Balvia Ecosystems Product Placement

Bruno António Alegre da Costa - a33667

Thesis presented to the School of Technology and Management in the scope of the Master in Innovation of Products and Processes.

Supervisors:

Prof. Rui Pedro Lopes

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Dedication

This work is the result of an idea that started in Demola in 2017 and the effort made for a long time, since joining the university in 2014 until now.

I want to dedicate this work first and foremost to my family, specially my parents (Peregrino and Alice) and my siblings (Nídia, Nélzia and Fábio), who always give me support and love.

Another special thanks is for my girlfriend (Nikola), who always give me courage and love, to never give up and at all times keep moving forward.

My next dedication is for my friends that countless times gave me positive energy and were my second family here in Bragança (Anselmo, Mary, Ingrid, Ana Lucia).

Thank you so much, all of you that brought me more joy and made this path much easier to follow.

Acknowledgment

The development of this work had support from many people in different levels.

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I'm grateful to acknowledge the support given by "la caixa" Foundation, who funded SelfMed, without that funding the project would not leave the paper. The support enabled the development of the project SelfMed, this work and the possibility of commercialization of the product, which will undoubtedly increase quality of life, well-being, and health for many clients.

Abstract

Technological advancement in medicine enabled humankind to surpass many difficulties and cure countless diseases. These solutions improve the quality of life and well-being for mankind.

Non-adherence to prescribed medication is a problematic that decrease the overall quality of life and health, while increasing the costs of health care. It can have many reasons and the consequences can be dire. The project “Automatic pills dispenser device - SelfMed” aims to provide a solution for that problem.

The project SelfMed envisions the creation of a machine that can store, organize and dispense medication in the proper quantity and time, alerting the user of the medicine and facilitating remote access to data. It is a smart and independent machine capable of communication with other systems, and with many security features.

This work is in the scope of project SelfMed, further develops the pill dispenser prototype, creates a new scope for the solution, design the business base for the commercialization of the products. The solution being developed is an ecosystem that includes an automatic pill dispenser device, user interfaces, cloud system, a smartwatch application, and a service.

Keywords: Balvia Ecosystems, Entrepreneurship, Internet of Things (IoT), Medication

Resumo

O avanço tecnológico na medicina permitiu à humanidade superar muitas dificuldades e curar inúmeras doenças. Essas soluções melhoram a qualidade de vida e o bem-estar da humanidade.

A não adesão às prescrições médicas é uma problemática que diminui a qualidade geral de vida e saúde, ao mesmo tempo que aumenta os custos dos cuidados de saúde. Pode ter muitas razões e as consequências podem ser terríveis. O projeto "Dispensador Automático de Comprimidos - SelfMed" visa fornecer uma solução para esse problema.

O projeto SelfMed prevê a criação de uma máquina capaz de armazenar, organizar e dispensar medicamentos na quantidade e tempo adequados, alertando o utilizador sobre o medicamento e facilitando o acesso remoto aos dados. É uma máquina inteligente e independente capaz de se comunicar com outros sistemas e com muitos recursos de segurança.

Este trabalho está no escopo do projeto SelfMed, desenvolve ainda mais o protótipo do dispensador de comprimidos, cria um novo âmbito para a solução, e desenha a base de negócios para a comercialização dos produtos. A solução que está a ser desenvolvida é um ecossistema que inclui um dispositivo, dispensador automático de comprimidos, interfaces de utilizador, sistema em nuvem, um aplicativo smartwatch e um serviço.

Palavras-chave: Balvia Ecosystems, Empreendedorismo, Internet das Coisas, Medicação

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Chapter 1

Introduction

In the modern day, there are many stages to bring a new product, process, or service to the market. Companies aim to pass quickly in each stage in order to make their products or services available to the clients swiftly. The stages start with the idea generation, and conclude with the new product in the market.

With the help of technologies, companies are able to quickly develop and test their new ideas. It is possible to present prototypes to customers and investors, and receive their feedback, before moving forward. This saves time and investment, because it allows for errors correction prior to making long term decisions. The stages necessary to bring a new product in the market are:

1. Idea Generation;
2. Idea Screening;
3. Concept Development and Testing;
4. Market Strategy / Business Analysis;
5. Product Development;
6. Market Testing;
7. Market entry / Commercialization.

The idea generation is directly related to problem-solving. The new product and/or service will provide a solution to a specific problem or need of a group of customers. In this stage, it is necessary to understand the problem, the causes, the effects, the people affected, and all the other associated factors. This way, the idea will be as complete as possible for the phase.

The next step is to evaluate the idea. With the idea screening, it is assessed the strengths and weaknesses of the idea, and if it is feasible technically. Many ideas can be ahead of their time, or simple not feasible at the time, and it is important to recognize that in an early stage, to avoid unnecessary investments.

After having an idea and realizing it can be done, the next stage is the concept development and testing. The idea will be further developed and tested to receive the first feedback. As the idea will solve a problem, the testing should be with the people that the solution will help, directly or indirectly. These people will be able to recognize the value that is being proposed and the benefits. Thereafter, the feedback is analyzed, and it can lead to a validation of the concept or a reformulation of the idea. In this stage, it is also important to analyze the current market and solutions. The value proposed with the new solution should not be the same as existing ones.

In the market strategy / business analysis stage, it should be understood some components of the industry. The business analysis will help define the strategy for the market, pricing and model. It will also help understand the profitability of the idea.

The next phase is the product development. There are many methodologies that can be used in the product development. But, ultimately, the product or service will move from a concept, to a prototype and a Minimum Viable Product (MVP). A prototype helps to visualize how the product can look and work. Many prototypes can be tested before having a working prototype, with the desired design. When the prototype has the required functionalities, it is considered a MVP.

Market testing is the following phase. When the product is in a very advance stage of development, it can be tested. The testing can vary, there are testing in laboratories and in the field with real clients. The testing in laboratories will assist in the unveiling of errors before the testing in the field. Both tests will contribute to further improvement of the product.

Finally, the last stage is the market entry / commercialization, where the products or services are made available for the clients to acquire.

The present work is in the stages of market strategy / business analysis and product development.

1.1 Goals

The present study was part of the project “Automatic pills dispenser device - SelfMed”. SelfMed project is financed by “la caixa” Foundation, with the duration of three years, and aims to give a technological solution to the non-adherence of prescribed medication problematic.

The current work further develops the SelfMed pill dispenser prototype and creates a new scope for the solution. The solution being developed is an ecosystem that includes the automatic pill dispenser device, user interfaces, cloud system, a smartwatch application and a service. This work had as main objectives:

- Development of the pill dispenser hardware and software;
- Testing of the prototype in the laboratory;
- Exploitation of the results from the SelfMed project;
- Corporative identity creation;
- Development of Business model theories;
- Service conceptualization;

1.2 Development Method

The requirements and use cases were acquired prior to the beginning of this work. The requirements and use cases used were obtained during the beginning of the SelfMed project and the past work developed.

The development of the work is divided in two main areas: scientific development and business model theory's conceptualization.

In the scientific development, the prototype of the pill dispenser was improved, and a new concept was developed. Later, the prototype was tested. In parallel, the business models were developed.

1.3 Documents Structure

This document is composed of six main chapters.

This chapter, number 1, contains an introduction to the project, a brief description of the goals and the development methods.

Chapter 2 includes a background of the project, a description of the problems, a short report on the current solutions in the market and patent submitted. Additionally, this section contains the definition of a new concept and the market overview.

The chapter 3 describes the methodology, and an explanation of the ecosystem architecture, the pill dispenser design, software, and hardware. Furthermore, the startup corporate identity is outlined.

Chapter 4 is devoted to the development of the project, from the design stages until the implementation of the system. In addition, the business and financial theories are specified.

In the chapter 5 are discussed the tests and results of this work.

At last, in chapter 6, a conclusion is made and the definition of the next steps for the future.

Chapter 2

Context and Technologies

This chapter includes a background of the project, a description of the problems, a short report on the current solutions in the market and the patent submitted. Additionally, this section contains the definition of a new concept and the market overview.

2.1 The Problem and the Importance of the Solution

With the development of the science and technology, humankind created solutions for many diseases. For different conditions, distinct answers were created. With that, mankind was able to move past multiple illnesses, increase immunity and fight against pathogenic agents. The created solution can take many forms, such as vaccines, injections, syrup, creams and, probably the most common, pills. There are other types with a more specific purpose, such as, inhalers or implants (patches).

Recover from a diagnosed disease can be challenging, and controlling a chronic one even more. Normally, a specialist in the area will prescribe medicine to help the patient. However, it is very important to follow thoroughly the prescription, to avoid complicating even further the problem. This is an issue that many people have, and this works aims to develop a prototype to help solve it.

A medical prescription is passed to a patient with the information necessary for the medication intake. It has a date, frequency of intake, medication information, quantity, and others. All to ensure that the patient will take the appropriate dosage, and improve their health status.

Everyone that takes pills daily, needs to take those medicines at the correct dose and time. It becomes a stressful situation when they are not able to take the medication regularly. The consistency in taking the pills at the correct time and dose prescribed is deeply connected with maintaining a healthy lifestyle. Non-adherence to prescribed medication is a serious cause of morbidity and mortality, and contributes to the increase of health-related financial costs [1]. It also reduces the medicine efficiency.

There is no consensus on the definition of polypharmacy, however it is often associated with multi-morbidity and the use of multiple medicines [2]. Polypharmacy can be associated with non-adherence. The high amount of medication and the multi-morbidity can lead to following poorly the prescribed medicine.

2.1.1 Non-Adherence

Non-adherence is a global problem, with many factors. The present work and SelfMed project focus the solution to the people aging 55 and more, in the European Union (EU) market. Nevertheless, the solution can be used by anyone that takes pills regularly. The focus is majorly on the older people due to the fact that they are prone to multiple commodities, they are at higher chance of polypharmacy, and, therefore, may present with greater risk of non-adherence to medications compared to the younger population [3].

It is important to recognize the problem and understand it. Non-adherence can have many factors, World Health Organization (WHO) (2003) [4] classified it into:

- **Patient factors** - factors related to functional impairment, cognitive decline, depression, social isolation, lack of acceptance of the disease and understanding of the prescribed medication and perceived benefit-burden analysis;

- **Medication factors** - factors associated to adverse effects, interactions, multiple doses per day;

- **Health care provider and health care system factors** - factors connected to lack of communication, lack of patient education and lack of follow-up;

- **Socioeconomic factors** - factors linked to the lack of carer or large carer burden.

The factors are interconnected, but can have different origins.

When an older person is not able to follow thoroughly the prescription, it is important to know if it is a recurrent issue or punctual.

2.1.2 Consequences and People Affected

The challenge of the polypharmacy and the needed consistency in order to achieve the desired results can be overwhelming. As mentioned before, in developed countries, only about 50% of people follow correctly their prescription, leaving numerous people in error. Failing to take the medicine properly can lead to more health problems or to worsen of the current problem, increase in financial costs, family and social stress.

The medication is taken for a reason, to cure, help and others. Focusing on the elder population, the non-adherence to the prescribed medicine will result in illness that will not be properly treated. The patient's condition can worsen if the disease continues to affect him. For people with weaker medical status, this can mean being hospitalized, or in severe cases, death. The medical staff will try to help by increasing the dosage, striving to fight more aggressively the illness.

The personal financial effort that is needed to bear the health care expenses will rise with the increase of the medical services costs. It can become unbearable if the medical assistance is needed constantly. Adding to that, there is a social problem that can be created. The person can start loosing independence, autonomy, and can enter into depression.

To the family, this situation can become very stressful, financially and psychologically. Similar to their older family members, they will need to pay or help pay for the medical care that their senior family members need. The constant worry can affect their work productivity and mental state.

The load and responsibility that a family member non-adherence can bring is very distressing and burdensome. The families are not able to provide the proper support to their loved ones. As informal carers, most are not able to assess the situation to contribute to the improvement of the elder situation. Jointly with the lack of communication, this will bring distance in their relationship and psychological difficulties.

For the companies that provide the service and specifically for the formal carers, the non-adherence can become a burden, a source of stress and professional disappointment, that can have negative effects even in their personal life. The professionals that dedicate to assist can also feel powerless when they are not able to have the positive impact they want in their client's life. For the companies, it can mean a decrease in the efficiency of their work, allocation of resources, human or otherwise, that could be allocated in other cases.

In several cases, the government pays a part of the prescription that is given, and this money is squandered when the medication is not being taken appropriately. The other cost is with the health system as a whole. The people that do not follow the prescription, get worse and have to go back to using public health resources, unnecessarily increasing the costs of public health. Reported by Organization for Economic Co-operation and Development (OECD) (2018) [5], the poor adherence and health complications that come, are estimated to cost EUR 125 billion per year in Europe, with nearly 200 000 (200K) premature deaths per year. The costs include avoidable hospitalizations, emergency care, and outpatient visits.

In 2019, the certificated statistic website Portdata [6] reported that the Gross Domestic Product (GDP) of Portugal was approximately EUR 212 billion (212 320.6 million). The year of 2019 was a year of growth in the Portuguese GDP. The Instituto Nacional de Estatística (INE) stated that in the last quarter of 2019, the GDP in Portugal had a growth of 2.2% [7]. Even though the growth was significant, and the GDP was higher than the previous years, comparing the 2019 GDP in Portugal with the estimated cost of non-adherence in Europe, nearly half of the Portuguese GDP was wasted in Europe with non-adherence. The wasted money from non-adherence in Europe is comparative of adding the GDP of Slovenia (approximately EUR 48 billion), Estonia (around EUR 28 billion), Latvia (about EUR 30 billion) and Island (nearly EUR 21 billion), indicated by Portdata [8].

Annually, between 100 and 300 billion US Dollars in health care costs have been attributed to non-adherence, in the US, and could be avoided [9].

The costs are truly substantial (in the order of billions) and avoidable with the consistent and proper intake of medicine. This money could be applied in different areas, contributing to a better lifestyle for all citizens. In an overall view, reducing the non-adherence could assist in the reduction of the health systems costs as a whole and increasing the efficiency of all parts.

2.2 Current Solutions

At the present, the current solutions can be categorized as products and services. These solutions can be acquired separately, but also can work together. The client can enroll in a service and at the same time use a product.

2.2.1 Service Provisioning Based

The service is provided by specialized companies, institutions, or professionals. These services can be in many areas, cleaning, feeding, medication management, or other types of assistance. The focus of the comparison will be in the medication management services.

A client can hire a company, institution, or a professional for a medication management service. The service is based on visits, where the professional (affiliated to a company or not) will organize the medicine for the client and assist in the intake. There are different regimes for these visits, more frequent visits lead to higher costs and higher prices for the client. However, not having enough visits will not help to increase the adherence to the prescribed medication.

The monthly price for a medication management service varies according to the assistance that is provided. In the online platform for services Zaask, the domiciliary assistance for elder people can vary from €10 per hour to €65 [10]. The specialized company for elder assistance has different prices, that can vary from €4 per hour to €10 per hour [11]. The same company also offers other services that are charged by the assistance given. The company Fixando reports that the total average price for the domiciliary service for elder people is €607, and it can vary from €3 to €1.950 [12]. Furthermore, the same company mentions that the average price per hour is €22, and the price can vary from €4 to €641.

2.2.2 Product Based

Different to the service, the product based solutions are more specific to the medication management assistance. The types of products, devices, and machines can vary. It can be from a very simple device, without electronic hardware, to very complex machines. Below are some main products currently in the market worldwide.

Hero

Hero is the smart service taking the hassle out of medication management [13]. The table 2.1 shows the strengths and weaknesses of the Hero pill dispenser.

Pillo

Pillo Health, using a combination of adaptive AI and thoughtfully designed hardware, proactive and secure digital health companion offers enterprise solutions that Bring Healthcare into the Home [14]. Pillo is a health assistant robot who employs people at all ages to better manage their health. It takes care of all medications and vitamins and reminds the customer when they need to take it. It can connect directly to the health care professionals as well as with the doctors. The table 2.2 shows the strengths and weaknesses of the Pillo pill dispenser.

Livi

Livi is a smart home medication dispenser designed for both patients and their caregivers [15]. It simplifies managing multiple medications for patients while giving caregivers much needed support. In the table 2.3 it is possible to see the strengths and weaknesses of Livi pill dispenser.

Strengths:	**Weaknesses:**
Flexibility of the dispenser, manages scheduling for up to 10 different medications and daily doses;	Cannot handle liquids, gummies, or halved/quartered pills (but it can remind you about these);
Dispenser holds up to 90 days of medicine;	No back-up battery power;
Pill size/shape does not matter;	Small screen, what can be challenging for people with significant visual impairment;
Hero safeguards against missed doses with both audible and visible alarm;	Setup may require help, depending on the technology knowledge of the user;
Notifications keep everyone in the loop, for added security;	Medication outside blisters (risk of contamination);
More affordable than alternative systems;	Small screen, what can be challenging for people with significant visual impairment.
Never run out – Hero can automatically order medicine when running low;	
Free shipping in the United States of America (USA);	
Travel mode, dispensing pills for travel.	

Table 2.1: Hero strengths and weaknesses

Strengths:	**Weaknesses:**
Not having to go to the doctor for simple questions;	Not able to notify about the medication when the user is outside the house
Not having to spend much time searching up calories for a certain vegetable;	Medication outside of blisters (risk of contamination)
Text messages when are dispenses pills on time, or when the dose is not taken;	Small storage, requires more frequent refilling.
Not forgetting when to have your medications and vitamins.	

Table 2.2: Pillo strengths and weaknesses

Strengths:	Weaknesses:
Text messages when Livi dispenses pills on time, or when the dose is not taken;	Livi may have difficulty dispensing half-tabs, gummy supplements, rubbery gels, and pills that are inconsistently shaped
Dispenses pills for portable travel packs for up to 14 days for extra independence;	Filling process
Includes a battery backup, which the company says lasts for 8 hours;	The container into which are the pills pour;
The product notifies you when supplies are getting low.	It is not possible to add audio messages, such as – take the medication now.

Table 2.3: Livi strengths and weaknesses

Philip Medication Dispensing Service

The dispenser is easy to set up and even easier for seniors to use [16]. Typically, it's a caregiver who loads the machine with the single-dose pill cups and contacts us to program the dispensing schedule. Then, when it is time for a dose, the machine will sound a reminder. The users have to simply press the release button to dispense the dose and take their pills. If they have not pressed the button after 90 minutes, a caregiver will get a phone call to step in and advise them directly. The strengths and weaknesses of Phillips pill dispenser are represented in the table 2.4.

MedaCube

The MedaCube is the only automatic pill dispenser that is clinically proven to significantly increase medication adherence [17]. The table 2.5 shows the strength and weaknesses of MedaCube dispenser.

In the table 2.6, it is possible to analyze a comparison between SelfMed features and the other direct competitors.

2.2.3 Patents

Over the years, some devices capable of storing and dispensing pills have been developed. With an alarm system, these machines alert users when to take the medication. However,

Strengths:	Weaknesses:
This product does not have limitations concerning gel capsules or gummy medications, or half pills; It does not handle liquid or non-room temperature medications, although it can "remind" you about them.	Does not organize the pills into different doses inside the system, the product assumes that the caregiver will do the pill organization; Without internet connection, the connection is via conventional landline; Does not have a web portal or App; In case to do additional changes, it requires adjusting the loaded pill containers in the machine or contact Support Center; No online monitoring report; There is not the ability to record specific messages so that the system can communicate in the end-user voice rather than the voice of a robot or a beep; Old-fashioned design, large and not attractive.

Table 2.4: Phillip strengths and weaknesses

Strengths:	Weaknesses:
Reminder system for non-pill from medications such as insulin, inhalers, etc.; The system has a bar-code scanner / camera that can recognize bar-codes and QR codes on pill bottles, as well as a database of various medications; Option to set up a password to protect the dispensing of medications; Notification to caregivers in case someone may be tampering / lifting / tilting the device; Clinically proven; Neutral aesthetics design.	Difficult to travel with, the device is large; Only English language; Small screen, what can be challenging for people with significant visual impairment.

Table 2.5: MedaCube strengths and weaknesses

Features	**SelfMed**	**Hero**	**Pillo**	**Livi**	**Phillips**	**Medacube**
Automatic Pill dispenser	Yes	Yes	Yes	Yes	Yes	Yes
Pill storage	480 pills, up to 16 different	90-day's supply, up to 10 different	28 doses	15 doses	60 doses	Up to 16 different and 90 days
Web	Yes	Yes	Yes	Yes	No	Yes
24/7 Support	Yes	Yes	Yes	Yes	Yes	Yes
Video-calling with carers	No	No	Yes	No	No	No
Professional pill refill	Yes	Yes	Yes	Yes	Yes	Yes
Travel pills dispensing	Yes	Yes	N/A	Yes	Yes	Yes
Battery backup	24+ hours	No battery	6 hours	8 hours	18 hours	24 hours
Emergency pills	Yes	No	No	No	No	No
Language preferences	Yes	No	No	No	No	Commands in different languages
Smart band integration	Yes	No	No	No	No	No
Cost (for end-user)	Starting €19.99 / month	$99.99 initiation + $29.99 / month	$299.99 + $9.99 / month	($1499 + $30 shipping + $24.95 / month)	$59.95 / month	$1499

Table 2.6: Direct Competitor Analysis

these devices do not safeguard the conservation of medicines, communication with the system, modularity in storage, efficient and intelligent management.

The patent US2006/0266763 A1 discloses an automatic tablet dispenser, which has a microprocessor and some interesting features. However, this model does not allow connection to external servers. The model does not allow updating the medication remotely. Pills are stored in such a way that doses cannot be changed, and there is no flexibility for changes during normal operation, if necessary. The tablets are kept outside the blisters, which can be a factor in their contamination and reducing their effectiveness. There is also no efficiency in the use of tablet storage space. It has no emergency sockets and the possibility of communication with a smart bracelet or other local device.

Documents US2014/0097194 A1 and US2014/0131378 A1 present automatic tablet dispensers with a mechanical arm that integrates an aspirator that takes the tablet to be dispensed from the storage section and delivers it to the collection box.

The patent US10555873 discloses a modular tablet dispenser system. This model does not allow communication with other devices, relevant for user authorization to the dispenser and to extend the alarm range of the dispenser. Medication is sensitive and can be dangerous or harmful if unauthorized users gain access to it. The template does not provide a way to verify the user's identity. The dispenser alarm may not be noticed by the user, if necessary, passing the information to other devices allows a greater reach of the dispenser alarm, increasing the efficiency of the dispenser, the chances of perceiving the alarm and taking the medication.

The proposed idea is the development of a modular device, automatic and intelligent, with low production cost to enter the international market. Thus, a model of a tablet dispenser with mechanical, electronic, and computer parts was developed to store, organize and dispense the medication prescribed to users.

2.3 New Concept

As previously mentioned, non-adherence to prescribed medication is a global problematic, with many factors. After analyzing the problem and the current solutions, a new concept was created. The new concept is an integrated and smart ecosystem.

2.3.1 The Ecosystem

The smart pill dispenser device developed in SelfMed project and in the previous work [18], is a very capable machine that can store, dispense and give alerts of medication. It has sensors, a communication system and other features that can assist the user. However, there are other factors related to non-adherence that could be addressed.

Taking in consideration the pill dispenser, the communication system already in the device, and the necessity of addressing other factors of non-adherence, an ecosystem focused on improving quality of life, well-being, medication management and active lifestyle was created. This ecosystem integrates the pill dispenser device with a smartwatch, mobile application, website, intelligent systems in the cloud and a service.

In the figure 2.1 it is represented the ecosystem. It is possible to see the structure of the ecosystem and some connections between the different devices and systems. Although many of the systems are not yet under development, the ecosystem concept can increase the benefits for the clients.

An important part of the ecosystem that is not represented in the figure 2.1 are the carers. They can have access to the ecosystem and the patient's information, with prior authorization from the clients. After being authorized, the carers (formal and/or informal) can edit prescription information and remotely have access to all the ecosystem data. The carers can have direct access to the website and the mobile application.

2.3.2 Smartwatch Application

The ecosystem aims to integrate the pill dispenser with a smartwatch. For that, a smartwatch application will be developed. This application allows an out-of-shell smartwatch to

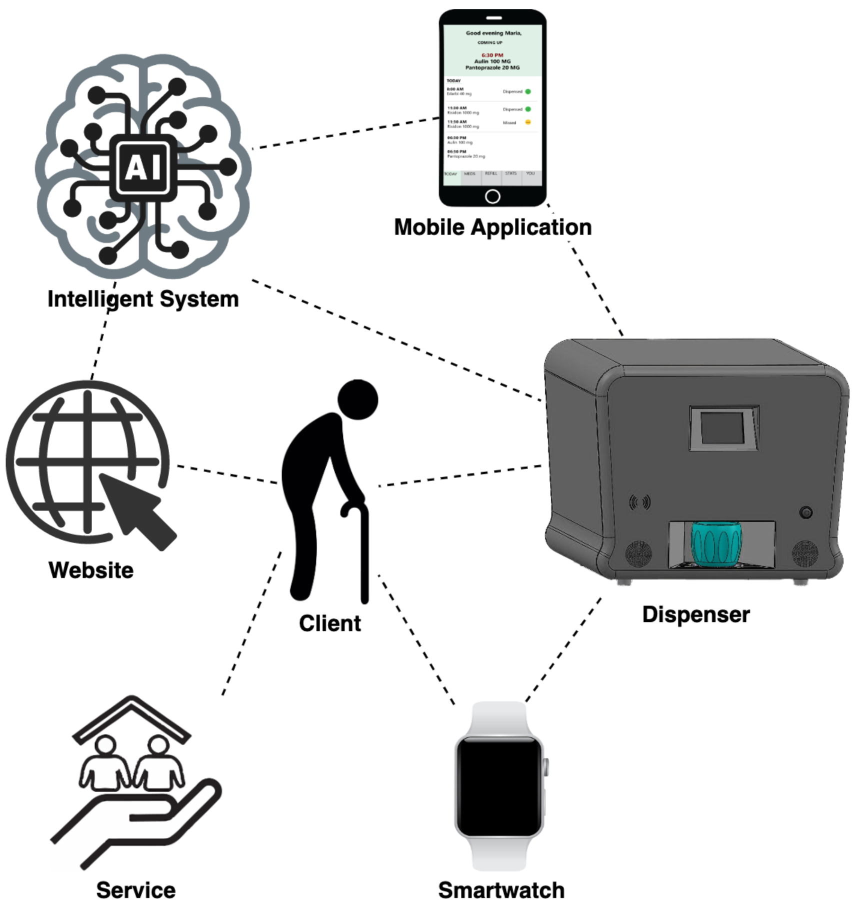

Figure 2.1: New ecosystem concept

communicate with the ecosystem. The main functionalities of the smartwatch application are: extending the medication alarm range, authentication of the client and collection of data.

The pill dispenser is a device that will be installed in the house of the client. The machine should be placed in an easy access position. The machine alarm is according to the prescription information introduced, however, it could happen that the client it is not close to the device. The sound volume can be personalized to the costumer's needs, nevertheless, the user may miss the alarm. In such case, the dispenser can snooze the alarm and set again a little later. The smartwatch application can be used to extend the range of the alarm of the pill dispenser. When the client is using the smartwatch, the alarm will always be noticed.

The integration of the smartwatch application can be further explored with the authentication of the user. When the alarm is noticed, the client will stop the alarm and the dispensing of the medication will start. The smartwatch can be used to authenticate the customer, stopping the alarm and triggering the start of the medication dispensing.

Additionally, the smartwatch can assist in the data collection. The data collected is sent to the intelligent systems for processing. The same information can be used for different purposes, to improve the active lifestyle or the security of the patient. Intelligent systems can create automatic alerts and notifications in the smartwatch to incentive the clients to walk more, for instance, which can make a difference, when it is done regularly. According to Centers for Dicease Control and Prevention (CDC), as an older adult, regular physical activity is one of the most important things you can do to prevent or delay many of the health problems [19].

2.3.3 Website and Mobile Application

The website and mobile application allow the user to manage all the information from the ecosystem. After logging in, the user has access to all the data of the ecosystem. This information includes the data from the prescription and the users. These interfaces enable the local and remote control of the ecosystem. Both, the website and mobile application, allow the user to change the dosage if needed, without being close to the dispenser. In case the user that is doing the changes is a carer, there will be no need to go to the older person's house to do these changes. There is also the possibility to dispense emergency pills, if needed.

The mobile application goes a little further and offers also local control of the dispenser. The application enables the user to directly synchronize information with the dispensing device.

2.3.4 Intelligent System

The intelligent system is composed of a network of servers to connect all the different platforms and devices. This system enables most of the communication in the ecosystem.

This system in envisioned to receive, store and process all the information of the ecosystem. According to the data received, the system can create alerts (in case the medicine was not taken, for instance), notification (in case the medication was properly taken, for example), or reports (pills intake reports).

The current backend is being developed using Spring Boot and MariaDB. Spring Boot is an open source Java-based framework used to create a microservice. With this framework, it is possible to establish a Representational State Transfer (REST) Application Programming Interface (API). Other devices and systems can access the API by using HyperText Transfer Protocol (HTTP) requests in JavaScript Object Notation (JSON) format.

The backend is responsible for the management of the database. The current database is being developed using MariaDB, a relational database fork of MySQL. Spring Boot can manage the database and do the Create Read Update Delete (CRUD), the basic operations of a relational database.

2.3.5 Service

The service in this ecosystem can be viewed in two ways, the first is the services that will be provided to the final customer, and the second is a system administration service. The service provided to the end-user includes the installation of the devices and systems, the refilling of the pill dispenser device and the maintenance of the ecosystem.

On the other hand, the system administration services enable all the ecosystem to keep connected. It includes the maintenance and updates of the systems.

2.4 Market Overview

Before introducing a new product to the market, it is important to understand this market. The understanding of the market will contribute to the success of the new product and/or new company.

A clear definition of the target market helps focus on the important features of the products and in the communication with that group of customers. Knowing the customers benefits the companies can understand of their behaviors, and offer better products and services.

2.4.1 Startup Identity

Balvia Ecosystems is the startup that will commercialize the ecosystem that was previously introduced. This company is not yet established, but when the products of the ecosystem will reach a maturity close to the market, the startup will be officialized.

Balvia is a technology based company that will be responsible for the manufacturing, distribution, commercialization, and continuous development of the product of the ecosystem. The legal structure is expected to be a limited liable company, with the headquarters in Bragança.

2.4.2 Target Market

The main target group are people suffering from chronic diseases, with a focus on elder people, since the consequences of non-adherence to medication are more severe for them. The other target groups are the care houses and health institutions, where the ecosystem will help all the service actors create a healthy ecosystem for older adults.

Balvia Ecosystems has segmented the target market geographically into both domestic and foreign. This plan focuses on Balvia potential domestic customers. Once established, the expansion into foreign customers becomes potentially rewarding.

Demographic segmentation did not involve any race, religion, caste, gender issues, rather it includes: Age, Income, Location, Lifestyle, Values, Interests.

Age: The baby boomers, born between 1946 and 1964 and Generation X, born between 1965 and 1981. The people born in this generation have specific similar characteristics and thought processes.

Income: Income is also one of the crucial variables, as it decides the product's pricing. Balvia is offering the products through a membership service, that will include an initiation fee and a monthly payment. Balvia Ecosystems focuses the sales of the pill dispenser in the B2B channel.

The current subscription and payment models are:

- Payments with initiation fee - option where it will be charged an initiation fee and a monthly subscription fee, depending on the type of service. The basic service will start at, approximately, €19.99 and will be increased according to the options of service selected by the customer. The monthly fee shall not be more than €70 for the most premium service with all options. The initiation fee will be between €150 and €300;

- Payments without initiation fee – option where it will not be charged an initiation fee, however the monthly subscription fee is higher than the previous option. With this option, the client doesn't have to make a large payment in the beginning.

Nevertheless, with further development of the business, the models can be modified.

It should be highlighted that these price ranges were defined based on equipment and service costs estimation, as well as end user perception of fair fees for the described service.

The table 2.7 shows the target groups of Balvia Ecosystems.

Customer	Age	Location	Lifestyle	Values	Interests
Primary end-user group	55+	EU	Retired, Polypharmacy, Low activity	Family, Healthy aging, Happiness, Comfortable life, Good health, Safety	Family, Traveling, Gardening
Secondary end-users Group (Formal carer)	18+	EU	Employees in Medical care	Helping people, Work in medical care	Working to help people
Secondary end-users Group (Informal carer)	18+	EU	Active family members, Close friends, Neighbors	Family security, Freedom, Happiness, Good health	Taking care of family
Tertiary end-users	18+	EU	Employees in Medical care	Customer satisfaction, Good relationship with clients, Provide service for all people in need	Profitability of the business

Table 2.7: Target groups

Primary end-user group: 55+ multi-morbid adults taking three or more prescribed medications, and patients burdened by many medications (organization wise), or having mild cognitive impairment that makes it difficult to keep good drug adherence. These patients have a complicated medication regimen to fulfil each day. The system will remind them to take the right medication at the right time, alerting with the help of sound, voice, light, and vibration according to the patient's preferences. Hence, our primary end-users can have the solution to their complicated medication regimen, which eventually improves the quality of their life by elevating their health overall. Apart from that, this can save elder people from spending unnecessary money on care, workers, and hospitals for just not taking medication as prescribed to take. Consequently, they can lead independent and stress-free lives with dignity apart from their age. The smartwatch will be easy to operate for a literate user, however it will be difficult for the people with vision impairment without any assistance, but we will make it as simple as possible for our elder adults to be able to operate easily. It is the best product or wise decision for those who can remember a few things like; the alarm is for medication (distinguishing ability, visibility, and can feel and take out the medication fall in the cup and again remember to take it. Also, physically able to move.

Secondary end-users Group: Informal carers: family members, close friends, neighbors who provide care to primary group, and formal carers in charge of, or helping with medication plans are make the secondary end-users. To this group, the dispenser allows remote tracking and facilitates the connection to the patient. They will be able to visualize the pill dispenser information, and, overall, accompany the health evolution. The system can also be used by care houses, and social services providing peace of mind for informal carers. It will help them to save money and time for travelling, hospital for emergencies, and appointing carers. As a result, they can have healthy mental, physical, and psychological health in order to carry out their daily jobs in their own household and private life job. The application and website of the product will help them to monitor their users.

Tertiary end-users: Physicians, nurses, pharmacologists, and other relevant stakeholders as well as health-care systems benefit from improved medication adherence. The aim is to provide products and services to a substantial market through these means, in order to sell by celebrating partnerships.

2.4.3 Customer Profile

The products and services provided are for low-end clients to high-end clients, who mostly, live alone or only with their elderly partner away from their family and carers on top have a complex medical regime and find difficulty to manage them multiple times each day. The target is people over 55 years old as a primary client. Their family members, loved ones, carer, and nurses will be counted as a secondary end-user. Similarly, policymakers, health institutions, health companies are considered as tertiary end-users in this project.

The different packages created with the features of the products will be targeted to the different customers profiles. The basic packages will include the minimum and most necessary features and will be targeted to low and medium - end clients. The more complete packages with extra functionalities will be targeted to medium and high-end clients.

2.4.4 Opportunity

With the current state of the market and society, there is a huge opportunity for products in the non-adherence field, to assist the elder manage their medication. The growth of the elder population, advancing of technology, and increasing adaptation of technology are some of the factors that contribute to this opportunity.

In 2020, according to Global Market Insights (GMI), the automatic pills dispenser global market size exceeded USD 2 billions, and is projected to grow at an Compound Annual Growth Rate (CAGR) of over 9.5% between 2021 and 2027 [20]. The global market of the automatic pills dispenser is already substantial, and it will continue growing.

A recent report from WHO shows that in the next years the population will continue aging. The report mentions that between 2015 and 2050, the proportion of the world's population over 60 years will nearly double from 12% to 22% [21]. It is extremely important to provide these citizens a healthy aging.

Chapter 3

Balvia Ecosystems Structure

The present work is in the scope of the “Automatic pills dispenser device - SelfMed” project. It continues the development of the prototype of an automatic pill dispenser device, and introduces the concept of an integrated ecosystem.

The prototype is composed by mechanic components, electronic hardware and a management system. In the mechanic components is included an exterior body that was made using Rapid Prototyping Technologies (RPT), interior components and motors. The electronic hardware is composed by controllers, sensors, PCB, and other components that will be necessary to implement the required functions. The management system will control all the hardware of the prototype.

In the end of the SelfMed project, a functioning prototype is expected, it will have the required features-set and will solve the problems that were established in the beginning of the project, and mentioned in the chapter 2.

The pill dispenser will present a fully automatic device, with a smart system and communication with servers. It is automatic because it can perform the tasks without human interference. It can automatically set off the alarms, dispense the medication, and update information. The device has a large capacity of storage for medicine, it is capable of storing close to 500 pills of one gram, enough for most people for a month period. With the modular system, it is possible to replace the module with another one with smaller compartments, enabling the storage of a higher amount of smaller pills.

The smart components of the device are the microcontrollers that are capable of communicating with servers from outside and adapt to the need of orders. In case of a dosage change, the dispenser can receive the new information, save it and implement the changes in the dosages.

Other features are offered by the machine, namely security of the pills. When bought, many pills are provided in blisters, which helps to preserve the state of the medicine. Taking the medication out of the blisters can contaminate the medicine, and eliminate the active principle. It was already previewed in the design of the containers of the dispenser to store the medication within the blisters, to better preserve and secure the medication. Similarly, it is foreseen a lock system for the storage compartment and the hardware. Jointly with the verification before dispensing the pills, these features will ensure the protection of the machine and the medicinal products.

The present work is on the second stage of development of the pill dispenser prototype. In the first stage, the first concept was developed and an early stage prototype. That prototype was made using breadboards and included basic functionalities.

An integrated ecosystem increases the benefits for the clients. Although the pill dispenser has many features, the inclusion of that machine in an ecosystem expands the advantages for the clients, improves user experience, and provides assistance in more areas.

3.1 Ecosystem Architecture

The overall architecture of the ecosystem includes different devices and platforms, that together composes it. Although, the scope of the present work does not include the development of all the ecosystem, this section contains a description of the complete architecture of the integrated system.

One of the pillars of the ecosystem is modularity. This is also used in the different parts of the ecosystem. Creating modules, and later on connecting them, allows for development and updates without editing all parts. In the figure 3.1 it is possible to visualize the modules of the ecosystem. Each module can be modified with few or any changes in other modules. For instance, even if the platform and language of the mobile application would be changed, the back-end can stay the same. The communication between these modules is made via JSON, so, there is no need for modifications in the back-end. The back-end is the group of servers that form the intelligent system of Balvia Ecosystems.

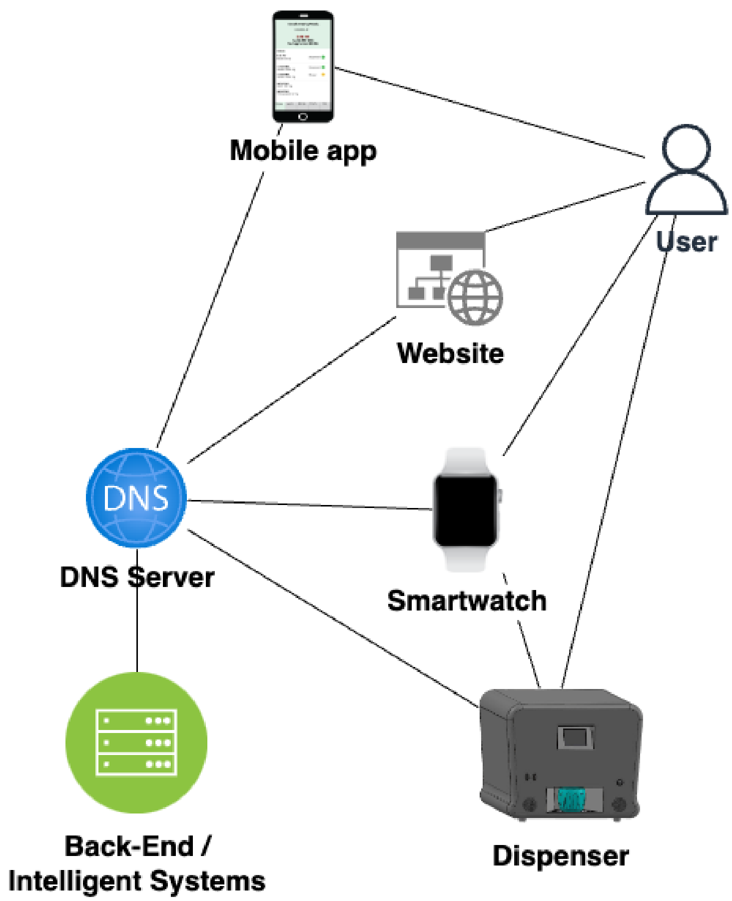

Figure 3.1: Ecosystem modules

The implementation of the architecture of the ecosystem requires financial investment, knowledge, and time. As Balvia does not have, currently, the financial investment and all the necessary knowledge, the implementation of the ecosystem will occur in phases. At the present, the development of the mobile application did not start. Furthermore, the execution of the back-end will be in three phases. In stage one, there will be implemented the essential services. Phase two includes an upgrade, and stage three there will be the full ecosystem.

At the moment, the back-end is in phase one.

3.1.1 Back-end: Phase One

The phase one of the development of the back-end continues after the conclusion of the present work. The structure that will be implemented during this phase is represented in the figure 3.2.

The domain of Balvia is currently on GoDaddy, the back-end and the front-end will be in Amazon Web Services (AWS). In this phase, there should be implemented a simpler back-end, with simple notifications services, API access for the users and machines.

The execution of phase one already started, and the structure is converted into services. The figure 3.3 shows the services currently being utilized. The platform GoDaddy is hosting the domain of Balvia Ecosystems. The Domain Name System (DNS) in GoDaddy forwarding requests to Route 53 service of AWS. DNS enables the user to use the domain name instead of the Internet Protocol (IP) address (users search for "balviaecosystems.com" instead of the unique address of the server). The service Route 53 receives all the request made to the domain and forwards the request to the appropriated channel. The requests can be forwarded to CloudFront or Application Load Balancer, according to the type of request. All requests use the certificate created for the domain by Amazon Certificate Manager (ACM).

The static website (front-end) is being hosted in a S3 bucket. This service allows storage and remote access to data. On the other hand, the back-end is being hosted in a Elastic Compute Cloud (EC2) instance, connected with a database in Relational Database Service (RDS).

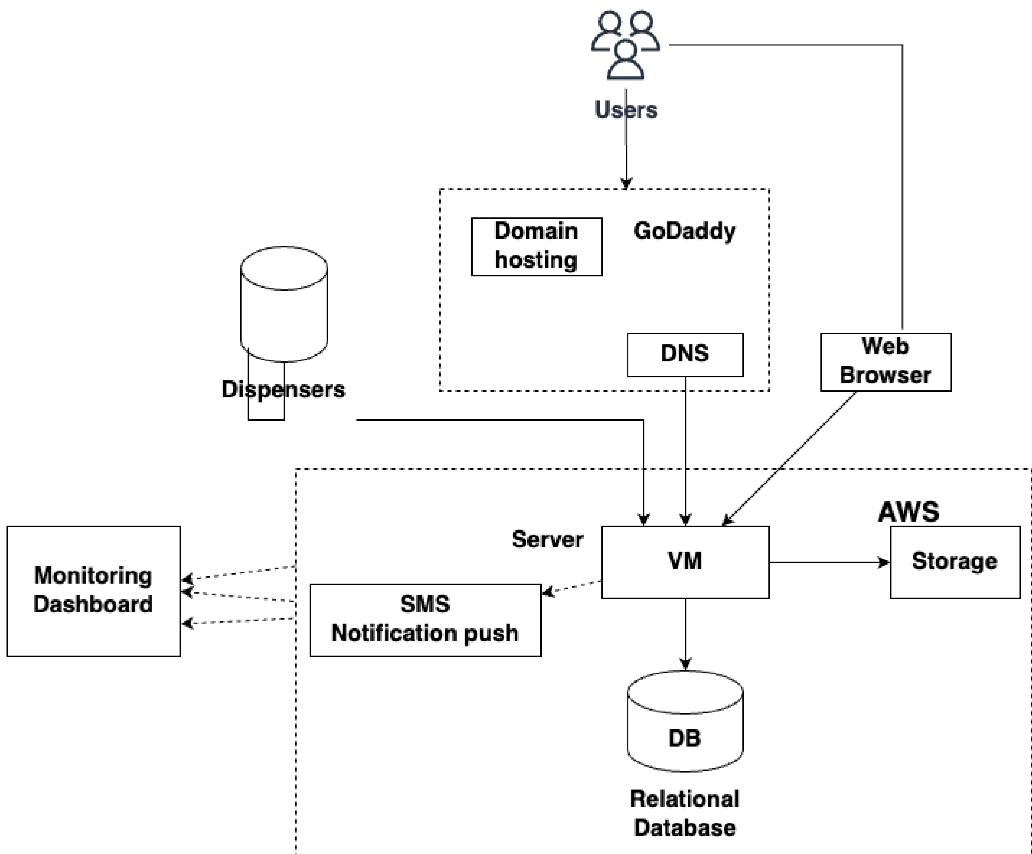

Figure 3.2: Structure of phase one of Balvia's ecosystem

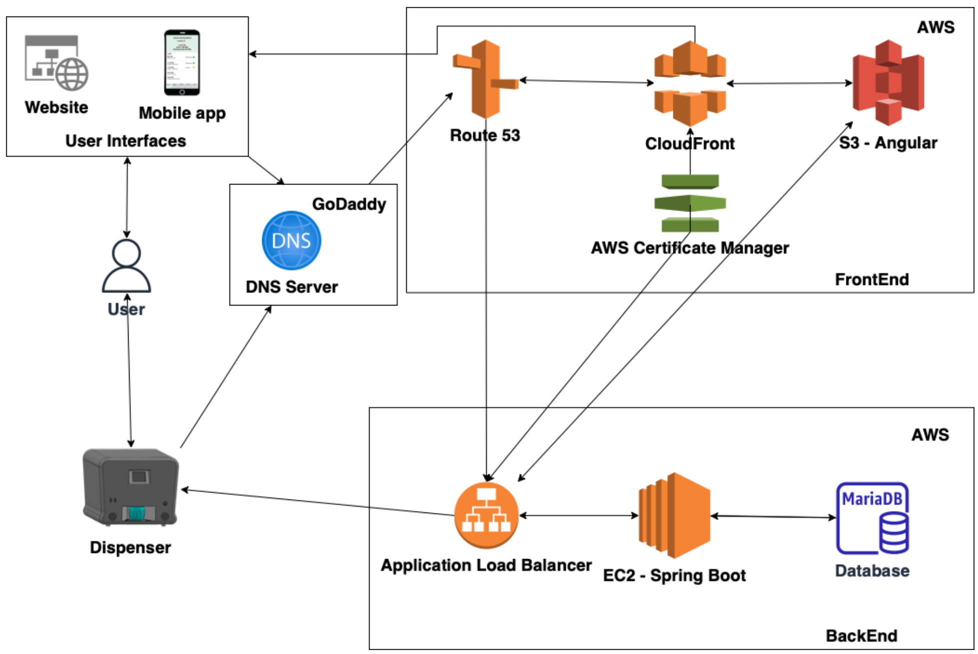

Figure 3.3: Services of phase one of Balvia's ecosystem

3.1.2 Back-end: Phase Two and Three

With the increase of users, functionalities and business, we expect the back-end necessities to grow. This will lead to the implementation of phase two.

Phase two includes and supports functionalities for mobile users, business intelligence and better structure of servers. In the figure 3.4, it represents the structure of the phase two back-end.

This is a transitioning phase, from the essential features to the full ecosystem. It enables the consolidation of some functionalities while inserting others.

The most complete phase we have envisioned is phase three. It includes all the functionalities we aim to implement in the ecosystem. Currently, there are no features we want to implement that are not supported in this phase. However, with the real implementation of the ecosystem and the business, jointly with the client's feedback, other phases can be implemented. The new stages would insert newer features to the back-end of the ecosystem.

The image 3.5 shows the structure for the back-end of phase three. The structure will

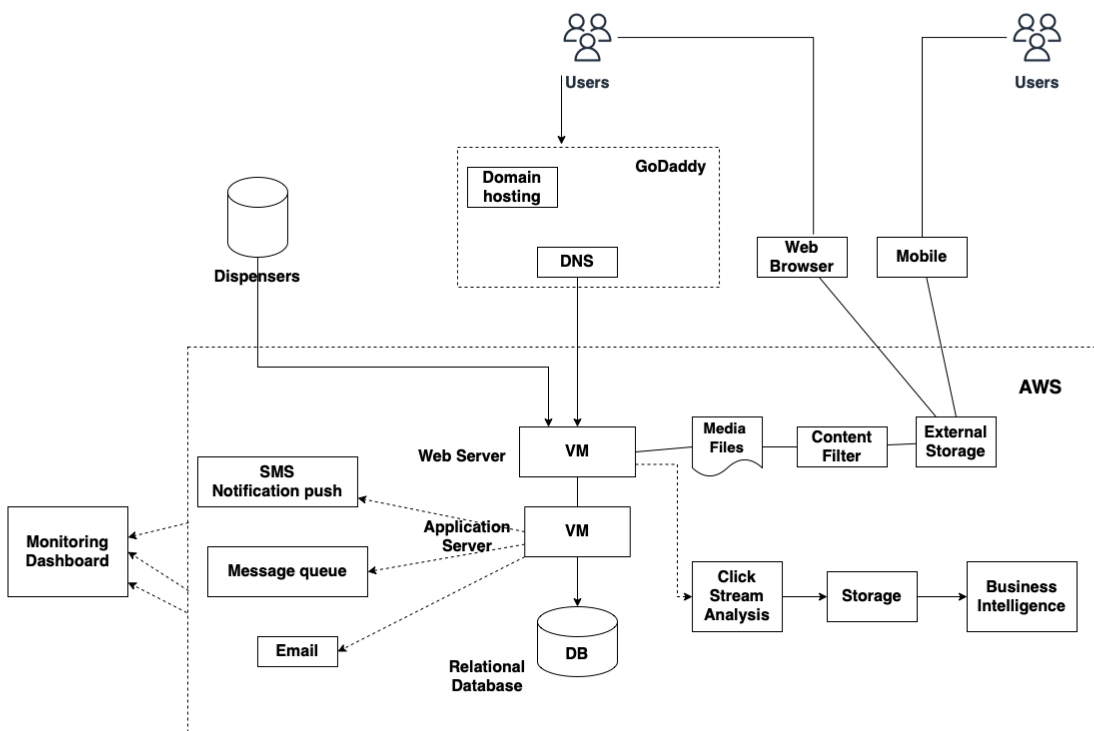

Figure 3.4: Structure of phase two of Balvia's ecosystem

be later converted into the appropriated services.

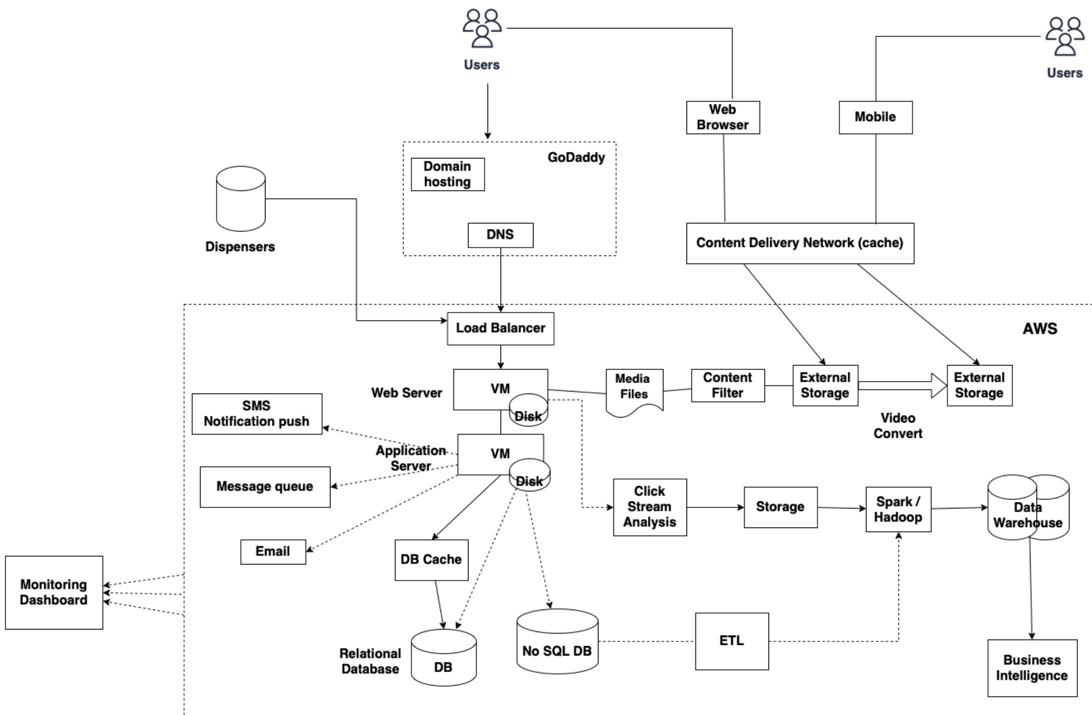

Figure 3.5: Services of phase three of Balvia's ecosystem

3.2 Pill Dispenser Design

The design of the pill dispenser enables many important features. Starting with the modular system, the delivery mechanism and the modules.

In the current state, the aesthetic design is not the main concern, however it is always kept in mind. The main guideline for the aesthetic design in this development phase is simplicity, because the device will be installed in the house of the client, therefore it must blend in with the furniture.

Furthermore, the design took in consideration the device operation, the different users and the accessibility. After installing the pill dispenser in the house of the client, once a month an authorized person will refill the machine. The refilling process must be fast and straightforward.

3.2.1 Modular Storing System

Overall, the dispenser's system is intended to be modular, from the storing mechanisms to the communication. The modularity will assist in the reduction of costs and increasing efficiency.

The storing system is composed by modules that can be inserted and removed. Inside these modules are stored pills, with a different type of medication. The modules can have different compartment sizes, making it easy to store the medicine efficiently. For smaller pills, modules with smaller compartments can be used. During the refilling process, the modules can be filled beforehand, and just inserted in the dispenser.

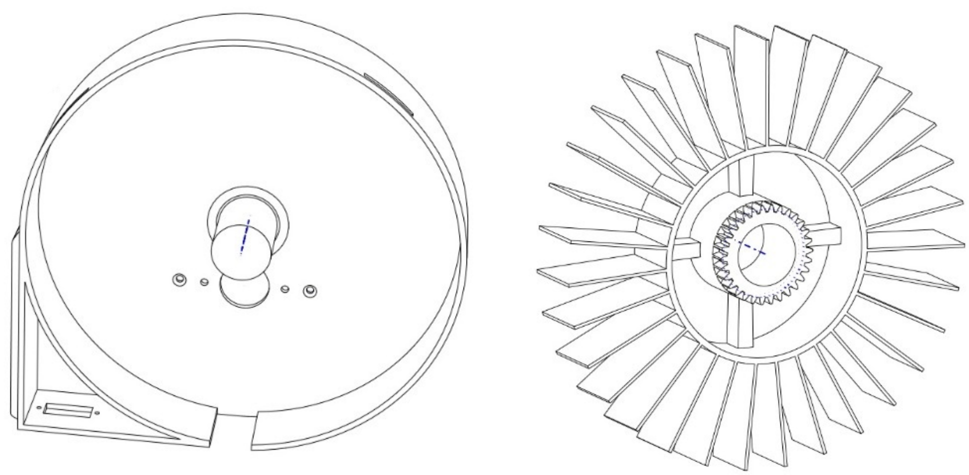

Figure 3.6: Pill dispenser module

In the image 3.6 it is possible to observe a module of the pill dispenser. On the left, there is the base of the module and on the right the partitions component. The figure 3.6 does not present the cover of the module, but the storing module has a lid. When the partition component is inside the base, the pills can be stored inside the open compartments of the partition, and the cover will protect the medicines. Each module has attached an actuator to rotate the internal components. It also has a connector to link the actuator with the management system. Furthermore, on the base of the module, there is a connector that allows the management system to control the motor and the dispensing of the medication.

With the design of the storing module, we can change modules to increase storing efficiency without changing the size of the dispenser. For smaller pills, the module can have smaller partitions, storing a higher amount of pills. For larger pills, the partitions size can change again without changing the overall size of the module nor the dispenser.

3.2.2 Delivery System

The modular storing system jointly with the delivery system enables the pill dispenser to efficiently and safely dispense medication.

The modules actuators rotate and release the medicine in a chute, that will forward the medication to the delivery cup. This is a channel made of plastic that can forward the medicine to the intended destination.

Throughout the delivery system there are sensor and vibration motors. The sensors help the management system be aware of any errors during the dispensing. In case a pill gets stuck in the delivery channel, vibration motors can be activated to move the medicine towards the delivery cup.

In the figure 3.7 it is possible to see an image of the pill dispenser without the front cover. The number of the figure is the delivery chute, where the pills fall after being dispensed from the module. This chute has sensors to ensure that the medication was released from the module. The number 4 is the delivery cup. The delivery chute forwards all the medicine to the delivery cup. The cup also has sensors to guarantee that the pills arrived. In the number 5 it is represented the guides for the modules. These guides help insert the modules inside the pill dispenser. The number 10 is a module that contains medication.

3.3 Pill Dispenser Hardware

The electronic components enable the feature of the dispenser.

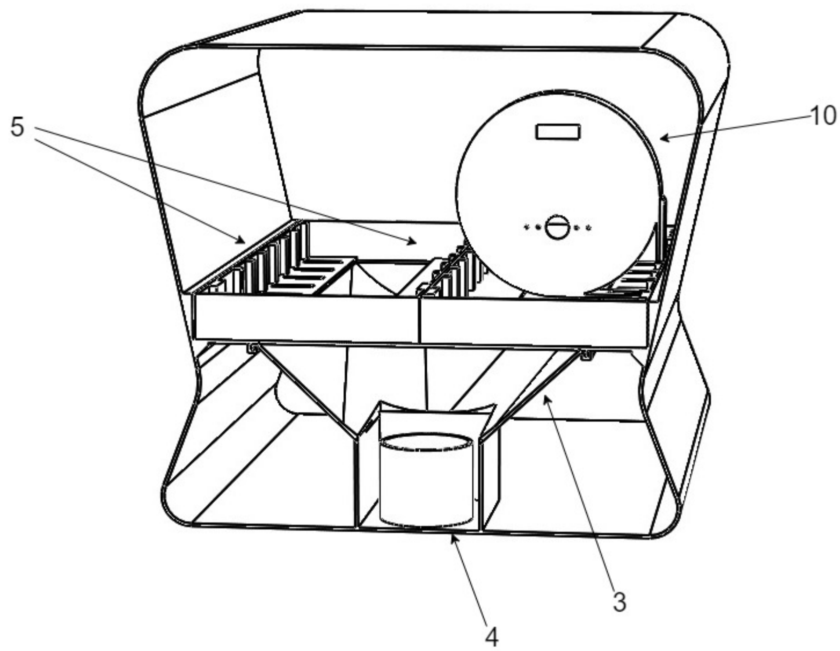

Figure 3.7: Pill dispenser device: 3 - delivery chute, 4 - delivery cup, 5 - module guides, 10 - module

In the beginning of the prototype, the components were connected through a breadboard. However, this was improved, the components used now are in a PCB. The passage to a PCB is an important step in the development of the prototype.

In the figure 3.8 it is possible to see the main electronic components of the pill dispensing device.

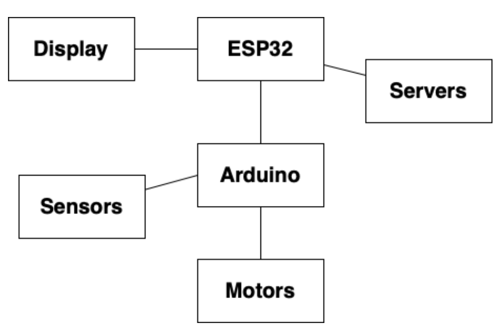

Figure 3.8: Electronic components of the pill dispenser

3.3.1 Microcontrollers

The different components of the dispenser enable different features. During the selection process, the characteristics of each component was analyzed and compared to the products available in the market.

To manage the other components, we selected ESP32 for a higher management and Arduino Mega2560, for a lower level management. ESP32 microcontroller connects the dispenser with the outside world. Using the built-in Wi-Fi and Bluetooth. The selected board was ESP32 DevKit. With many ports, high processing power and low cost, this microcontroller can exchange information with the servers and serve as leader for the other microcontroller.

ESP32 is a microcontroller developed by Espressif Systems. It is a low-cost, low-power System on Chip (SoC) and very capable. In the table 3.1 it is possible to see the specifications of the ESP32 WROOM 32D, acting at a higher level than the Arduino.

An alternative for ESP32 microcontroller is the Raspberry Pi. This line of micro-computer has many features, including high computing process, internal memory, and operating system. It allows connection with many devices. However, for the pill dispenser prototype, we selected ESP32, because it is cheaper, robust, consumes less power, has a quicker startup due to the operating system, the language is very easy (C/C++ programming language), and still has good processing power and connecting ports.

In a lower level, Arduino Mega 2560 was selected to control most of the peripherals. The huge Arduino community, many projects available and libraries makes this platform very easy to develop on. From the many Arduino boards available, the Mega 2560 was selected to the prototype due to the high number of ports. This allows us to connect to many peripherals without the need for extra components. In the table 3.2 there are represented the specifications of the Arduino Mega 2560.

Both Arduino and ESP32 microcontrollers can be programmed using the Arduino Integrated Development Environment (IDE), another advantage of using both together. However, the platform selected for the software development was VS Code, due to the attributes the program offers. To allow the connection between VS Code and the microcontrollers, it was installed PlatformIO, an extension that facilitates the connection.

3.3.2 Motor

Each module of the prototype has a motor attached, and we intended to keep the size of the machine as small as possible. Therefore, the size of the motor was very important. Other features of the motor that were considered in the selection phase were the weight, the voltage, the torque, and precision. After many attempts, we selected the SSTC360030. It is a small motor, with high precision and weight only 50 grams. The component functions in a circuit of 12 volts, which is compactible with the pill dispenser circuit.

3.3.3 Display

In the early stages, the display was only an Liquid Crystal Display (LCD). After many iterations, the prototype has now a Nextion display Intelligent Series. Nextion is an Human Machine Interface (HMI) solution that combines an on-board processor and memory in a touch display [22]. This display is very capable, it allows for programming inside the components itself, that later is connected with the microcontroller.

The figure 3.9 represents the Nextion display.

With the select Intelligent series comes added features, such as:

- Built-in Real Time Clock (RTC) - Built-in RTC that can be used in the projects;
- Improved Micro Controller Unit (MCU) - Up to 200 MegaHertz (MHz) MCU;
- Higher internal memory - Increased memory, including flash, Electrically-Erasable Programmable Read-Only Memory (EEPROM) and Static Random Access Memory (SRAM);
- Larger set of components - Greater number of components that can be used with the Nextion editor.

Figure 3.9: Nextion display 5 inches

Nextion editor, figure 3.10, enables the creation of programs for the Nextion displays. In this program, the interface of the display is created and functions can also be included.

In the interface, different components can be included, buttons, texts, numbers, and others. These are common components that all Nextion series offers. Each component can have different characteristics, such as fonts, name, identification. There are also components that are specific for the Intelligent series, the RTC, file stream, video, and audio playback.

Jointly with the components, code can be included in the Nextion displays. For instance, to have a clock on the display, a function can be made to take the values of the RTC and display it. Additionally, a component called a timer can be included to update the values every 50 milliseconds. With that, it is possible to always show the current time only with the Nextion display.

Nextion displays communication with microcontrollers using Universal Asynchronous Receiver/Transmitter (UART) ports. The code or component from the display can fetch or send data to the microcontrollers. For that, the microcontroller code creates the components on its side, correspondent to the display component. The correspondent

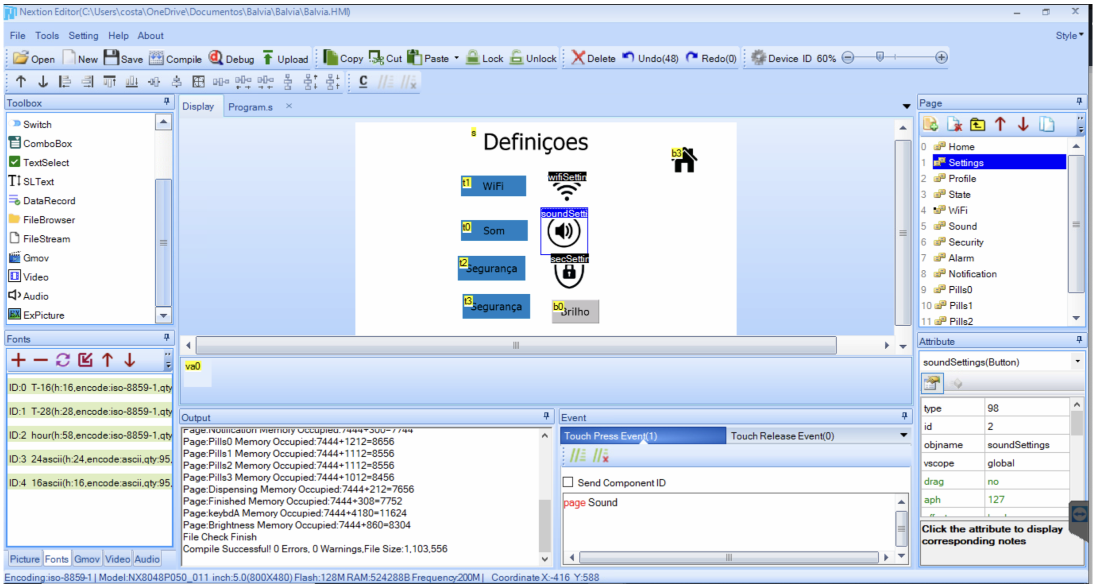

Figure 3.10: Nextion Editor

components on the microcontroller must indicate the page, identification, and name of the same component in the display. Using serial communication, the microcontroller is able to send, receive and process data from the display.

3.3.4 Others

The Infra-Red (IR) sensor will be used to verify if the pills were dropped, to know if any error occurred. There will also be used a load cell, to verify if the medicine arrived in the delivery cup and a magnet sensor to check if the cup was removed from the dispenser. This way there will be three verification phases, with those sensors to ensure the proper functioning of the pill dispenser.

The speakers are a computer set, with two speakers and a 3.5 mm jack connection. Between the speakers and Arduino, there is a MP3 module. It has a built-in amplifier and Secure Digital (SD) card. This module simplifies the usage of the speakers, controlling the connection and even the sound, namely the volume or the equalization.

Initially, to provide the electric power to the prototype, it was used a power supply machine of the laboratories where the work was developed and tested. The power source for the system was added later on, with a battery and AC/DC adapter. There are also converters that were placed to avoid damaging the components. The battery is a Valve Regulated Lead Acid (VRLA) with 12 Volts. Unlike lithium batteries, VRLA batteries can be plugged throughout the day and only charge the system when it is needed. The lithium batteries are better in a situation such as with smartphones, it is charged and then only charged again when the battery is low. We intend to create an Uninterruptible Power Supply (UPS) for the pill dispenser.

The module for the Radio-Frequency Identification (RFID) has an antenna that is able to read the RFID tags. This module is used for authentication, in the future it could be replaced by other technology. SelfMed project envisions having a smart band, in that case, the smart band could have Near Field Communication (NFC) or other technology that could be used for authentication. The RFID module was later replaced by a NFC/RFID module. The new module can read both tags, making the prototype more adaptable.

3.4 Pill Dispenser Management and Communication Systems

Two very important parts of the pill dispenser prototype are the management and communication systems. These systems increase the competitive advantage of the dispensing device. It allows the machine to be independent, receive and send information automatically, and the users an overall good experience.

3.4.1 Management System

The management system controls all the hardware of the pill dispenser. It can receive new information and process it. The management system is an event-based system.

The management system uses the ESP32 to receive and process all the incoming data, and also send information. When new data is received, it is first compared, to verify which information is more up-to-date. The overall system is event-based and asynchronous, it is possible for the servers and the dispenser to have different information. In case the connection was not possible in a certain moment or the information is very new, this allows the device and the systems to keep working normally until it is possible to update. The version of the incoming data is compared to the internal information of the pill dispenser. In case the incoming data is newer, the system updates the internal information and informs the servers.

The new information needs to be processed, sorted and saved properly. Internally, the dispensing device stores the full prescription information, enabling it to work without the connection to the servers. There is a full mapping of the medication, the exact module where each medicine is, the number of pills and the time period.

The management system always verifies the internal information to check when it is time to dispense medication. The system allows the two microcontrollers to communicate and exchange data. When it is time for medication, ESP32 sends data to Arduino requesting an alarm ring, and after informs the medicine that must be dispenser and the number of pills. Arduino returns the information with the errors, if any occurred.

3.4.2 Communication System

The communication is very important to allow data exchange, between the servers and the dispenser, but also between the microcontrollers themselves and the pill dispenser and local devices. Local devices can be a smart band or other device used to communicate with the dispensing device locally.

The communication with the server is through JSON. The information associated with all the dispensers is stored in a server, installed in a Infrastructure as a Service (IaaS) cloud server. The server is developed in SpringBoot, exporting a RESTful API and supported by a relational database (PostgreSQL).

The dispenser is capable of parsing the JSON information received from the servers. It is also able to create and send JSON messages to the servers.

3.4.3 Software Development Environment

The microcontrollers chosen can be programmed using Arduino IDE. It is a software that offers all the necessary tools to program and control the microcontrollers. Despite that, it has many issues when the development is on a big scale. The separation and organization of the files is not very much supported. Also, small, but useful extensions cannot be added. An example of that is the auto-complete, the programming with that is more efficient and with less stress, many times programmers have to lose time to verifying the structure of a function. Other features such as color differentiation and automatic indentation add to the efficiency. Due to the lack of these features and a prevision of a gradual growing in the program, lines and files, another choice had to be selected.

The chosen software was VS Code. A software made by Microsoft, one of the best in the market. The software offers connection with GitHub, which facilitates the group work. Additionally, it offers all the features necessary for efficiency and organization of a development project, including an easy expansion of the program.

VS Code offers many extensions that can help the programmer. To allow the connection with the microcontrollers, it was used the PlatformIO extension. This extension enabled an easy management of libraries, configurations of the devices, over the air updates and other features. The figure 3.11 shows the home page of the PlatformIO extension.

3.5 PCB

PCB is a more reliable, advance and improve solution to use instead of breadboards previously used. Unlike PCBs, breadboards are very useful for laboratory testing and building the first circuits. After these phases and having a circuit built, there is a passage to PCB.

The printed boards are composed by non-conductive materials with layers of copper. These layers of copper allow connecting the different components welded to the board.

The passage from breadboards to PCB allow the reduction of the space necessary for most of the components, namely, microcontrollers, MP3 module, 3.5 mm jack connector

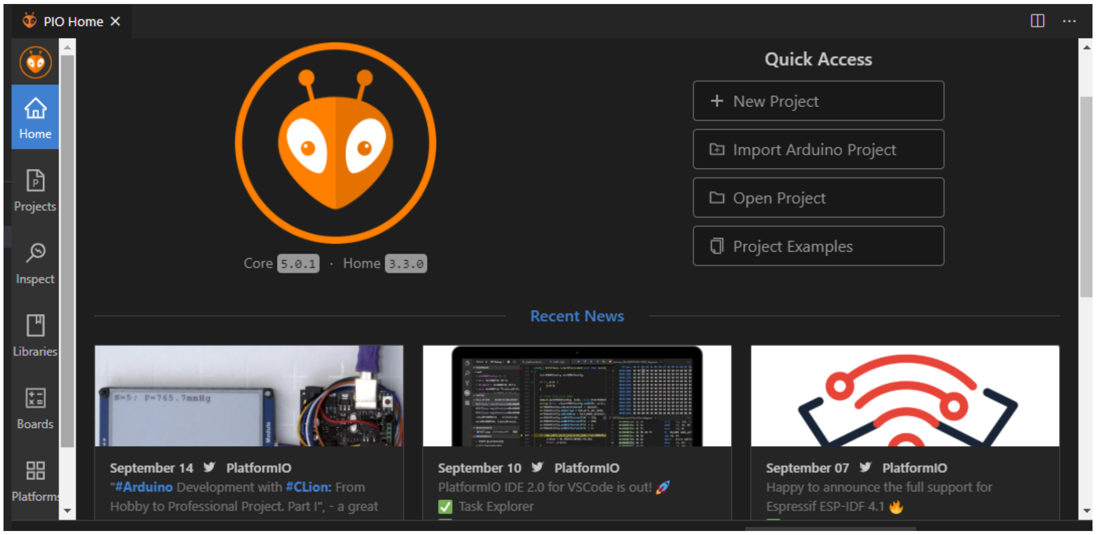

Figure 3.11: PlatformIO Home page in VS Code

and various pins. The circuit is more reliable, the risk for components to disconnect when moved is minimal.

3.5.1 PCB Development Environment

The PCB was developed using Fusion 360, an AutoDesk application. Fusion 360 is a cloud-based 3D modeling, Computer-Aided Design (CAD), computer-Aided Manufacturing (CAM), computer-Aided Engineering (CAE), and PCB software platform for product design and manufacturing[23].

The desktop application of Fusion 360 was downloaded and an account was created there. It is possible to share the project and other files from inside the app to another people. It can ease the work on a team, because all members can have access to the same files, and it is always updated.

Inside the Fusion 360 a project was created, with 2 distinct parts, one for the main PCB and the other of the drivers PCB. Bellow, there is an explanation for why the prototype has 2 boards. Each separate part have different files. The first file is for the schematic. There the components are included and the connection between the different pins of the different components are established. The second file is a PCB document. In this document, the components are placed and the circuit ways created. The last file is a 3D version of the PCB.

The schematic file allows the users to include specific components, that later will be included in the PCB. Fusion 360 offers many components, but others can be included from online libraries or other places. The component that will be welded to the PCB, and the component included in the schematic must be a perfect match, otherwise, in the welding phase, it will not work.

After including the components, the circuit can be created. The pins of the components can be connected to a route, that is part of the circuit. By simply giving the routes the same name, the software will later join them. To ease the all process, it is important to name all components with the appropriate name and description. Later on, and in the welding phase, it can be crucial.

The PCB document imports all the data from the schematic. There the size of the PCB is defined, the hole places and many other characteristics of the board. The following place requires many iterations, the components must be placed in a position that does not make linking the pins too hard. When the components are placed, there are two layers that can be used to connect the pins, the top layer and the bottom layer. Different connections in the same layer must not touch, it is possible to change the layer of a route using a via. All pins that were connected in the schematic must also be connected in the PCB document.

The final document is a 3D visualization of the PCB, and how the components will be after the welding.

There is a fourth file, however it is an automatic file. All the three previously mention files are connected and synchronized. This makes the development much faster, the components that are included in the schematic and also included in the other files. It works for all other changes in the parts that the files have in common, routes, component names, and others. The synchronization is enabled by the fourth file, it links all the other files, makes updates automatically and warns in case errors or inconsistency occur.

3.5.2 PCB Design

Inside the pill dispenser prototype, the bottom is reserved for hardware and dispensing cup. The available area must be divided between the different components. The PCBs will be placed inside that area.

All the components that can be welded in the PCB were included, others are not possible. Components such as IR sensors or display cannot be welded directly to the PCB.

Instead of a bigger PCB, we decided to make two smaller ones. There are benefits and drawbacks to this approach. With only one PCB there is no need for extra separation of the circuit or the extra components to connect the boards, that can increase the overall price of the PCB. However, in that PCB it will be harder to find errors or replace components, therefore we chose to have two boards. In more advanced phase of this project or the next evolution of the prototype, a test can be made to replace or not this design with a one PCB design.

The first PCB is the main board, with the microcontrollers, pins for sensors and other components previously mentioned. This board receives the power, converts it and feed all components, including the second board.

The second board is for the drivers. Each module of the dispenser had a motor attached, and each motor requires a driver to help control it. Thus, the second board has the same number of drivers as the prototype has modules.

3.6 Corporate Identity

Balvia Ecosystems is the startup that will take the pill dispenser prototype and the rest of the ecosystem to the market. The development of the first product of the ecosystem is in parallel with the creation of the startup identity and business plan. The corporate identity is how a company presents itself to the outside world.

Balvia is a technology-based company that develops hardware and software for medication management. The company strives to assist the clients in that department to increase their quality of life and health status.

In the table 3.3 it is represented the value's matrix of Balvia Ecosystems. In the first row, there is a synthesis of the mission, the vision, and the values of the company. In each row there are the different perspective the clients can have. The second row (mission) shows the expected view from a client's mind, heart, and spirit. The following rows display the same perspectives, however, for the vision and values of the startup.

3.6.1 Name and Logo

The name Balvia is an Invented Brand name. The letter B stands for Bruno, L stands for Laxmi – the first names of the co-founders of Balvia and A for Ana and V for Vera – the first names of the project coordinators. There are added vowels between to create a creative, quick to remember, and easy to read name, which best embody the brand's personality.

The logo of the Balvia Ecosystems is composed by two parts, a symbol and a typography. Overall, the logo has a simple design, and easy to read. The color blue was selected because of the meanings it represents, including trust, loyalty, sincerity, confidence, stability. The image 3.12 the main logo of Balvia Ecosystems.

Figure 3.12: Balvia Ecosystems logo

The symbol is a junction between Voronoi pattern and a circumference. The Voronoi pattern is a representation of the logic of the universe and nature as to its tendency to favor the efficiency: the nearest neighborhood, the shortest path and the strongest link, through the decomposition of a given space by the connection of dispersed points. The circumference is a symbol of globality, harmony and unity. Together they are Balvia Ecosystems. And this is the representation of the brand's values and purpose: A cohesive ecosystem that promotes efficiency, harmony, and proximity to people, helping them in their lives and health, through strong and lasting connections. The figure 3.13 shows the simpler version of the logo with only the symbol.

Figure 3.13: Balvia Ecosystems symbol

The last version of the logo is represented in the figure 3.14.

Figure 3.14: Balvia Ecosystems alternative logo

3.6.2 Mission

The main mission of Balvia Ecosystems is: “Provide quality tools to improve the community well-being, safety, and enhance communication between people.”

The company will develop and provide tools to assist the clients to prevent and erase the non-adherence of prescribed medication, improve their well-being, and safety. Furthermore, the tools will allow elder customer to live more independently, and with autonomy.

Balvia intends to decentralize the technological knowledge in order to ensure the basic principles of humanity.

3.6.3 Vision

Balvia’s vision is to be a leader in the development and delivery of innovative tools that contribute to the quality of life.

It intends to create a better everyday life for many people by developing an integrated smart health system composed of different devices. Balvia can secure and provide the correct medication taken by the older adult, with the goal of improving and stabilizing the health of the users, while promoting a secure independence of the older adult and providing useful information to informal and formal carers. Balvia intends to provide the medication management service and products to all people that need it. Assist to the improvement of the quality of life, strengthening relation and communication with carers, keep the client active and included in the society, boost their confidence and independence levels.

3.6.4 Recognition

Throughout the years, the concept showed in this work, and in SelfMed project was presented and submitted in many awards and contests.

One of the first ones was Promove Program of la caixa foundation and BPI Bank. It allowed the establishment of SelfMed project and the development of the prototype. The scientific and innovation progress allowed the project to further differentiate from current solutions of the market.

The concept was also submitted in Poliempreende 2021, 4th Mostra Nacional de Jovens Empreendedores, and Encontro Internacional de Jovens Empreendedores (EIJE). Poliempreende is a contest of the polytechnic institutes in Portugal. In the first phase, all students of each polytechnic compete with themselves, and the best project moves to the national contest. In 2021, the concept of this work was submitted in Poliempreende, winning the regional phase and moving to the national one. Due to the winning of the regional phase, the Instituto Politécnico de Bragança (IPB) appointed the idea to the national contest Born from Kownledge (BfK). Only winning projects can participate in BfK, where Agência Nacional de Inovação (ANI) awards the innovation and entrepreneurship of the applicants. There are four categories and many high quality innovative project, that already won previous contest. Balvia received the award for the category of artificial intelligence and advanced production technologies.

Mostra Nacional de Jovens Empreendedores is a contest promoted by the Foundation of Youth to foster entrepreneurship. In the 4th edition of this competition, Balvia concept was awarded the second place.

EIJE is a competition with young entrepreneurs from Portugal and Spain. Balvia concept won this competition.

Categories	Items	Specifications
	Audio	CVSD and SBC
Hardware	Module interfaces	SD card. UART. SPI, SDIO, PC. LED PWM. Motor PWM. PS, IR, pulse counter, GPIO, capacitive touch sensor, ADC, DAC
	On-chip sensor	Hall sensor
	Integrated crystal	40 MHz crystal
	Integrated SP flash	4 MB
	Operating voltage/Power supply	30V 36V
	Operating current	Average: 80 mA
	Minimum current delivered by power supply	500 mA
	Recommended operating temperature range	-40 °C +85 °C
	Package size	(18.00+0.10) mm x (25.50+0.10) mm x (3.10+0.10) mm
	Moisture sensitivity level (MSL)	Level 3
Certification	RF certification	FCC/ CE-RED/ C/TELEC/ KCC/SRRC/NCC
	Wi-Fi certification	Wi-Fi Alliance
	Bluetooth certification	BOB
	Green certification	ROHS/REACH
Test	Reliability	HTOU/HTSL /uHAST/T-T/ESD
Wi-Fi	Protocols	802.11 b/g/n (802.11n up to 150 Mbps)
		A-MPDU and A-MSDU aggregation and 0.4 us guard interval support
	Frequency range	2.4 GHz 2.5 GHz
Bluetooth	Protocols	Bluetooth v4.2 BR/EDR and BLE specification
	Radio	NZIF receiver with -97 dBm sensitivity
		Class-1, class-2 and class-3 transmitter
		AFH

Table 3.1: ESP32 specifications

Microcontroller Atmega 2560	
Operating Voltage	5V
(Input Voltage (recommended)	7-12V
Input Voltage (limit)	6-20V
Digital I/0 Pins	54 (of which 15 provide PWM output)
Analog input Pins	16
DC Current per 1/0 Pin	20 mA
IDC Current for 3.3V Pin	50 mA
Flash Memory	56 KB of which 8 KB used by bootloader
SRAM	8 KB
EEPROM	4 KB
Clock Speed	16 MHz
LED BUILTIN	13
Length	101.52 mm
Width	53.3 mm
Weight	37g

Table 3.2: Arduino Mega 2560 specifications

Company	**Mind**	**Heart**	**Spirit**
Mission: Contribute to community well-being, safety, and better communication	Technological tools for businesses and consumers	Promoting quality of life and well-being through innovative tools	Decentralization of technological knowledge to ensure the basic principles of humanity
Vision: To be a leader in the development and delivery of innovative tools that contribute to the quality of life	Create a link between technology and well-being	BFK Ideas Award for innovative projects	To be a reference as an entity promoting safety, health, comfort, and self-esteem
Values: Humanity, excellence, information, security, quality of life	The company develops quality tools to promote user autonomy and independence	Accessing the use of technologies to boost collective well-being	Implement practices that benefit the community in its personal and social development

Table 3.3: Values Matrix

Chapter 4

Balvia Ecosystems Development

The development chapter focus on the installation of the software that was used to develop the system, a description of the programming of both microcontrollers and the assembling of the hardware.

4.1 Software and Hardware Development

There were used different programs for the software development and the PCB. Below, there is a description of the software and libraries used.

4.1.1 Software development environment

The environment created in the previous work [18] was used to continue the software development. It included GitHub, for version control and VS code.

For the PCB development, Autodesk Fusion 360 was used. Fusion 360 is a cloud-based CAD, CAM, PCB and 3D modeling software platform for product design and manufacturing, developed by Autodesk [24].

First, a student account was created in the Autodesk website. All forms were completed and the necessary information given. The creation of the account allowed access to an executable file of the Fusion 360 program. After installing the program, the essential libraries were included to Fusion 360. The program requires components to be added in the project, it comes with many libraries pre-installed, however, these may not contain all the requires components for the PCBs. Therefore, other libraries can be added to ensure that all necessary components for the circuit boards are available.

With the creation of a project there generated four files: a schematics file, a PCB document file, a 3D PCB file and a linking file. The schematics file contains the scheme for the PCB, where the electronic components are inserted and the ports connects. When a component is added to the schematics files, all the data from the element is included, the port's information, the format, and all other important information. It is possible to create connect all the ports of the components, for instance the Ground (GND), the Voltage Common Collector (VCC) and other ports. In this file it is also possible to name the signals of each port, name components, and give other additional information for the signal that will pass or component.

The PCB document file contains the layout for the PCB. All components and connections created previously are passed to this file, and some features can be edited. The layout of the board is made in this file, the position of each element can be selected, screwing holes can be added and the whole circuit connections are made. For the boards developed, there were used two layers for the circuit connections.

The 3D PCB file contains a 3D design of the circuit board, represented in the figure 4.4. It is possible to visualize the final result of the board.

Finally, the linking files assists in the version management and to keep all files updated. When a change is saved in a file, the version increases and the linking file helps update all the other files. In case a change is made in the schematic file, the linking file will reproduce the change in the PCB document and 3D PCB files, increasing the versions and keeping all files updated. It is very important to avoid losing the track of the updates, it would be harmful to have a component in the schematic file and use a different one in the PCB document file.

4.1.2 PCB

The PCBs were designed using Autodesk Fusion 360. That software enabled the creation of the circuit for the board, and setting up the boards.

The first step in the creation of the PCB was the conception of the circuit. The circuit had to integrate all the necessary hardware for the functioning of the pill dispenser prototype.

The conceptualization of the PCB took into consideration the requirements for the dispensing device and the hardware. The early stage circuit created is represented in the figure 4.1.

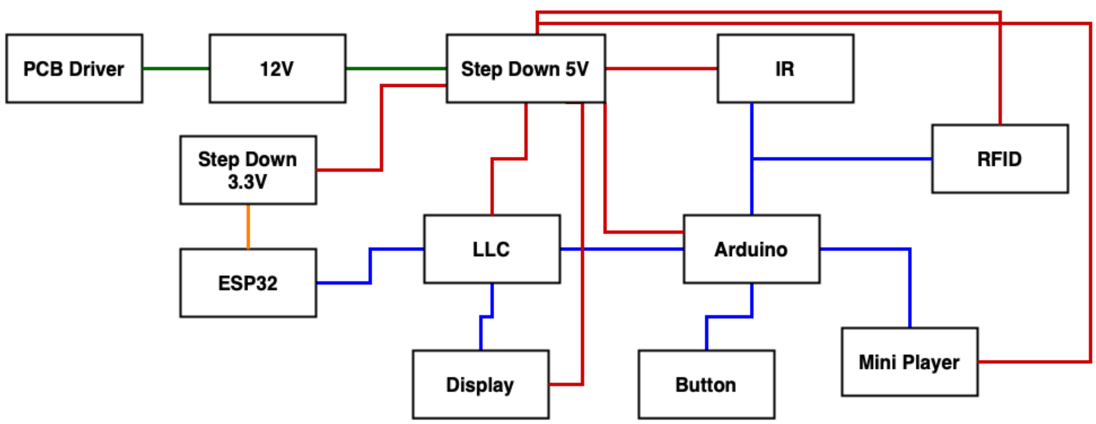

Figure 4.1: Early stage version of the circuit for the PCB - Green lines represent 12V connections, red 5V, orange 3.3V and blue shows signals

In the following phases, the circuit was improved and connections simplified. After that, the hardware was assembled and tested using breadboards. Applying each component specification, with the pinouts, electricity requirements and others, the parts were tested to ensure that the circuit was correct.

With the circuit tested using the breadboards, the following step was the creation of the PCB schematics. In the first part, the electronic components were added to the schematic. Adding the parts allow the connection of the pins. The figures 4.2, 4.3 and 4.4, show respectively, the components, schematic, and the 3D design of the main PCB.

The figures 4.5, 4.6 and 4.7, show respectively, the components, schematic, and the 3D design of the driver PCB.

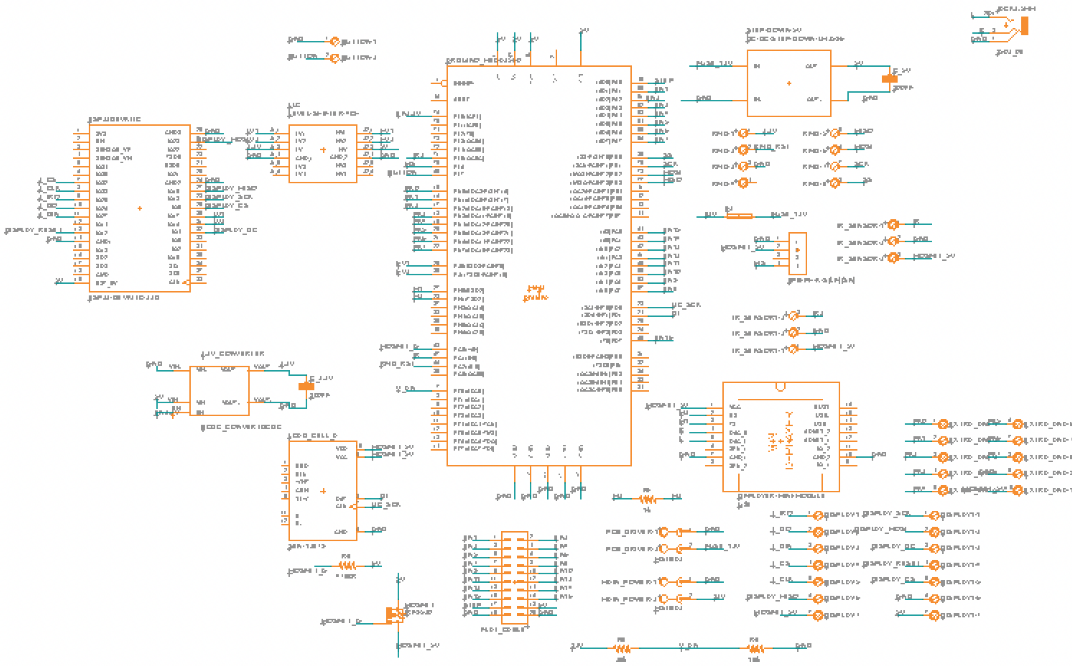

Figure 4.2: Main PCB components

Finally, when the schematics were ready and sent to production.

4.1.3 Assembling

The PCBs were fabricated by a specialized company. The first step after the board arrive was the verification of the circuit. Using a power source, the VCC and GND pins of the board were connected. After that, and utilizing a multimeter, all pins were tested. With that, it was possible to determine if the circuit was correct.

In the figures 4.8 and 4.9, it is possible to see both main and motor driver PCBs after production.

Afterwards, all the components were welded to the PCBs. The figure 4.10 it is showed how the PCB was assembled. The final result, the assembled PCB is represented in the figure 4.11.

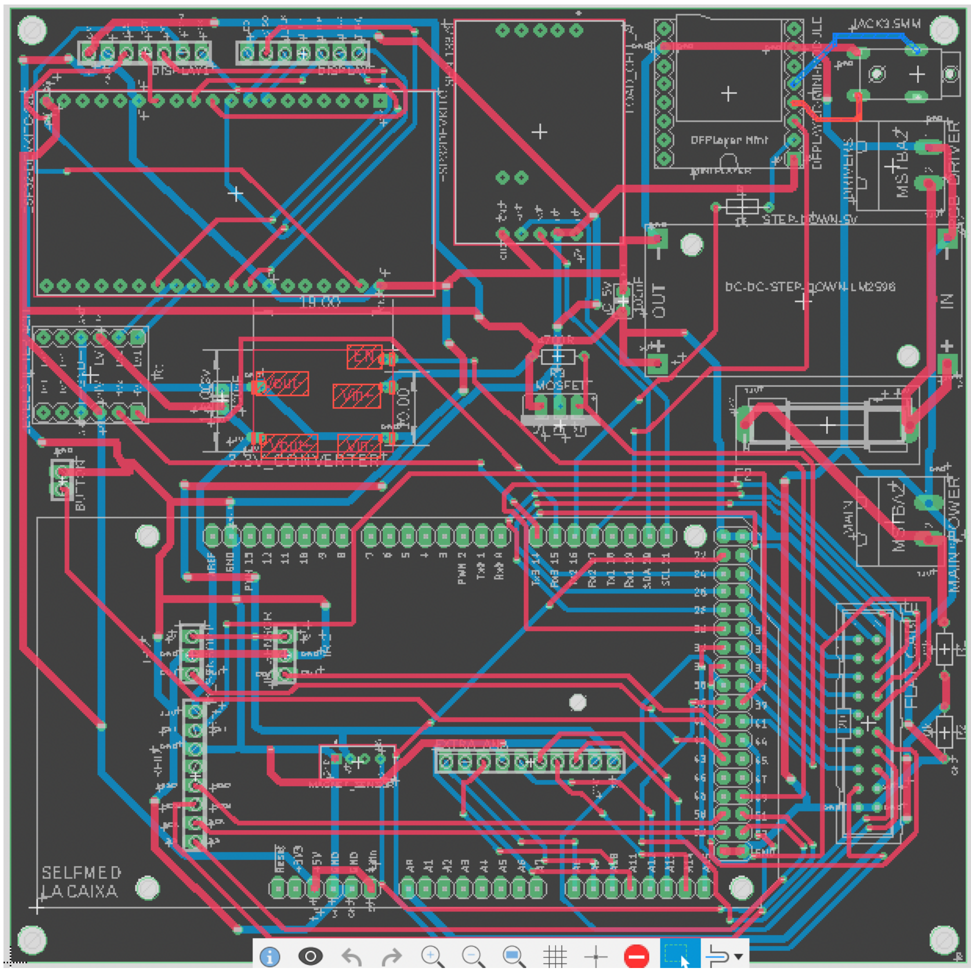

Figure 4.3: Main PCB schematics

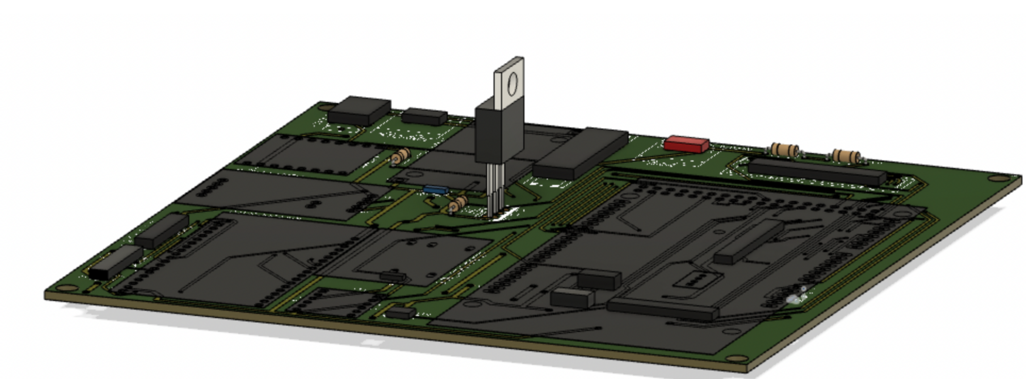

Figure 4.4: Main PCB 3D

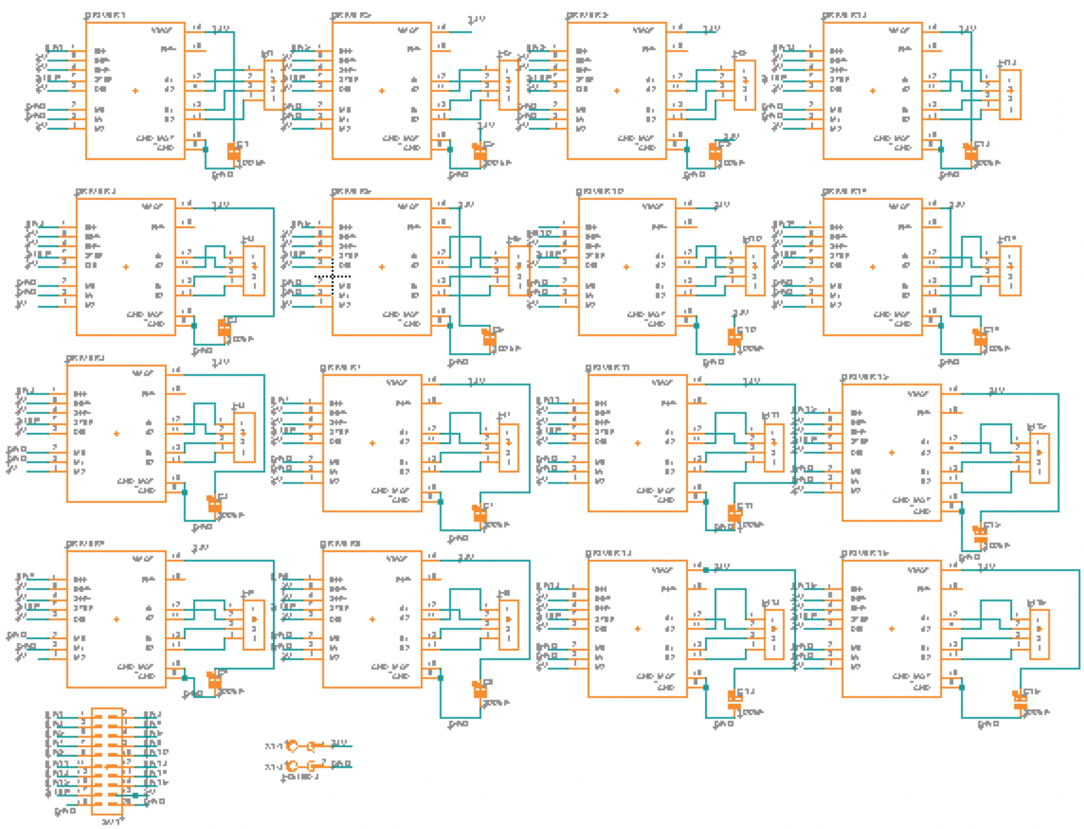

Figure 4.5: Driver PCB components

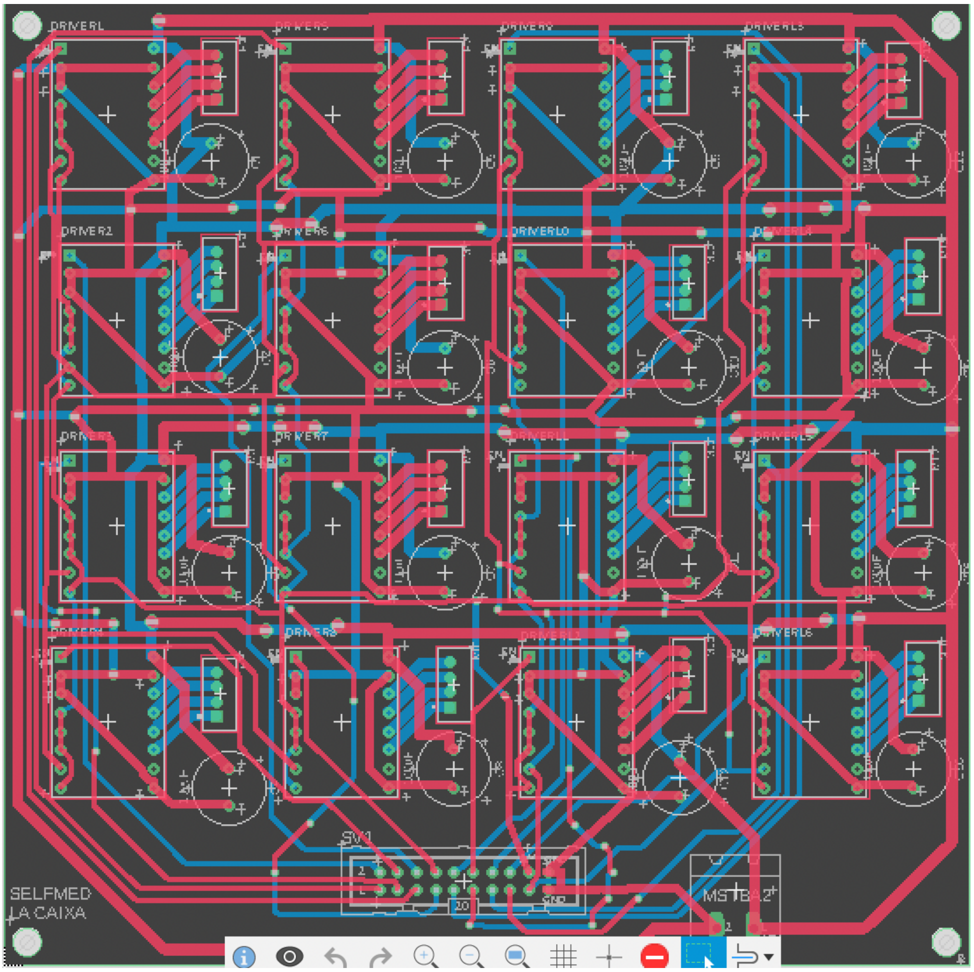

Figure 4.6: Driver PCB schematics

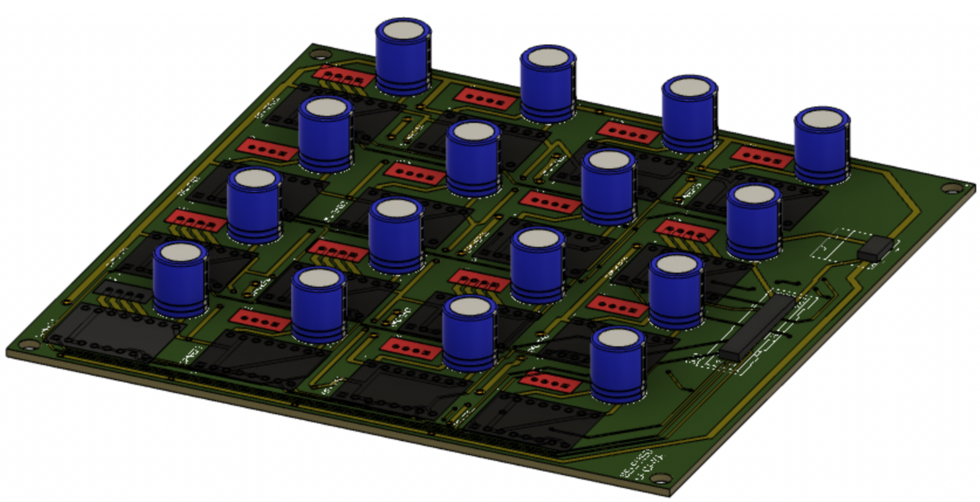

Figure 4.7: Driver PCB 3D

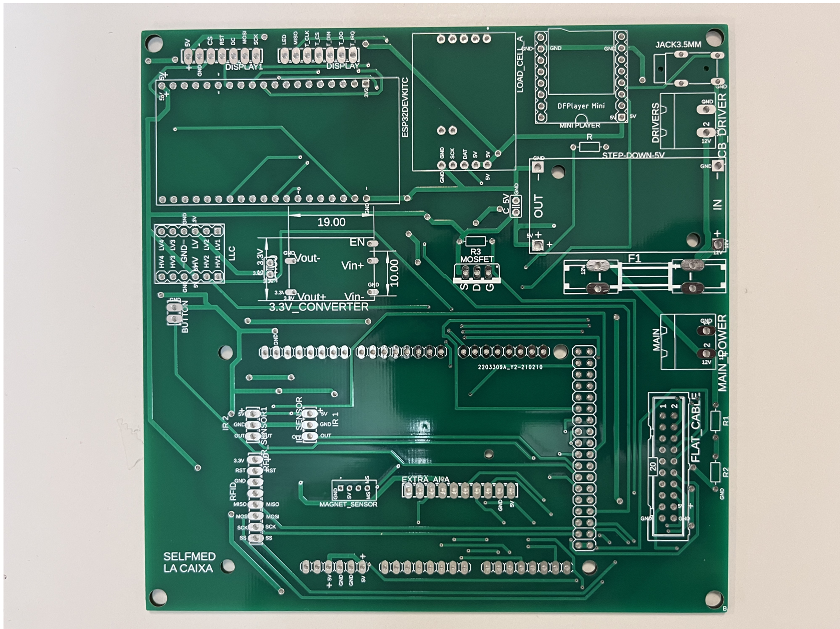

Figure 4.8: Main PCB after production

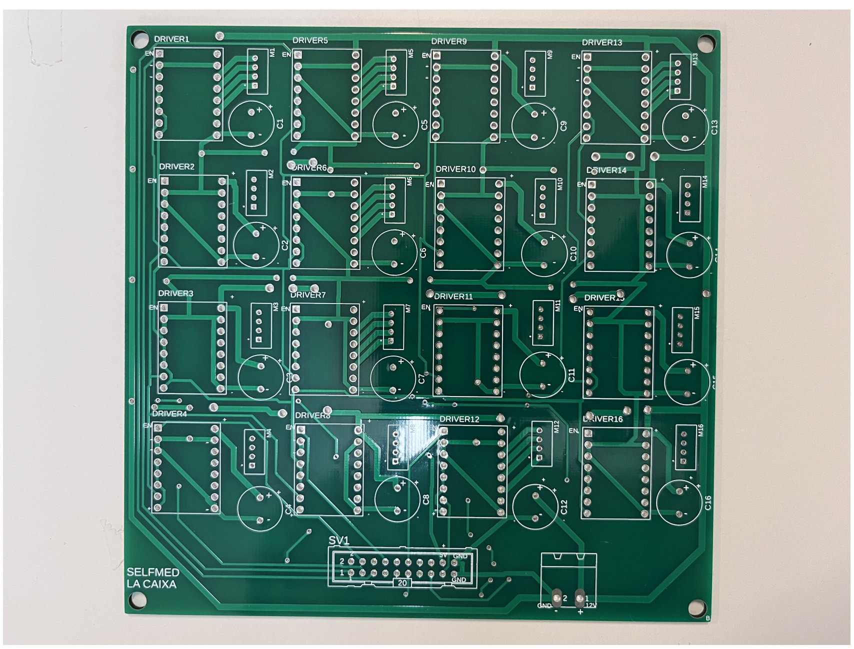

Figure 4.9: Motors drivers PCB after production

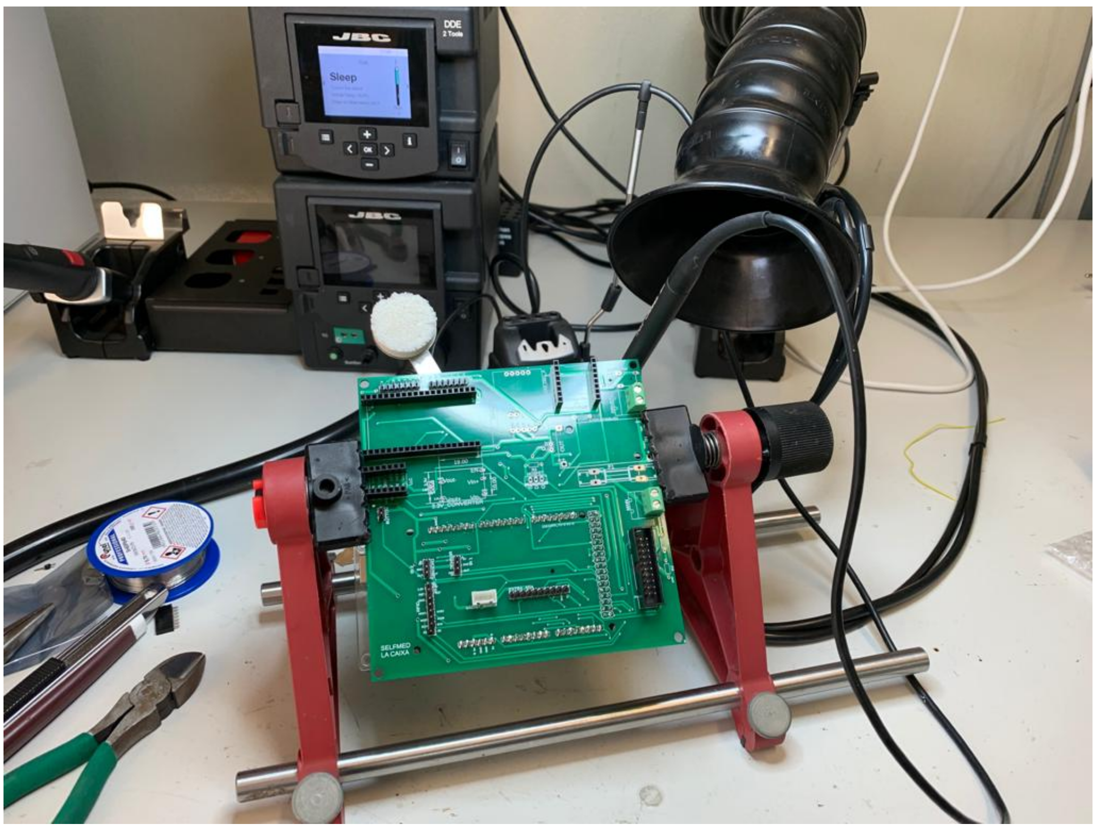

Figure 4.10: PCB assembling

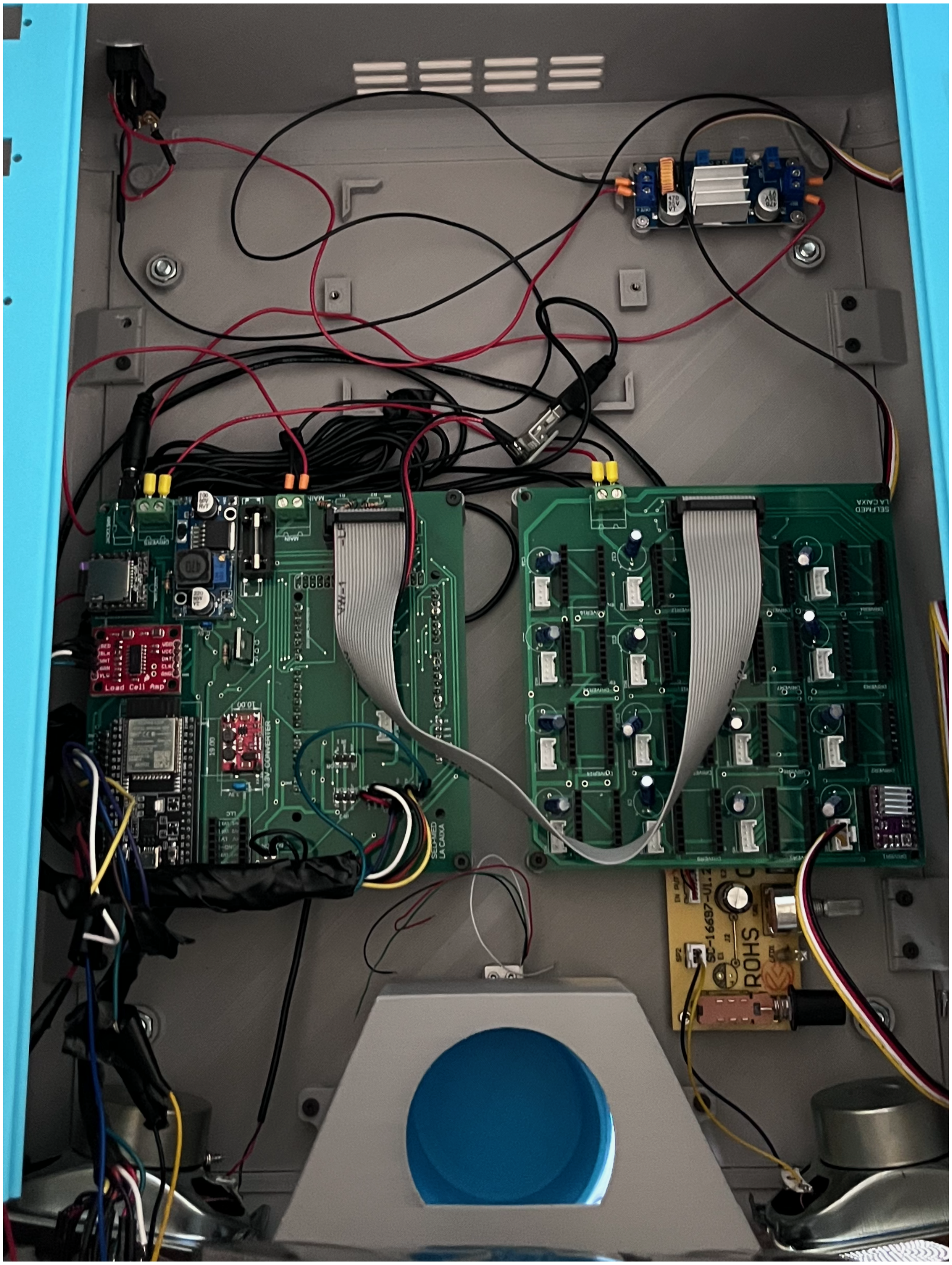

Figure 4.11: PCB assembled

4.2 Programming the microcontrollers

The base of the software for the ESP32 and Arduino were made in a previous work [18]. However, to improve the architecture, changes were made. The new architecture has an event-base approach. The modularity of the software was maintained and the event-based approach implemented. The new architecture allows the system to be asynchronous.

An event-base software allows different parts of the code to change state and update others. In this context, an event can be comparable to a notification. When a state of an object significantly changes, an event is sent and all the other objects that are waiting for that event will be notified.

On this approach, there are event creators and subscribers. Event creators are the objects that generate an event and send it out. The event itself can have specific information, depending on the objective of the event. When a state is changed, the creator publishes the event, inserting all the necessary data for that specific event.

Subscribers are objects that act when an event is published. These objects subscribe to an event, and when the event is published, they are notified.

4.2.1 ESP32 Programming

This microcontroller stores the information regarding the medication prescription of the users. The database in this component is based on SQLite. SQLite is a C-language library that implements a small, fast, self-contained, high-reliability, full-featured, SQL database engine [25]. The database in the server will follow the structure of the database of the dispenser.

In the figure 4.12 it is possible to see the overall database structure.

The figure 4.13 represents the modules present in the pill dispenser software.

The first module of the dispenser is the database. All the connection and the access to the data is controlled by that module. The information of the prescription is verified every second and if a dose is to be dispensed an event is published. The first event is to start the all dispensing process. After that, other events are published, notifying other

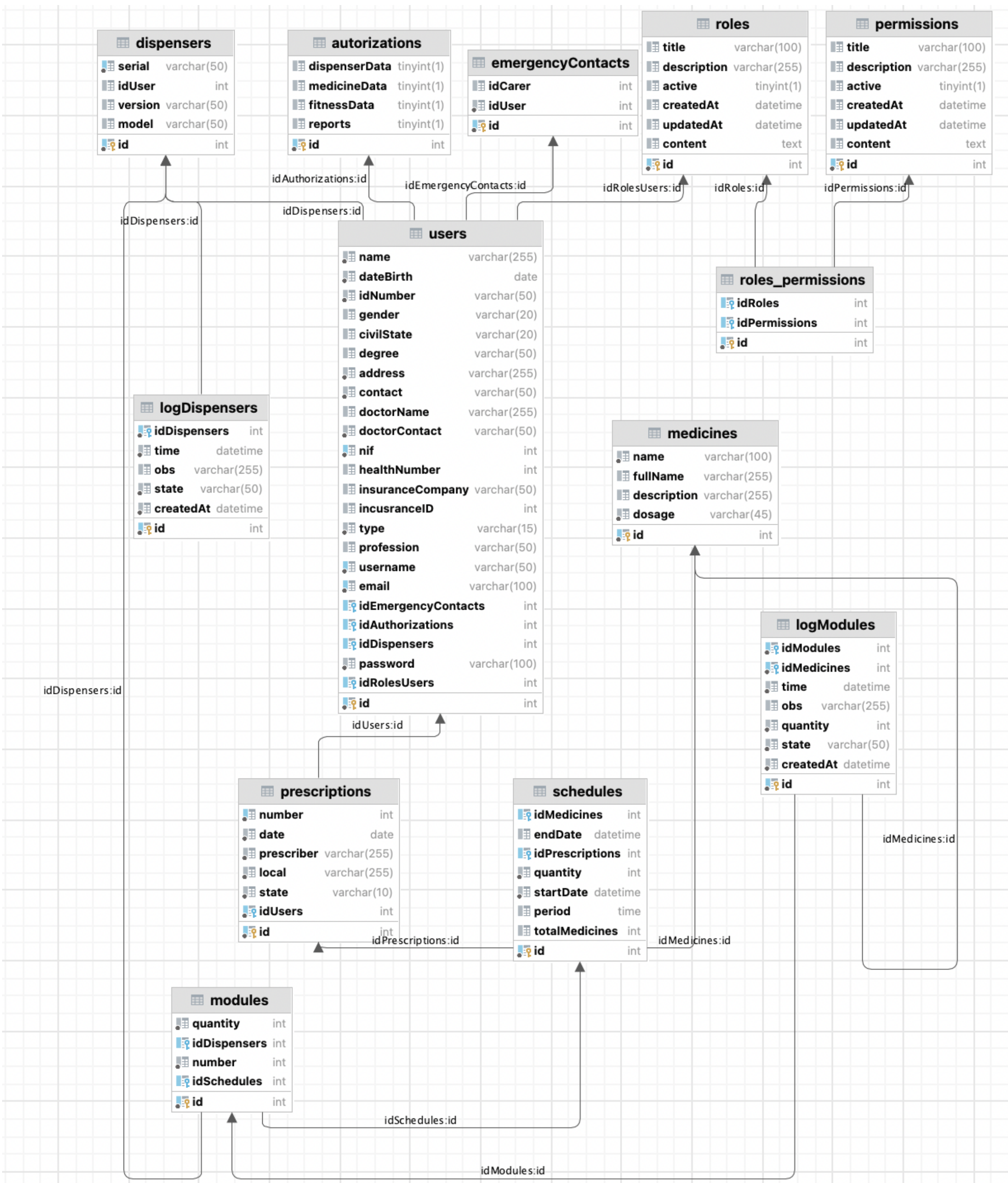

Figure 4.12: Database structure

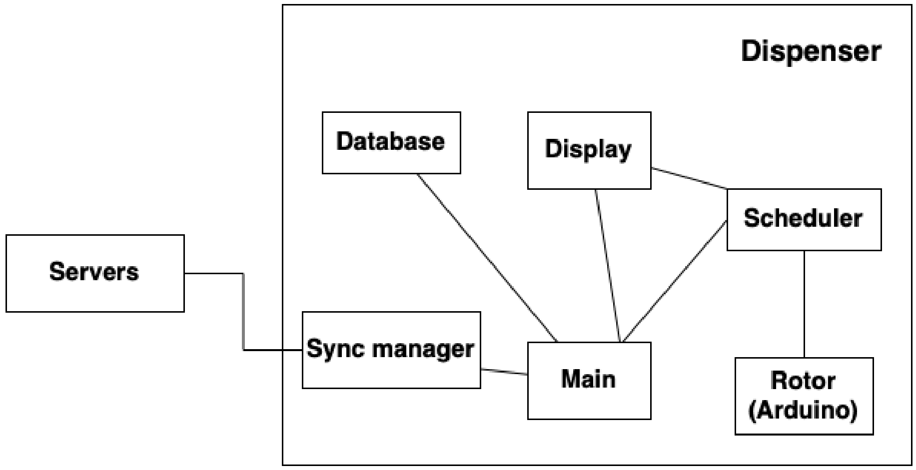

Figure 4.13: Modules of the pill dispenser

modules of the change of state.

The display module is responsible to manage all the communication with the display, sending and receiving the data.

Rotor (module representing Arduino inside ESP32) module enables the management of the Arduino. It allows the execution of the commands necessary to activate the functionalities connected to the Arduino.

The scheduler module verifies all the prescription that should be dispensed and sends the information to the Arduino and the display.

The main module is where the primary code of the dispenser is stored. Finally, the sync manager allows the communication with the servers.

The diagram 4.14 illustrates the main events of the dispenser system. On the left, there are the publishers, the responsible for the creation of the events. In the middle, there are the objects, the events created, and on the right, the subscribers, the modules that are notified when the events are published.

4.2.2 Arduino Programming

Both ESP32 and Arduino share a common library. This library has the information regarding the communication protocol. Each microcontroller implements the class that it

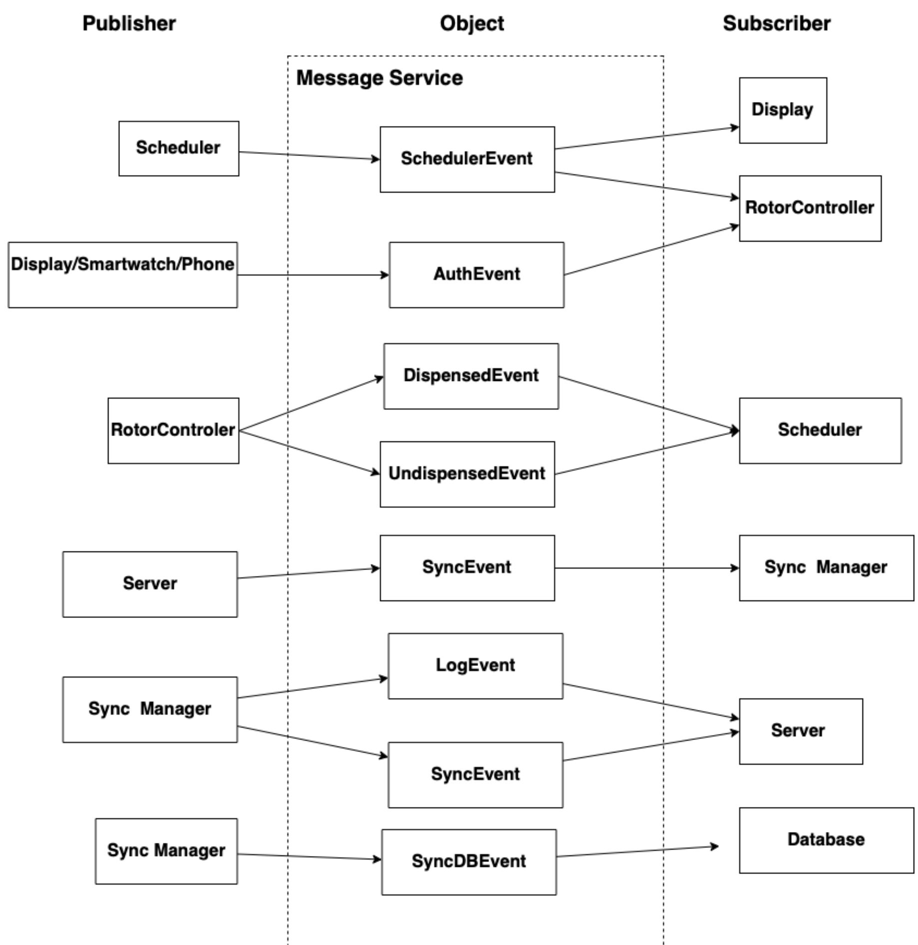

Figure 4.14: Events of the pill dispenser

needs to operate.

Arduino does not implement high operation methods nor classes. This microcontroller has a much lower processing power comparing to ESP32. Resuming, Arduino operates executing functions it receives from ESP32, and sending messages regarding those processes.

The figure 4.15 represents the architecture of the system in a lower level. The messages from ESP32 will be passed via an asynchronous physical connection between this microcontroller and Arduino. Each micro will always check to verify if there is anything in the channel to be read. In case a message is sent by ESP32, Arduino will read it and use the ESPRotorDispatcher module to process it. This module functions as a dispatcher, it opens the message and verify what is the command to be executed. After that, the appropriate module will be activated

Furthermore, the different electronic components connected to Arduino are represented by different modules, including the sensors, motor (module), and speaker (sound). It allows the microcontroller to separate the functionalities and execute only the necessary actions.

4.3 Business Plan

The development of the business model is essential to determine how the value will be created, captured and delivered to the final customer. In this section there will be presented theories, models and hypotheses for the business. Later on, these hypotheses should be explored and consolidated. In the current stage of development, there are costs and requirements that cannot be accurately portrayed, therefore calculations for the business would not be precise.

The definition of the key parts of the business help to clarify the business model and aspects. The business model canvas is a tool that helps describe, analyze and design business models. Furthermore, it includes all the key part of a business to better visualize the model output. The canvas catalogs all the business from the beginning to the end,

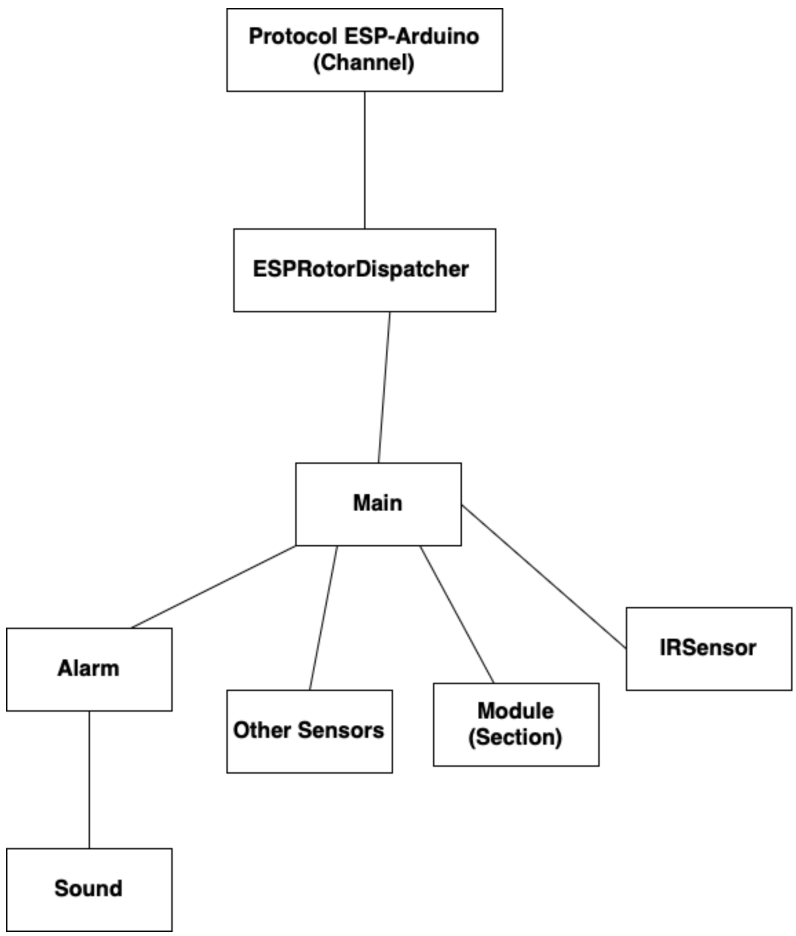

Figure 4.15: Architecture of the Arduino system

and all in between.

The first product that will be introduced to the market are the automatic pill dispenser, the website and a simpler version of the intelligent system. The other products will be developed and, later on, introduced in the market. The technical viability is the process of proving that the concept is technically possible [26]. The process analyzes different factors to assess the viability of the manufacturing, production, and operation of a product.

In the present work, the technical viability of Balvia Ecosystems will be analyzed. Nevertheless, the viability of the mobile application, and smartwatch application will not be considered due to the fact that these platforms are not yet developed.

4.3.1 Technical Feasibility

The first step of this assessment is to examine the technical feasibility of the products and services. The study will be in three major parts of the ecosystem, the hardware, the plastic, and the software.

The hardware used include microcontrollers, sensors, display, speaker, and other smaller electronic components. These are parts that can be easily purchased from different suppliers.

The plastic is personalized to the ecosystem. It needs to be manufactured. Different methods can be used to manufacture these parts according to the quantities, lead time and the expected final quality. For the prototyping and early products phase, it is expected to be used different 3D methods. After consolidating the product, the production can be moved into plastic injection, which is better for mass production. Nonetheless, plastic injection requires molds and a high capital investment.

The software connects the different devices, platforms, and users. There are different development systems in Balvia, namely, Spring Boot (for the API), Angular (for web interface), IOS and Android (for mobile), watchOS and wearOS (for smartwatch), Arduino IDE (for the dispenser), and Nextion Editor (for the dispenser's display). Other platforms will also be used, such as MariaDB (for database), and many AWS services.

Each part presented previously requires technologies that are currently in the market. Nevertheless, there is need for professional with experience and knowledge in those areas to implement the work. There is also need for structure and equipments.

4.3.2 Business Model Canvas

Business Model Canvas (BMC) is a strategic management tool to quickly and easily define and communicate a business idea or concept [27]. Within this tool there are the fundamental aspects of the business, the idea, and the product/service. BMC summarizes and structures all these aspects in a one-page document.

In the Annex B there is the BMC developed within this work. The main components of that canvas are explained below.

Value Proposition

In the central part of the BMC is the value proposition. This aspect is related to the values offered by the solution to the clients. These are the benefits of the usage of the solution and the impact it can have in the client's life. In the case of Balvia Ecosystems, the value propositions are related to the simplicity and usability of the interfaces, the integration, access of the data, the security, and efficiency of the medication management.

Customer Segments

The definition of the segments of the customer the business intends to reach is an important step. It leads to the identification of the customer relationship and channels of communication. The main segments of customers of Balvia are people 55+ with complex medication regimes, their formal and informal carers and companies that provide home services for them.

Customer Relationship

In the customer relationship is defined, how the customer can contact the company. It is essential to create a good relationship with the different customers. Balvia intends to use different strategies to approach distinct clients.

Channels

These are the channels to be used to communicate with the different customers. These are the most efficient channels identified by the company to reach the clients.

Key Activities

It is important to establish the main activities of the business. These are the activities that generate revenue.

Key Resources

Related to the key activities, the key resources identify the main assets necessary to perform the key activities.

Key Partners

The necessary partners in the various business areas. In case of Balvia, the key partners are distributor companies (can be various types of enterprises), manufacturers, research institutions, and consultants.

Cost Structure

In this part the costs are outlined, the necessary expenses for the successful implementation of the business.

Revenue Streams

The revenue streams. The main revenue streams are from the sale of products (pill dispenser and modules), and from the administration service fees.

4.3.3 Production and Assembling

The production and assembling of Balvia's products can be done using three different strategies. The first, is full in-house production and manufacturing, which requires investment in infra-structures, but gives full control of all steps to the company. The staff requirement is also greater, with needs for people to inject the plastic, produce all components and then assemble them.

The second strategy is a full outsourcing. In this case, the company does not need a big investment, however the price for each component will increase and the control of the process will be passed to another company.

The third, and last strategy, is a hybrid of the first two. Balvia Ecosystems can outsource the production and assembling to specialized companies with vast experience in the area, and perform only the programming, testing of the products, and quality control. The necessary investment is reduced, and the company keeps control of the last steps of the process. For now, this is the preferred option, nevertheless, all three strategies should be deeply analyzed and compared to ascertain the best option.

4.3.4 Programming, Testing, and Distribution

Selecting the third strategy previously explained, Balvia Ecosystems will receive the pill dispenser after the production and assembling. The next step is the programming and testing of the product. To protect the proprietary software, the programming of the dispenser should be performed inside the company.

After being programmed, the machines can be selected for tests and quality control. The tests include three separate parts, tests on the mechanical components, the hardware, and the software.

The distribution of the product after the tests is made through a logistics company. The company will pick the product in the storage house of Balvia and transport it to the distributor partner.

4.3.5 Research and Innovation

It is critical to keep the solution updated and relevant. Internally, Balvia will create mechanisms to keep researching and innovating. The technology is always evolving, and the solutions proposed by the company also have to evolve.

Partnerships with research institutions is essential to be relevant in the market. As a company that will be born from the academia, these partnerships will help maintain a connection with the innovation, research, and creation of new solutions.

The mechanisms that will be created internally, jointly with the research partnerships, can give the company the necessary knowledge and tools to always create, research and innovate.

4.3.6 Business Model

The solutions developed in the present work and in the project SelfMed answer to a global problem. It is important to ensure the scalability of the products and services. This scalability can be in the production, with the possibility of mass production of the physical products, the expansion of the services and software. The business model must guarantee and promote the expansion of the operations.

In the current business model, Balvia Ecosystems sells physical products to the distributors partners. Jointly with the physical products, Balvia also provides software / systems administration services. The startup focuses on the Business to Business (B2B) market. With the current business model, the company can scale rapidly the availability of its products and service. The main goal is to create a multinational distribution network, where clients can get the services and products through the distributors that are closer to them.

Balvia will provide the pill dispenser, modules and any other accessories to the distributors, which will acquire the product. With the acquisition, the companies can rent to the final clients through a monthly subscription service. In this renting system, a dispensing device can be installed, and moved according to the necessity.

It is envisioned that there will be at least two subscription packages, a basic and a premium. The basic package includes all the essential products and services, namely, the pill dispenser, access to the website, mobile application, and a basic version of the intelligent system in the cloud. Furthermore, this package will include maintenance and medication refill services.

On the other hand, the premium package includes the basic subscription and adds others. It is the most complete package, with the integration of the smartwatch and smartwatch application, the full version of the intelligent system in the cloud.

Other packages can be created during further development of the business model, in case of need. Nevertheless, the basic package will continue to have the essential products and services, and the premium the full ecosystem.

The subscriptions will be made available by the distribution network. This network includes all Balvia distributors. With this approach, the company can create the base for a rapid expansion.

4.3.7 Intellectual Property Protection

The protection of the intellectual property can be ensured by different strategies, including patents, trade secrets, trademarks, and copyrights. The current approach utilized for Balvia Ecosystems is the submission of patents and the trademark.

The patent can be an important document in the protection of new products and processes. In the patent, there are described the characteristics of the products, and comparison with the previous patents. Nevertheless, the patent owner must ensure that the patent is being respected. Other companies may try to create similar product, and the owner of the patent is the responsible to avoid that.

The patents submitted were the Portuguese national patent and the European patent offices. The national patent was submitted under the request number 20212002182581 to the Instituto Nacional da Propriedade Industrial (INPI). The European patent was presented in the application number EP22176318.8 to the European Patent Office (EPO). These patents will help protect the new design created for the pill dispenser device.

A trademark registers the recognizable sign, design, and other marks that help distinguish a brand. There is a negotiation being done with a company with a similar name. The company agreed to a coexistence of Balvia Ecosystems and their own name. After signing the agreement, the submission for the trademark will be made.

4.3.8 Costs

The main costs of the External Supply and Services (ESS), the staff and the investment necessary to start. The ESS includes all the day-to-day expenses required to manage a business. It can go from the specialized services, material, electricity, to rent and others. These services can have a fix or a variable cost. The fix costs services, as the name suggest, are charges that do not change, regardless of the quantity of products being sold. Examples of these costs are rent, insurance or communications, where the monthly bill is always the same.

A company can also have variable costs, where the costs change. Normally, these expenses will increase with the growth of sales. For instance, in a factory the more products are produced the more electricity will be used, and vice-versa. The same happen to commission. In case an enterprise offers commission to agents when a product is sold, when there is no sale, no expenses will be charged.

Furthermore, there are costs that can have a part that is fixed and another that varies. In the electricity example mentioned previous, part of the bill is always charged for the renting of the electric counter.

A good strategy for a company is to keep the costs variable, meaning that it will only be charged when there is a sale or the enterprise is producing. Nevertheless, some costs can not be variable.

Balvia Ecosystems costs should be mixed, the expenses that can be variable will be, and the others that can have a variable part will also have.

The other essential cost of the Balvia is the staff. The company must have specialized collaborators to perform tasks. The base team includes an administrator, one marketing director, one systems administrator, one mechanical/industrial engineer, and one junior technician. With the increase of production and sales, the team can add more areas and grow in number. In the expansion, the added areas can be finances administration, human resources, maintenance and quality, development and research, and sales administration.

In the production of the products, there are also costs associated in molds, components acquisition, manufacturing, assembling, and transportation.

4.3.9 Business Volume

The business volume indicates the amount of the products and services sold. In an estimate, this value can have a big impact in the final result.

For Balvia Ecosystems, the business volume is represented by two values, the volume of products and services sold in the national market, and in the international market. Balvia intends to be active and expand sales to other European countries.

In the national market, the company intends to sell pill dispensers, modules, basic and premium services. The unit price of the pill dispenser is estimated to be €799. The price for a module as an accessory is €50. Additionally, Balvia charges 25% for the monthly subscriptions. The monthly fee for the basic package is estimated to be €19.99 and the premium €39.99. In a year, around €60 are charged by Balvia for the basic package and €120 for the premium.

On the other hand, the prices in the international market are different. There was made a calculation to better represent the actual prices of the products and services. Taking in consideration, that for the estimations, 25% of the number of products sold internally in the first year are expected to be sold in the international market in the same period. Although, the growth of the international market is much accentuated.

Chapter 5

Tests and Discussion

This chapter explains the steps that were taken to manufacture and test the components and software. Overall, for the mechanic and electronic components, the steps included the exporting of the production files, the production of the parts, the assembling, and the laboratory tests. For the software, the tests included the installation of the new software on the assembled hardware, and the laboratory tests.

5.1 Manufacturing

After developing the 3D models of the pill dispenser and the schematics of the PCBs, the next stage was the manufacturing of the components. In that stage, the 3D models were fabricated using different resources. The first modules of the pill dispenser were printed in the FabLab of IPB. This allowed to have a component very quickly, because it is an in-house production. After many iterations and arriving to a better 3D module, the production was passed to a specialized company. The manufacturing of the modules was in charge of Codi, and the production of the pill dispenser was in charge of MirrorFactory. The production of the PCBs was in charge of JLCPCB.

5.1.1 Mechanical Components

The first module (figures 5.1 and 5.2) printed in the Polytechnic Institute of Bragança, on the FabLab, and it had many mistakes. The components did not fit together and corrections had to be made. The size of some components were reduced, and it finally fitted. In FabLab, there were manufactured modules in four different iterations. From one iteration to other, the design of the module was improved. After the fourth iteration, the module was analyzed and the conclusion was that it needed now to be printed with higher quality to unveil more errors.

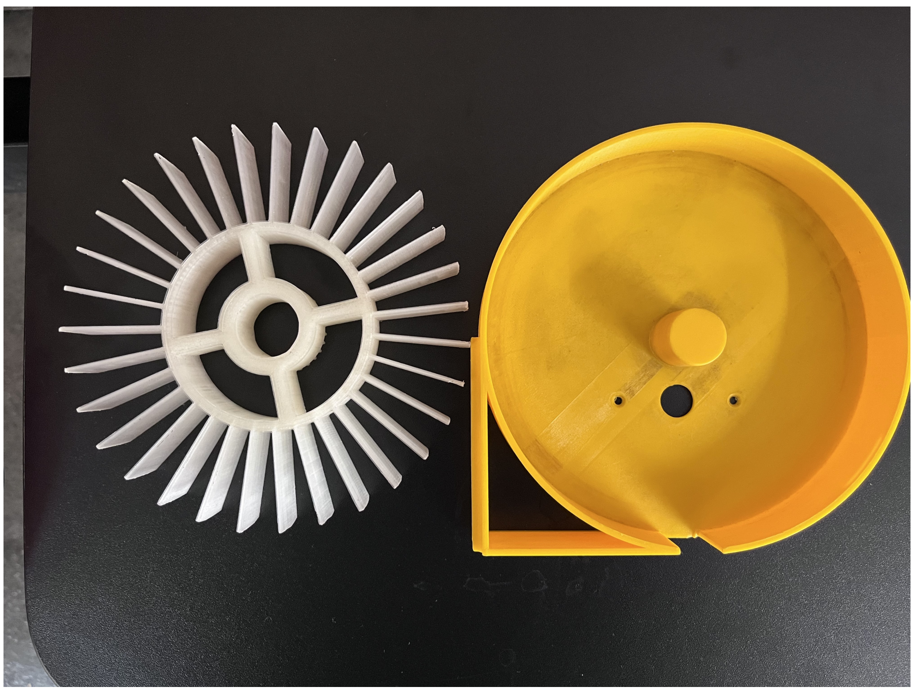

Figure 5.1: First module of the pill dispenser (1 of 2)

After reaching a satisfying improvement level, the production of the modules was moved to a specialized company, for professional manufacturing. The company selected was Codi. The precision and the quality of the components increase, allowing for further tests of the components. Many iterations occurred, correcting different types of errors. The shape, tolerance between the internal components, some modifications were made. The figure 5.3 shows the module produced by Codi.

With the module manufactured and tested, the next stage was the production of the

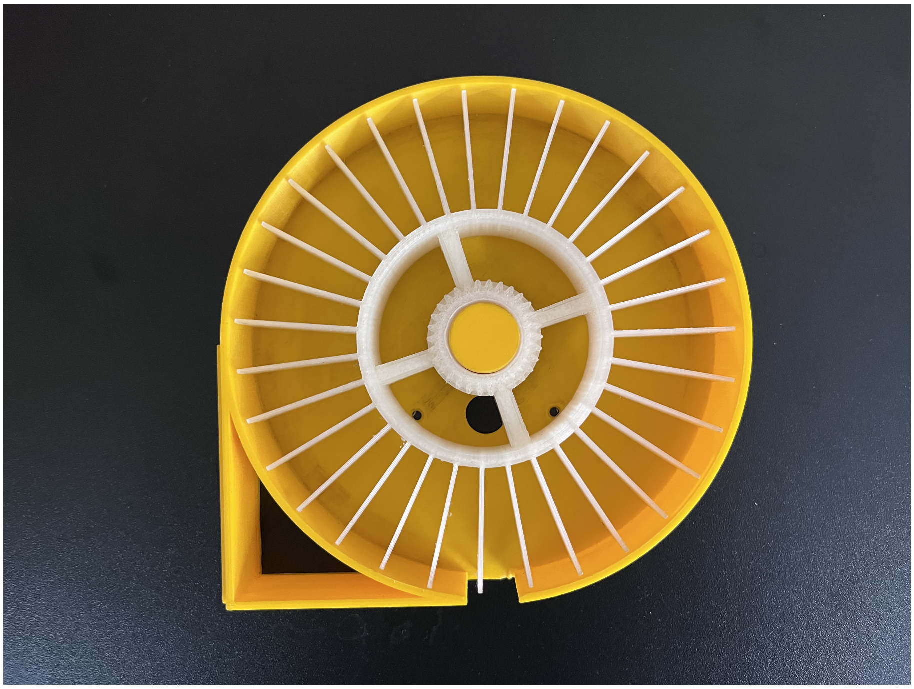

Figure 5.2: First module of the pill dispenser (2 of 2)

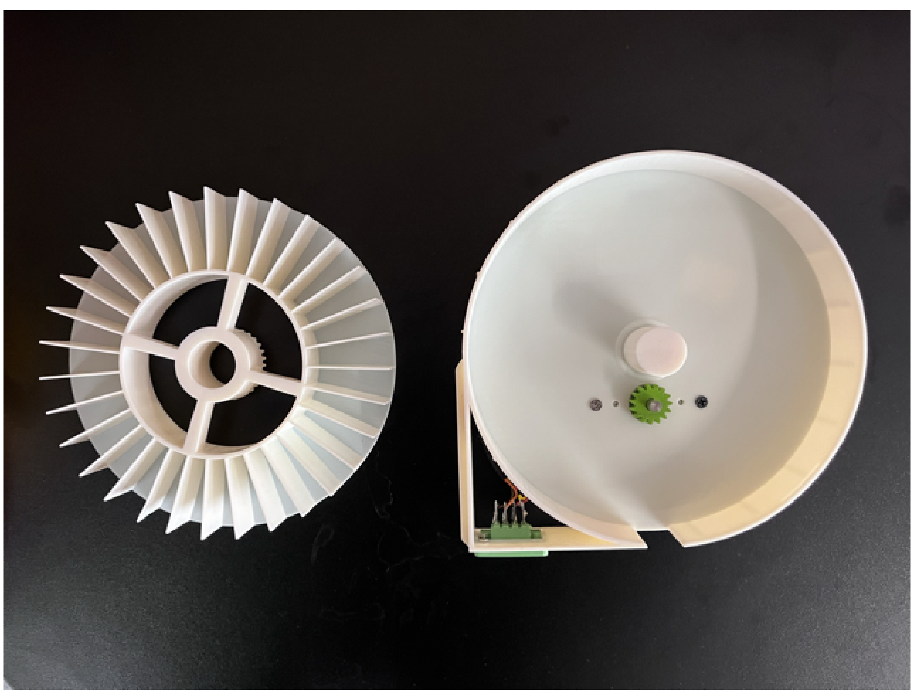

Figure 5.3: Module produced by Codi

dispensing machine. The pill dispenser device was only printed with MirrorFactory, due to its size. The machine has big panels that require bigger machinery to print. The production of the dispensing device had a one-month period, however errors occurred, and it was extended. The real time of production was around two and half months, which included modifying some components.

One of the parts that had the highest challenges during the manufacturing was the chute used to forward the pills to the delivery cup. That component has slim walls, a curved shape and substantial size. The first chute produced had many problems, the component presented many deformations. The slim walls, the size, and lack of support contributed to the deformations. With the variations of light, in the image 5.4 it is possible to notice some deformations present on the component.

5.1.2 PCB

The order for the PCBs were made in JLCPCB website. The Gerber files exported from the development environment were sent to the company for manufacturing. Producing and delivering the board took around one month. The figures 4.8 and 4.9 show the PCBs after production.

5.2 Laboratory Testing

During the iterations and after having the final components, laboratory tests were conducted. The laboratories used were in the Escola Superior de Tecnologia e Gestão. Different laboratories were used to assemble and test the components.

5.2.1 Module

The modules were tested in the laboratory with and without being assembled with the motors. The first tests made were to ensure that the modules were working properly. The results showed that the modules bases were oval, not circular. This was due to problems

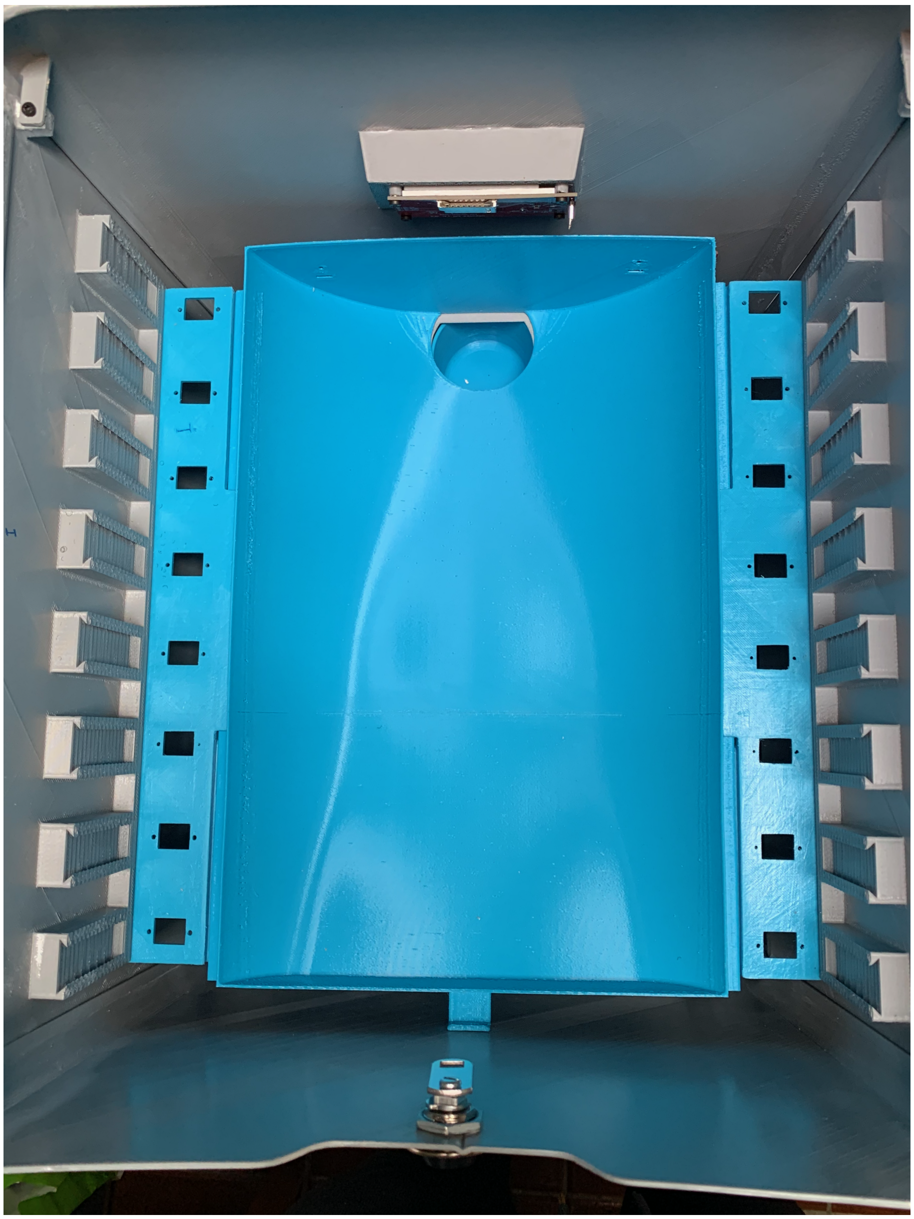

Figure 5.4: Chute of the pill dispenser

while printing. The components were twisting while cooling down. To correct these errors, the exterior of the base of the modules were fortified. In the image 5.5 it is possible to see a comparison between the first module and the one produced by Codi. The size increase to better accommodate the medication, and the component has fortifications on the wall to not twist.

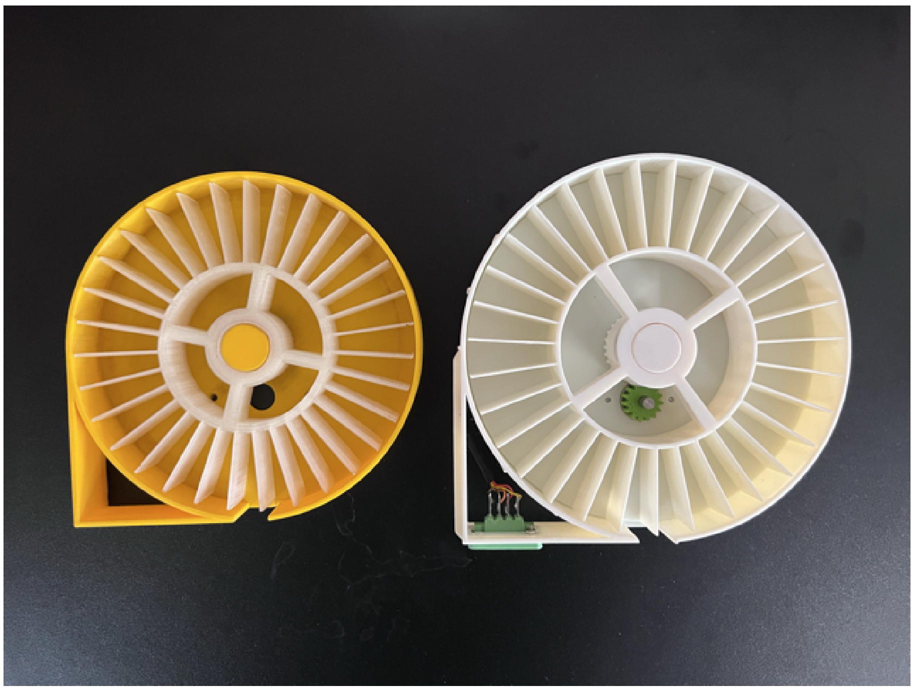

Figure 5.5: First module (yellow) and module produced by Codi (white)

There were also errors in the tolerances of some parts of the module. With the iterations, the ideal tolerance was unveiled, one that let the internal component move, but did not allow for elliptical movements. The latest module produced is represented in the figure 5.6.

5.2.2 Dispenser

There are until now two iterations with the pill dispenser. In the first one, many components were breaking, had deformations and many other errors. The image 5.7 shows the first dispenser produced. A report was made during the testing, pointing out all the

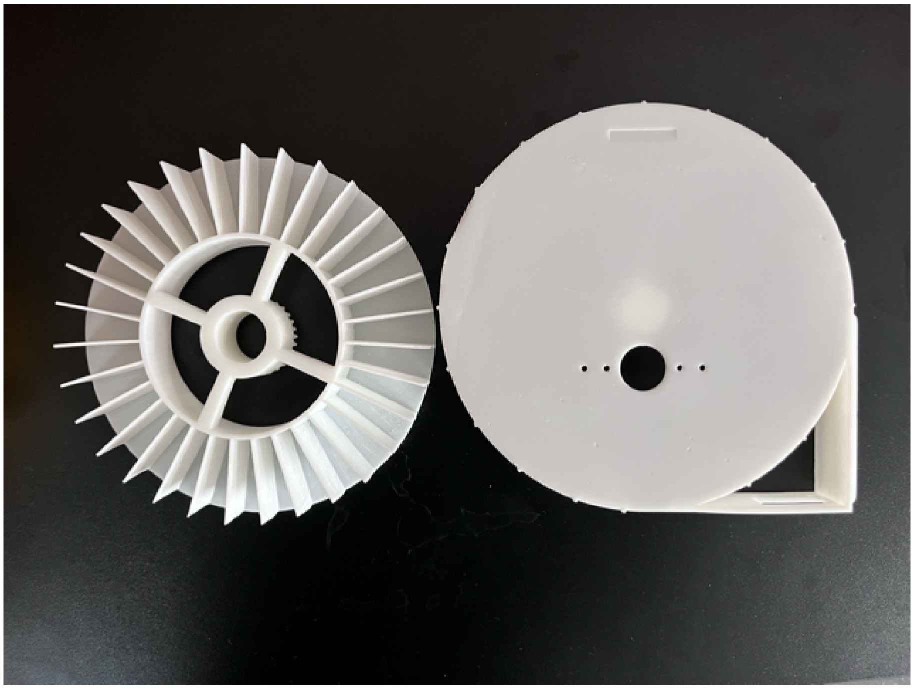

Figure 5.6: The latest module produced

problems of the first iteration. After that, the second machine was printed with all the improvements (image 5.8).

The current errors of the machine include the lack of internal structure and fragility of the large components. In a next optimization and improvement phase, these problems must be addressed.

5.2.3 PCBs and Electronic Components

The first test with the PCBs were the inspection of the GND and VCC pins. Using an external power source, the circuits of the boards were connected and, using a multimeter, tested. With that, it could confirm that the GND and VCC pins were correct and avoid burning electronic components.

Subsequently, the assembly of the PCBs started. Few errors were encountered while welding the components, the female jack component had a wrong position, the fuse holder was different, and it was missing power for the speakers.

Figure 5.7: First dispenser produced

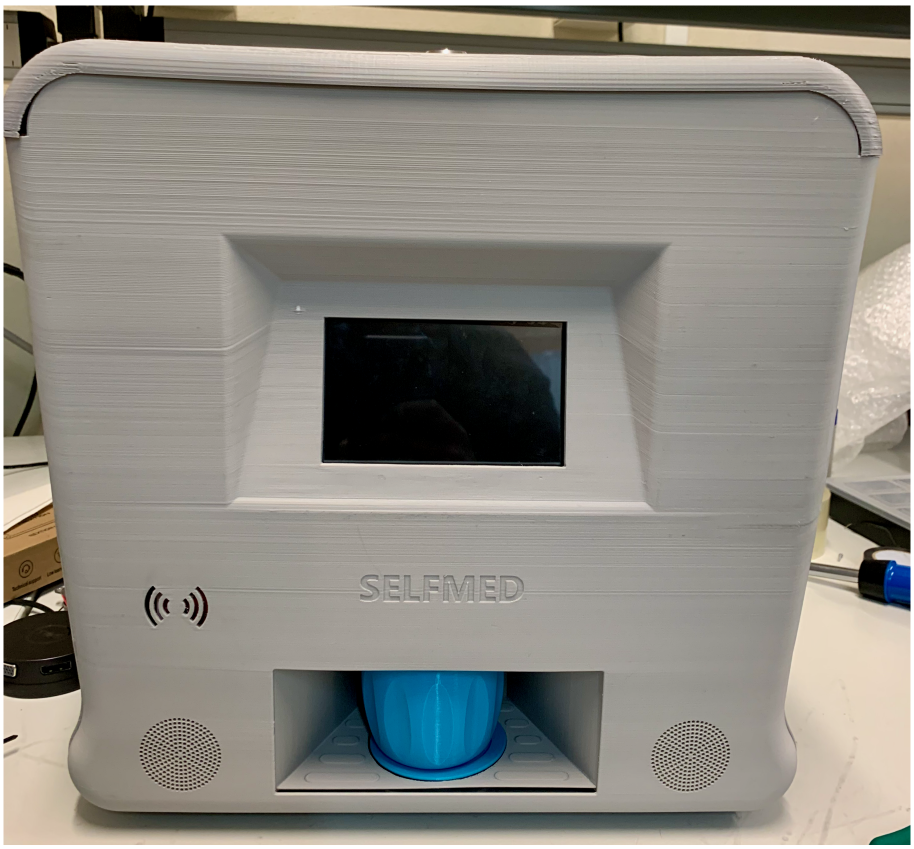

Figure 5.8: Second dispenser produced

5.2.4 Software

The software was tested jointly with the hardware. First, the software was divided in simple functions that could be executed to test a specific component. Functions were created for the sound, the rotation of the motor, display and other components.

Some challenges came with the passage of the software to classes.

Chapter 6

Conclusions

This chapter summarizes the current state of development, and projects the next phases for the different parts of Balvia Ecosystems.

6.1 Mechanical components

The mechanical components are the base structure for the pill dispenser, one of the first products of Balvia Ecosystems. Bellow, there is a summary of the current state of the mechanical components, and then a brief description of the future development.

6.1.1 Current State

In the present, the mechanical components need more tests, not only in the laboratory, but also with potential clients. The current state was achieved using the feedbacks and opinion of people that understand the market, however, fully testing the device will assist attaining better assessments.

The dispensing device is now in the prototype phase, which allows still for changes, tests, and improvements. It is necessary to mature the prototype and expose the device to the real operational environment.

6.1.2 Future Development

The goal of Balvia Ecosystems is to take the pill dispenser prototype to the market. The current prototype requires an iteration and transformation into a product ready for the market.

The transformation involves the improvements of the mechanical components, reduction of the size (and cost), testing and implementing an industrial design. In the execution of such phase, there is need for knowledge, experience, and financial investment. The knowledge required varies from the functional understanding of the device, and the expertise in industrial designs. The changes need to go very deep, from the assessment of the best and cheapest screw, to the analysis of the best manufacturing methods. The functional knowledge can be provided by the team that is developing the pill dispenser from the beginning. The experience and expertise in industrial design can be added by a consultant team.

The investment is required to make transformation a reality. There is need for hiring specialized teams, acquire and test components, apply the industrial design and other activities.

6.2 Electronic components

The electronic components enable many of the essential features of the pill dispenser. Below, there is a description of the current state of the electronic and the future development.

6.2.1 Current State

At this time, the prototypes are already using PCBs. It is a major step into a robust product. Nevertheless, in the PCBs there is still room for improvement, the same with the overall components. For instance, the dispenser machine has a magnetic sensor and a weight sensor. The magnetic sensor is used to verify if the delivery cup is inside the pill dispenser. In an improved version of this machine, the weight sensor may replace the magnetic sensor, reducing the components list.

6.2.2 Future Development

Following the future of the mechanical components, the electronics need a transformation and optimization phase. This phase will include reduction of the size of the PCBs, costs decrease and overall improvement of the boards.

The current PCBs are using many out-off-shell components, such as ESP32 and Arduino Mega. These components are great for the prototyping phase, however, the final product should not use it. Instead, the ESP32 board can be stripped down to only the microchip, the same as the Arduino. The chips can be inserted directly to the pill dispenser PCBs. The components will be analyzed one by one. Few will be reduced, others replaced or maybe removed. After that, the electrical security of the boards will be assessed.

The main goal of this phase is to reach cheap, secured and easily manufactured PCBs.

6.3 Software

The last component of the pill dispenser device, and a major component of Balvia Ecosystems, is the software.

6.3.1 Current State

The software is currently in an early state. Only the basic and core functionalities were implemented. With further development, the same hardware can have more features, if the software is improved.

The current software needs testing, and time to mature. The bases are set, but there are parts of the architecture that need improvement and testing. With the user testing, many errors, bugs, and weaknesses would be revealed, helping strengthen the software.

6.3.2 Future Development

The software will be one of the differentiators between Balvia Ecosystems and other products. Therefore, the software requires special attention. The development of other systems is an important step to complete the ecosystem.

Furthermore, there are essential features that must be verified, implemented and always kept up-to-date. These features are security, reliability, availability, resilience, and user experience. The ecosystem includes many sensible data, it must ensure the safety of its information and the users. The pill dispenser must always provide the medication, regardless of the connection with the server.

6.4 Business Development

The development of business and strategies is an important step towards the commercialization of the products.

6.4.1 Current State

At the present, the business development contains strategies and models, all created with feedback from the clients. Nevertheless, these strategies and models must be tested and consolidated.

The strategies, models, and ideas have to be flexible, in order to include further feedback from the clients, mature and advance towards the most appropriate path.

6.4.2 Next Steps

To accelerate the development and consolidation of all exposed in the text above, Balvia Ecosystems will need investment. The opening of the startup can contribute in the investment phase, however it should be timed very correctly. The opening and maintenance of a company have cost, and those should be avoided until the appropriated time.

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Appendix A

Original project proposal

INSTITUTO POLITÉCNICO DE BRAGANÇA

Master in Products and Processes Innovation

School Year 2021/22

"Prototype development for SelfMed automatic pill dispenser device"

Student Name: Bruno António Alegre da Costa

Supervisors: Rui Pedro Lopes, José Lima

Thesis Objectives

Development of the SelfMed automatic pill dispenser device prototype, namely:

- Validation of the mechanical structure;
- Assembly of the prototype;
- Definition of the test methodology;
- Test of the prototype in the laboratory and in the field, and discussion of the results.

Work Description

The project "Prototype development for SelfMed automatic pill dispenser device" intends to design and assemble a smart system to provide pills according to a pre-programmed schedule. It consists of a device, with the capacity to store one month worth of pills in a difficult to access container, and that can expend pills according to a pre-programmed set of rules. The device is structured in modules, so that it can accommodate different sizes and adaptable number of medications per day. It should also have mechanic actuators, associated controller and a network accessible smart controller, to manage all the details. Moreover, it should also have a remote API and capacity for storage. The prototype developed is expected to be in the TRL 4-5 and it will be the basis for the final product.

Work Methodology

1st Phase: Validation of the Mechanical Structure

Begin date: 09/2021 End date: 10/2021

2nd Phase: Software Development (controllers and interface)

Begin date: 10/2021 End date: 01/2022

3rd Phase: Remote API

Begin date: 12/2021 End date: 03/2022

4th Phase: Assembly, laboratory testing and improvements

Begin date: 01/2022 End date: 04/2022

5th Phase: Field testing and discussion of the results

Begin date: 03/2022 End date: 07/2022

Work Place

Brigantia Ecopark (and CeDRI)

Data: ____/____/_______

Signatures:

Appendix B

Business Model Canvas

Business Model Canvas

Bruno António Alegre da Costa — bcosta@ipb.pt

Date: 2021-12-27

Key Partners

- Importers and distributors of orthopedic equipment
- Care houses and institutions
- Manufacturers
- Pharmacies
- Research institutions
- Consultants (legal advisors, accountant)

Key Activities

- Subscription services
- Selling Products
- After-sales products
- Platforms administration
- Manufacturing management

Key Resources

- Pill dispenser
- Software platforms
- Distribution network
- Others: Human, financial, capital, infra-structures, materials, tools

3. Value Propositions

- Ecosystem for safe and efficient medication management
- Integration of the information
- Simple and easy to use interfaces
- Pill dispenser with high storage, verification of doses and security
- Medication tracking and refilling
- Fitness and activities tracking
- Real-time remote and local control
- Connection with carers, alerts in case of errors, two-way communication
- Accessibility of the products

Customer Relationship

- Online platform / Mobile app
- After-sales services
- Direct connection / conversation
- Social media
- Customer feedback / survey
- Direct approach

Channels

- Online platform / Distributors network
- Physical store
- Sales force
- Public relations / Direct marketing
- Events, conferences

Customer Segments

- People 55+ with complex medication regimes and take it daily
- Care companies and institutions

Cost Structure

- Human resources: IT, administration, sales, marketing, finances, engineering
- Product development
- Manufacturing and transporting
- Marketing and advertisement
- Legal costs and insurance
- Company costs: rent, overheads, patent, software, licensing

Revenue Streams

- Products sales
- Subscription fees