP**

# Digital Identities: Customization of Open Source Wallets


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|---|---|
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| **Execution time:** | 24 months |



**Abstract**: Identity wallets are an emerging interface for the new systems based on self-sovereignty identity. However, implementing it poses several challenges, including complexity, security, and conformance to industry standards. This project aims to evaluate wallet initiatives and provide customizable open-source mobile wallets for simple use cases. In addition, the Brazilian market's characteristics will be taken into consideration. All results will be made open.



**Keywords: wallets, identity, security, Self-Sovereignty Identity (SSI), blockchain.**


São José dos Campos-SP, Brazil. January 2023

# 1 Problem overview

Identity is an open problem for society. According to the World Bank [1], one billion people face challenges in proving who they are, struggling with essential services and even having a mobile phone. The problem gets even more critical with the Internet because identity fraud is one of the most common security attacks [2].

Digital identity management has evolved from different models. The first and most prevalent is the centralized model [3], where only one service provider creates, authenticates, and authorizes the identities and the permissions it has (e.g., using login and password). The second is the federated model, in which several third-party identity providers intermediate the identity management (e.g., using OAuth2) [4]. The third one is the user-centric model, where the user owns and manages its own identities (e.g., using OpenID Connect) but still depends on a centralized entity to verify its credentials [*ibid.*]. The last model is the self-sovereign model, in which the user-centric model is extended to use a decentralized verifier, creating user autonomy and user-centered applications.

**Self-Sovereign Identity (SSI)** [5] is a new technology where the individual has full control over their personal data; he can easily share it with others. In traditional digital identity models, the data is often controlled by centralized entities such as governments or corporations, and there are often restrictions on how the data can be shared and used. Self-sovereign identity allows individuals to control their own personal data and share it with others as they see fit, enabling more control and privacy over their online identity.

In the context of SSI, **Verifiable Credentials (VCs)** [6] play a crucial role, it is the container of units of information. VCs allow individuals to prove their identity and attributes, such as age, qualifications, or membership in a group, without needing a centralized authority. This is achieved by issuing VCs from a trusted **issuer**, such as a government agency or educational institution, and then allowing individuals (**holders**) to present these VCs to **verifiers** when needed. The verifiers can use the digital signature on the VC to verify the authenticity of the claims. Figure 1 illustrates the SSI model and the relations among the three main actors: holder, issuer, and verifier [7]; their roles are:

- **Issuer:** an entity that asserts something about a subject, issuing a verifiable credential and transmitting it to a holder (usually the subject itself).
- **Holder or User:** an entity that possesses verifiable credentials and use them to create a verifiable presentation to prove an assertion;
- **Verifier:** an entity that validates the assertions made by the issuer by validating the verifiable credentials presented by the holder.

Examples of applications of verifiable credentials include digital employee identification

cards, digital birth certificates, and digital educational certificates (diploma). Every physical credential could be represented as a Verifiable Credential.

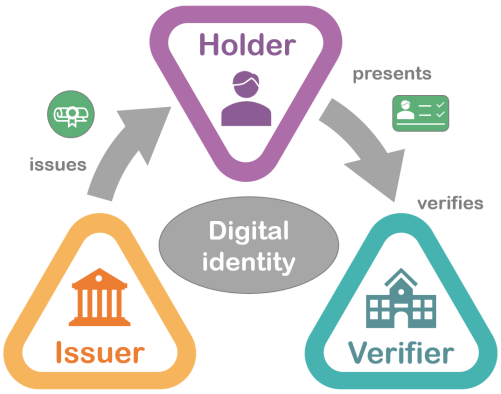


Figure 1: Self-Sovereign Identity (SSI) model [8]

It is difficult to predict how SSI and VCs usage will evolve. However, digital wallets will likely become more common as an interface to SSI-based services. But what is a digital wallet?

Nowadays, the most common type of digital wallet is used to transfer cryptocurrencies; for example, we can use Metamask[1] to transfer Bitcoins (BTC) or Ethers (ETH). In this research, we refer to **Digital Identity Wallets**, that are used as containers to VCs. For example, we can use a Google Wallet[2], a Microsoft Entra[3] or a Trinsic[4] wallet to present our driver's licence. In this text, for sake of simplicity, we will refer to Digital Identity Wallets simply as **Wallets**.

There are several reasons to investigate wallets. It is a ~~relatively~~ new technology, and as such, there is much room for scientific research to be conducted to better understand their usage, benefits, and potential drawbacks in society. It requires a multidisciplinary approach involving experts in **blockchain [9][5], cryptography, user experience, and privacy law. From the computer science perspective, the challenges are scalability, interoperability with legacy systems, security and privacy, usability, and compliance** with SSI standards [10].

This research project shows that new tools and methods are necessary for the fast development and deployment of wallets. To show this, we evaluate the ~~market~~ motivation and ongoing initiatives; we show that open-source solutions are still incomplete and immature.

[1] https://metamask.io
[2] thttps://wallet.google
[3] https://www.microsoft.com/en-us/security/business/microsoft-entra
[4] https://trinsic.id
[5] In fact, it is possible to create SSI solutions without blockchain technology. However, blockchain is a perfect tool to create verifiable identities and credentials. In general, it is used to create a reliable and verifiable repository for Decentralized Identities (DIDs), Credentials, Presentations and Data Schemes.

## 1.1 Motivation

The current Internet users have more vigorous digital habits than previous users. The use of wallets can enhance security, privacy and trust in online interactions by providing verifiable information. This can positively impact e-commerce and financial services.

Nowadays, several companies and governments plan to launch SSI-based systems and services. Some noteworthy large-scale examples are: European Blockchain Services Infrastructure (EBSI[6]), trust services for eIDAS[7], financial market[8], and IATA Travel Pass[9].

We can also cite the integration of Central Banks Digital Currencies (CBDCs[10]) and wallets as a pillar for the future economy and the programmable money [11].

It is reasonable to suppose that the adoption of SSI will continue to grow; in this scenario, more organizations will likely adopt VCs to provide their users with more control over their data, improving security and privacy, and increasing the interoperability and usability of the system.

Therefore, we can expect that wallets will be the "new browser" in the next years. The companies will probably offer wallets services for their clients. In addition, new wallet-based services will be created, such as education, health, and circular economy wallets.

We can predict that a few global suppliers (Microsoft, Apple, Google, etc.) will dominate the **multipurpose** wallet market. But the SSI solutions will require developing one-use-case solutions, integration, and customization. For example, an union has the capability to issue verifiable credentials as proof of a member's eligibility for discounts. Likewise, a residential condominium can leverage verifiable credentials to grant residents access to the building securely. In another scenario, a gym can establish a verifiable credential system to manage student attendance efficiently. These examples illustrate the diverse range of wallet applications that small and medium-sized businesses can explore. Most examples require wallet customization.

Thus, this research project aims to allow the fast development and deployment of wallets, preparing society for the ~~next wave of~~ innovation based on digital identities, trusted services, and programmable money. In the long term, Brazilian society would benefit from starting to develop wallets while their markets are still growing and under development.

[6] https://ec.europa.eu/digital-building-blocks/wikis/display/EBSI/Home

[7] https://digital-strategy.ec.europa.eu/en/policies/eidas-regulation

[8] https://www.evernym.com/blog/evernym-accepted-into-fca-regulatory-sandbox/

[9] https://www.iata.org/en/pressroom/pressroom-archive/2020-press-releases/2020-12-16-01/

[10] It is worth highlighting the recent launch of the base for digital version of Real (R$), called DREX (https://www.bcb.gov.br/estabilidadefinanceira/drex). This proposal is in line with the Central Bank's initiative.

## 1.2 Problem statement

Society has new digital habits and new decentralized and user-centric services are available (EBSI, eIDAS2, CBDCs, etc.). Wallets will be the primary method of interaction between users and these future systems. However, the available wallets are at an early stage of maturity and are not fully open. This research project aims to mitigate this gap, by investigating and integrating open-source initiatives. ~~For the sake of simplicity, we focus on simple use cases rather than trying to develop multipurpose wallets.~~

## 1.3 Objectives

The general objective of this research project is to **facilitate the development process of digital wallets**. This includes:

- To evaluate and update the state-of-the-art in the area of free software digital wallets. To use an observatory strategy and monitor ongoing projects, documenting and comparing the advances in digital wallets.
- To develop, test and publish open-source code for wallets.
- To publish reports about security issues and usability challenges related to identity wallets.
- To develop customization tools to allow reuse and fast deployment of one-use-case wallets. Publish open tutorials about this process.
- To prepare specialized human resources capable of customizing digital wallets.

After this project, we expect to be able to boost new companies in the market for the development of SSI digital wallets.

# 2 Expected results

The project outcomes are:

- To develop free software and publish it in our Github repository and related projects.
- To provide a set of tools for wallet customization. It may include business modeling tools, UX customization tools, and conformance tests.
- To publish a systematic review about wallets solutions.

- To publish an article about wallet customization processes.
- To prepare academic work about the wallets (two master's and four undergraduate's works).
- To prototype an use case to demonstrate and validate wallet usage.
- To contribute to OpenWallet Foundation initiative.

In addition, we will organize events and workshops for researchers, professionals, and students, stimulating future cooperation.

# 3 Scientific and technological challenges and the means and methods to overcome them

This section presents the state of the art in Identity Wallets and the challenges addressed by the project.

## 3.1 State of the art

This section makes a summary of the state-of-the-art in Wallet development. We cite the eleven ongoing projects, and comment the major limitation. After two years of research, development, and integration, the objective is to have a open source solution, functional, and **easily customized** to Brazilian reality.

Table 1 presents a list of most relevant ongoing projects related to SSI and wallets. To the best of our knowledge, there is no free software complete solution or initiative that can be called leader. The projects are not end-to-end solutions or are immature products.

The Linux Foundation is leading a project called Open Wallet and proposes an architecture for general-purpose wallets. Figure 2 shows the architecture; however, there is no code available. It is noteworthy that the architecture is complex and contains components for the most typical use cases, such as cryptocurrencies, payment methods, and ticket-holder. Recently, in August 23, the BigTech Alphabet Inc. announced[11] the plan to donate software to the Open Wallet project, reinforcing that our choice of to integrate this project was a an appropriate choice.

The most mature source code available for the SSI use cases is the ACA-Py library, a Python implementation to interact with Hyperledger Aries and Indy solutions. The ACA-Py

[11] The announcement is available at https://openwallet.foundation/2023/08/23/openwallet-foundation-announces-google-as-premier-member/.

| Product | Characteristics |
|---|---|
| **Google Wallet** | Integrated with payment methods. Easy to integrate with Android mobile phones. There is no source code available, only integration APIs. Available at https://wallet.google . |
| **Jolocom** | This German company provides decentralized and SSI solutions. There are code repositories in the site, but only web3 solutions are listed, they are not integrated or reusable. Available at https://jolocom.io . |
| **Evernym** | The company provides a complete solution for SSI and digital identities. Founder of Sovrin foundation (https://sovrin.org) and main contributor to Hyperledger Indy. Their core code is not open. Available at https://www.evernym.com . |
| **Venmo** | Global payment solution. No SSI support and no source code available. Site https://venmo.com . |
| **ESSIF** | European research project created to promote SSI solutions. It describes the overall architecture and components, but it does not provide a wallet sollution. Available at https://essif-lab.github.io/framework/docs/essifLab-vision . |
| **Lissi** | This company offers SSI service and wallet integration for some use cases. There are EBSI and eIDAS compatible solutions. There is no source code available. Available at https://docs.lissi.id/lissi-wallet . |
| **EBSI** | The European consortium for blockchain services has a list of wallets. None of them offers open-source end-to-end solution. Most of the wallets provide limited integration using APIs to/from the wallet. Available at https://europeanblockchainassociation.org/ssi-wallets . |
| **Trinsic** | It is the most used solution. Offers a wallet with good usability. There is no source code available. Available at https://trinsic.id/open-source-ssi-codebases/ . |
| **Thales Digital ID Wallet** | The American company sells public services integration using SSI. There is no source code available. Available at https://www.thalesgroup.com/en/markets/digital-identity-and-security/government/identity/digital-identity-services/digital-id-wallet . |
| **Hyperledger Aries** | The most functional backend solution, but is all controlled by console tools. There is no friendly interfaces. Easy to integrate with the blockchain solution Hyperledger Indy. Available at https://github.com/hyperledger/aries . |
| **OpenWallet** ~~Linux~~ Foundation | Recently initiated, the OpenWallet initiative does not provide a solution yet. They plan to have a source distribution in 2023. Available at https://openwallet.foundation . |

Table 1: List of related work.

implementation[12] will be the main reference to the development of this project.

[12] https://aries-cloud-agent-python.readthedocs.io/en/latest/

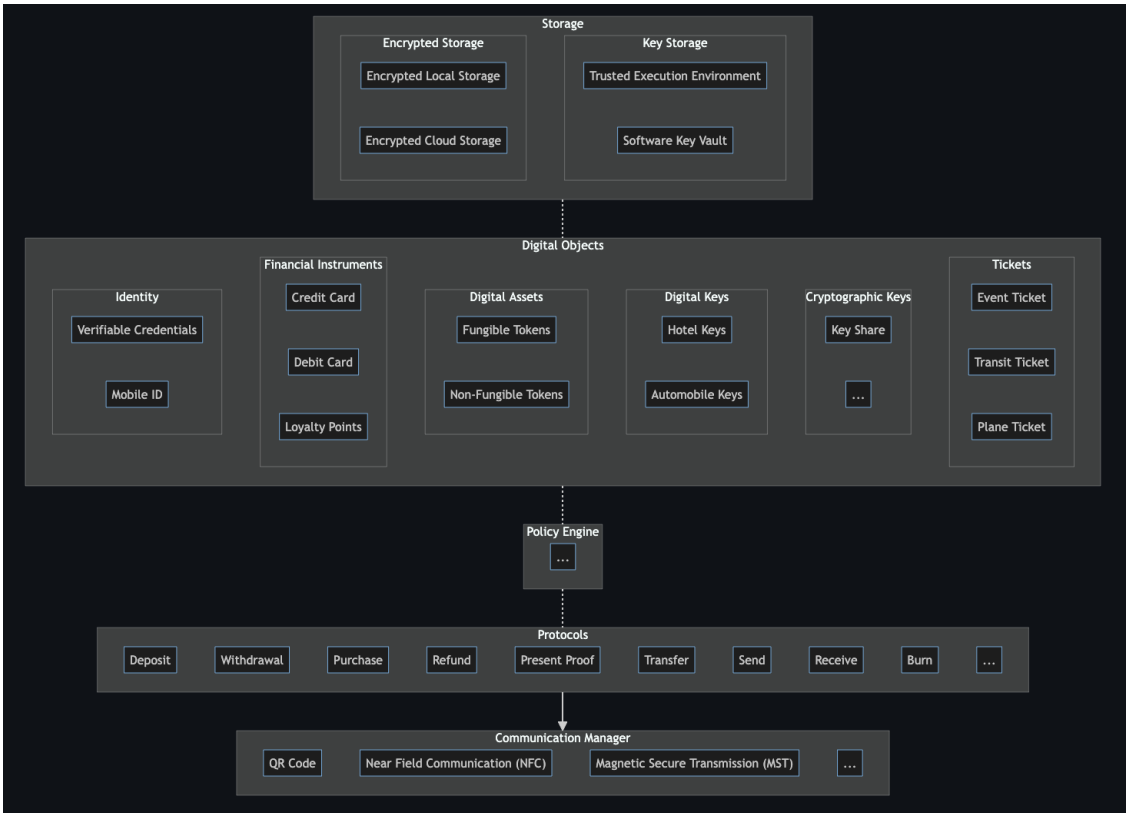


Figure 2: OpenWallet Foundation architectural proposal for multipurpose wallets

## 3.2 Major challenges, our specific objectives, and research questions

The wallet market is in its infancy. There are research questions about how the users will adopt it and its impacts on society. In the context of Computer Science, the following major questions can be stated:

1. **Architecture**. How can we project wallets, minimizing security risks and maximizing the reuse of components? How to design test-driven development process?
2. **Interfaces**. How to provide user-friendly interfaces? How to write multi-platform and responsive interfaces?
3. **Services**. How to develop and integrate SSI services as a Digital Object of the Wallet? How to provide interoperable services? How to test and evaluate service security and conformance to standards?

In addition to these global questions above, it is essential to evaluate the usage of wallets as cloud applications instead of mobile applications. In this scenario, the mobile component could be a proxy to credentials and tokens stored on cloud services. This approach makes it easier to recover control of a wallet in case of access loss to the mobile component [12].

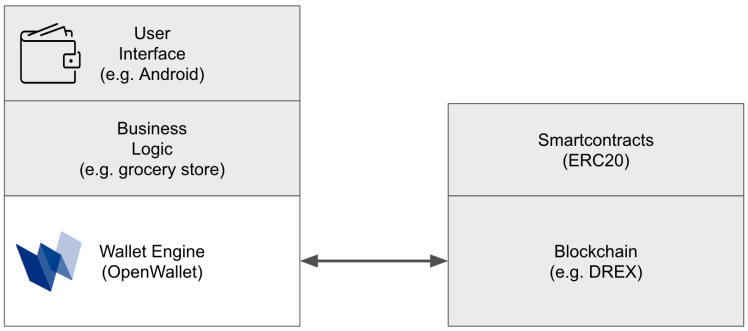


Figure 3: Cashback Application Architecture

We will keep track of these major questions. But in this two-year project will focus on the practical aspects showed in Table 2:

### 3.2.1 Use Case: Cashback for Small Business (*NEW SECTION*)

To make the potential of this research clearer, we will describe and implement a use case to show how open wallets can change the society. But the focus of the project is to provide a engine that can be used to implement wallet use cases; the focus is not the application.

Cashback applications are mobile apps that empower users to recoup a portion of their expenses by making purchases through the app. Developing a cashback app is a substantial endeavor, often **more viable for larger enterprises than small businesses**. Generally, cashback programs are closely associated with credit cards. However, there's potential for central bank digital currencies (CBDCs) to introduce cashback incentives, which could benefit businesses of all sizes.

In this illustration, see Figure 3, the wallet serves as the user interface and implements specific business logic, such as cashback conditions. The Wallet Engine is responsible, for example, for user authentication and token management. On the server side, a smart contract can execute cashback rewards based on predefined conditions.

For instance, consider a small grocery store that offers a 5% cashback on purchases exceeding a certain threshold or provides cashback for loyal customers with regular buying habits. Moreover, cashback policies can be tailored to promote sustainability, incentivizing customers who opt for eco-friendly products.

In the current landscape, the creation of a cashback application is hampered by the absence of an open software stack readily available for use. This project aims to address this gap by developing such an application through the integration of existing solutions and meticulously documenting the entire process.

Furthermore, our objective extends to ensuring the ease of replicating this process, enabling small businesses to independently establish their own wallet solutions. The presence

| Questions | Activities |
|---|---|
| **Open-source code**. Which are the open-source solutions available? Can we test and integrate it? How exactly is it integrated? How components are being used? Which are the open-source gaps? | • Conduct a systematic review of open-source wallets.<br>• Organize a comprehensive list of both mandatory and desirable requirements for wallets.<br>• Establish a connection between existing open-source solutions and wallet requirements while identifying any gaps.<br>• Perform a comparative evaluation of open-source wallets.<br><br>The project will yield the following deliverables:<br>1. **Requirements Map**: A structured overview of the wallet requirements.<br>2. **Integration and Testing Process**: A detailed plan for integrating and testing open-source wallet solutions.<br>3. **Articles**: Research articles summarizing the systematic review, requirements analysis, and comparative evaluation. |
| **Customization**. Is it possible to simplify the solutions for single-use-case? For example, can we easily build a wallet and SSI solutions for a small businesses? | • Mapping Software Dependencies: Analyze the software dependencies within Self-Sovereign Identity (SSI) wallets.<br>• Web Tool Design: Create a user-friendly web tool for configuring wallets, requiring no programming skills from the user [13].<br>• Assess security vulnerabilities using static analyzers for Ethereum Solidity Smart Contracts [14] and employ code scanners, such as Sonarqube, for mobile code.<br>• Usability Assessment: Evaluate the usability of automatically generated wallets.<br><br>The project will result in the following deliverables:<br>1. **Interactive Web Page**: A web interface that allows users to specify wallet requirements interactively.<br>2. **Data Format**: A standardized data format for representing wallet functions.<br>3. **Assembly and Deployment Procedures**: Detailed guidelines for assembling and deploying wallets on various operating systems. |
| **New services**. Which new services can be created in the context of the Brazilian market? Do these services positively impact the Sustainable Development Goals [15]? | • **Cashback Application Framework**: Create a versatile cashback application framework designed for reuse; assess its performance through real user evaluations.<br>• **Mapping of Key Use Cases**: Investigate and map the most pertinent use cases within the Brazilian landscape, including “Connect SUS", “Cartão Bolsa Família", and the traceability of organic product origins.<br>• **SSI Application Design for Sustainability**: Devise Self-Sovereign Identity (SSI) applications and prototypes that prioritize environmental sustainability, exemplified by features such as organic product origin verification and minimal carbon footprint.<br><br>Deliverables: Functional prototype of the cashback application and research articles summarizing the project’s findings, methodologies, and outcomes. |

Table 2: Research questions, planned activities and deliverables

of a wallet engine is not only essential for expediting development but also for fostering interoperability among different solutions.

Drawing a parallel to the evolution of web browsers, in the past, creating a new browser necessitated starting from scratch. However, today, there exist robust core libraries that serve as the foundation for creating browser solutions. These libraries adhere to industry standards and undergo extensive testing. We envision a similar evolution in the realm of wallets, where standardized and rigorously tested solutions become the norm.

## 3.3 Initial approach

Our initial approach to mastering the multipurpose wallet development involves investigating the Hyperledger ecosystem, monitoring the evolution of Web3 interfaces, and trying to contribute to the initiative coordinated by OpenWallet Foundation. Recently, motivated by the discussion of the initial operation of the Brazilian digital currency, DREX, we mastered the process of assembling the wallet *Aipha Wallet* (https://alphawallet.com/) for managing ERC20 Ethereum tokens. We have also dominated the Aries development process [16].

After dominating these components, we plan to understand the customization process, including a complete comprehension of the component's dependencies. We plan to provide templates to simplify wallet deployment. The objective is that in the future, any user could create his own SSI process and wallet mobile solution using simple tools. In the past, we have developed a strategy to automatically create mobile applications [17] only using Web interfaces and without programming skills, we plan to use a similar strategy to enable users to create simple decentralized applications based on wallets.

The team will be organized into three core tasks: front-end, back-end, and test environment. More details can be obtained in the Work Plans.

Our contributions will be the knowledge mapping about wallets, the free software development, and the proposal of the customization process.

## 3.4 Evaluation methods

The objective of the evaluation method is to comprehensively assess digital wallet software to determine its suitability for specific use cases and user needs. This includes security evaluation (authentication and authorization, encryption, privacy, tamper resistance, etc.), user interface usability, functional and performance assessment. In addition, we have to evaluate the conformance to recently published DID and SSI [18, 19] standards.

The security assessment will be made using static analyzers and code evaluation. We plan also to make user evaluation, collecting feedback from real users. For conformance tests, we

plan to design and run unitary tests.

# 4 Project schedule and costs

The project is planned for 24 months. The work packages are defined below. Figure 4 illustrates the duration of the tasks.

- **Work Package 1: Project management and coordination.**
  Resource: Principal investigator, Arlindo Flavio da Conceição.
  Objective: guarantee the project execution.
- **Work Package 2: Observatory strategy.**
  Resource: All.
  Objective: monitor market evolution and opportunities.
- **Work Package 3: Open-source wallet development and integration.**
  Resource: Two TT3 collaborators: one for front-end and the other for back-end development. Grad students must help with this task also.
  Objective: test and integrate available wallet solutions, emphasizing creating a functional solution. Usability is a crucial aspect here. Deliverable: an open-source functional wallet.
- **Work Package 4: Testing.**
  Resource: TT4-A collaborator (work plans A and B). Grad students must help with this task also.
  Objective: provide a reliable test environment, act as a tester, and develop test tools. Deliverable: test routines and development environment.
- **Work Package 5: Dissemination.**
  Resource: All.
  Objective: guarantee the project visibility, including technology transfer to project continuity in the future. We plan to apply the solution to create several SSI-based products in the future.

There will be **monthly** follow-up meetings with all project collaborators and **weekly** meetings with the development team, where the agile Scrum methodology will be used.

## 4.1 Budget

Figure 4 shows the resources requested. This project requested around three hundred thousand BRL (*R$ 300.000,00*). We requested:

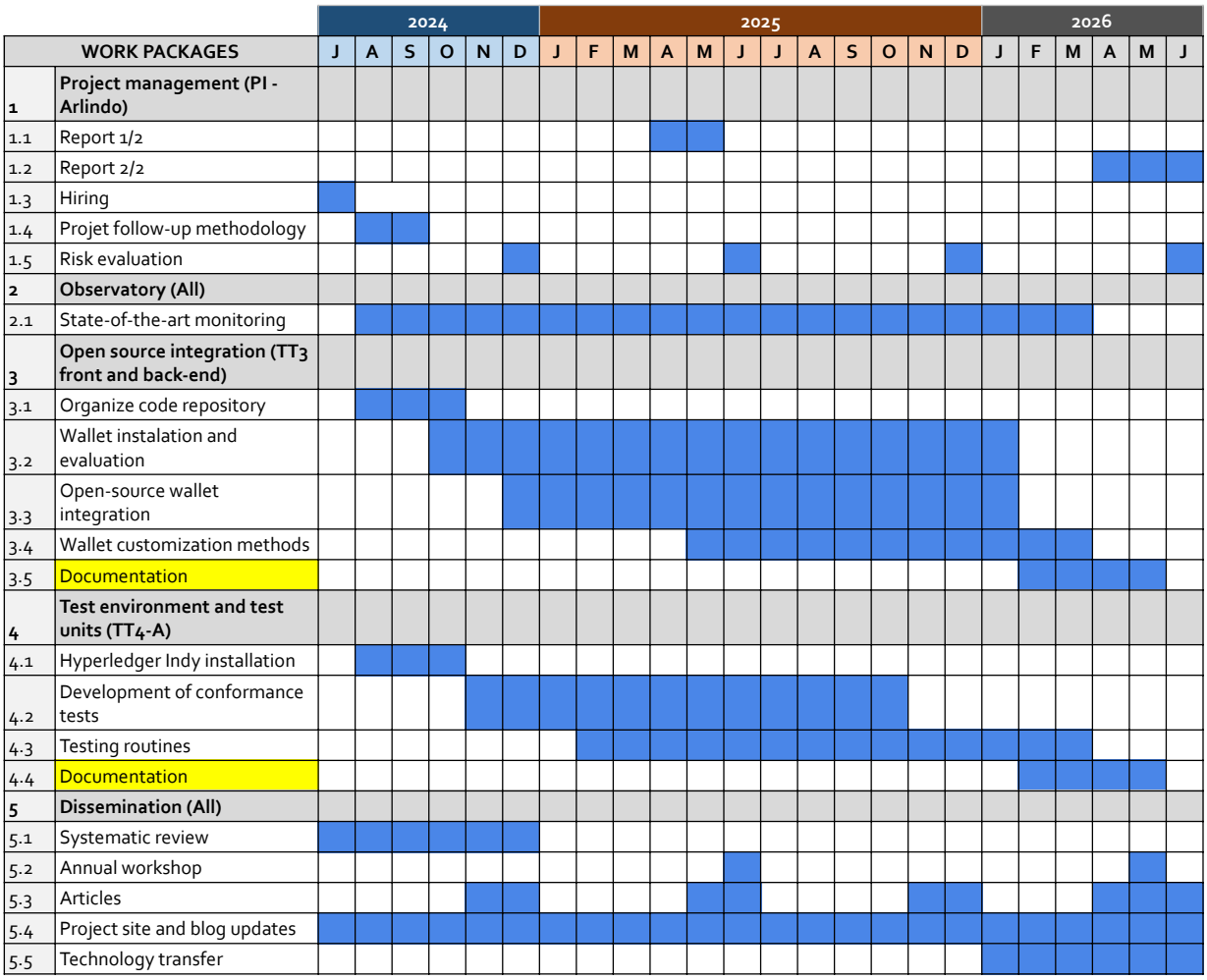


Figure 4: Scheduled tasks for the work packages.

- **One TT-4A** for ~~20~~ 21 months, 40 h/week. This resource will respond to keeping the test environment running and documentation. The candidate must have experience in execution environments and containers. More details on the work plan.

- **Two TT-3** for ~~20~~ 22 months each, 40 h/week. Software developers. One dedicated to UX and front-end development. Other dedicated to back-end, including VC manipulation and verification. Both have to help with software documentation. More details on the work plans.

- We requested R$ 23.700,00 for the acquisition of mobile equipment to be used on wallet evaluation. The plan includes buying equipment from different operating systems, such as Android, iOS, and HarmonyOS. The acquisition of phisical devices is essential to validate the interfaces with real users, getting the real experience of usability; emulators cannot provide this feedback. In addition, emulators have well known limitations, such us slower time response compared to the real tools, lack of software dependencies,

**Orçamento**

| **Benefícios** | **Valor (R$)** | **Valor (US$)** |
|---|---|---|
| Capital | | |
| Material Permanente | 23.700,00 | 0,00 |
| Custeio | | |
| Despesas de Transporte | 0,00 | 2.143,00 |
| Diárias | 0,00 | 4.320,00 |
| Material de Consumo | 0,00 | 0,00 |
| Serviços de Terceiros | 0,00 | 0,00 |
| Reserva Técnica - Benefícios Complementares | 32.000,00 | 0,00 |
| Reserva Técnica - Custo de Infraestrutura Direta do Projeto | 8.450,72 | 0,00 |
| Provisão para Importação | 0,00 | 0,00 |
| TOTAL | 64.150,72 | 6.463,00 |

**Quotas de Bolsa**

| Modalidade / Nível | Carga Horária | Duração (Meses) | Quantidade |
|---|---|---|---|
| TT-3 | 40 | 22 | 2 |
| TT-4A | 40 | 21 | 1 |

| | | |
|---|---|---|
| Bolsas como Item Orçamentário | 197.424,80 | |
| Reserva Técnica Institucional | 5.633,81 | |
| Custo Total da Proposta (em R$) * | 299.847,48 | |

* - Calculado com a cotação do Dólar FAPESP da data da submissão da proposta.

Figure 5: Budget revised (extracted from SAGe-FAPESP, Sept. 10th, 2023.)

and it is impossible to produce isolated performance measurement. Finally, to have real devices accelerate the debugging process in some cases; that is essential for a two years project.

  - **Android**: Samsung Galaxy S23 Ultra, Android *13* with OneUI. Estimated price: R$ 7,800.00.
  - **iOS**: Apple iPhone 14 Pro, iOS *16*. Estimated price: R$ 8,700.00.
  - **HarmonyOS**: Huawei P60 Pro, HarmonyOS *4.0*. Estimated price: R$ 7,200.00.

- Around six thousand USD to visit BlockchainLab.no, in Norway, where an EBSI network node will be running. The objective is to verify the integration of the wallet to the EBSI network, and with other SSI-based ongoing projects.

- ~~R$ 20.000,00 for documentation services. Documentation quality is essential in the system's adoption, and professional help will maximize the project's impact.~~

# 5 Dissemination and evaluation of results

The project's results will be available in the authors' repositories and project pages. In addition, we plan to publish the results in relevant conferences and journals. Undergradu-

ate students, young researchers, and professionals will be invited to follow the project and collaborate on it.

After having a functional prototype of the wallet, we plan to collaborate with several research partners in Brazil and abroad in the deployment of new SSI-based applications.

# 6 Other support

Two undergraduate stutents are working in the project, supported by FAPESP (IC) and CNPq (PIBITI). We expect also to add other bachelor and graduate students to this research.

# 7 Final considerations

In recent years, Professor Arlindo Flavio da Conceição has established collaborative relationships with various blockchain research groups in both Brazil and Europe (UiO, EFREI, UNIMIB). Notably, the wallet component has emerged as a bottleneck in numerous research and innovation endeavors that lack robust and functional interfaces. Therefore, this project holds significant strategic importance.

We hold a highly optimistic outlook for this initiative, anticipating its potential to foster collaborations and yield tangible outcomes. As we progress, we envision extending the project's results from small shops to large-scale businesses, including use cases based on the European Blockchain Services Infrastructure (EBSI), once we have a fully operational wallet solution in place.

Furthermore, it's worth noting that our proposal aligns with multiple priority areas outlined in the *FAPESP/MCTI/MCom/CGI.br* call. Notable areas of alignment include architectures and protocols (a.1), blockchain (b.9), free software (e.1), and applications (f).

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