Universidade de Aveiro Departamento de Engenharia Mecânica
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João Gonçalo Veloso

Innovative and future oriented automatic medication dispenser for older adults

Dispensador automático de medicação inovador e orientado para o futuro para adultos sénior

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Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestrado em Engenharia Mecânica, realizada sob orientação científica de Rui António da Silva Moreira, Professor Auxiliar e de José Paulo Oliveira Santos, Professor Auxiliar do Departamento de Engenharia Mecânica da Universidade de Aveiro. Esta dissertação teve o apoio dos projetos: UID/EMS/00481/2019-FCT, Fundação para a Ciência e a Tecnologia, CENTRO-01-0145-FEDER-022083, Centro2020-Portugal 2020.

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keywords Automatic Medication Dispenser, Medication Non Adherence, Older Adults, Geriatrics, Product Development

abstract The population is getting older due to higher life expectancy and lower birth rates. Medication is becoming a bigger part of older adults' lives. However, as all people do, it is easy to forget to take medication. This forgetfulness can bring a lot of consequences, specially in older adults. This is because of their more fragile health and the complexities in their medication, resulting in lower quality of life and higher number of hospital visits.

Non adherence to medication is cause by 3 main factors: patient factors, medication factors and health care providers factors. These intertwine adding to the complexity of the problem, however they can be fixed.

Technological solutions were developed along the years, some academically and some are available in the current market. Nevertheless, as all solution, there is always room for improvement.

This document sets out to collect the needs of older adults regarding their medication and review current developed systems, in order to idealize an innovative system capable of meeting the needs of older adults while improving current systems. This took a systematic approach, mixing adequate product development methodologies, linear and more traditional, State-Gate, and cyclical and more innovative, Lean.

This resulted in a idealization of a future proof system that tries to tackle the non adherence problem as whole. From this idealization it was possible to develop and build a prototype that demonstrates its main functionalities.

palavras-chave Dispensador Automático de Medicação, Não adesão à teraputica, Adultos Sénior, Geriatria, Desenvolvimento de Produto

resumo

A população está a envelhecer devido a um acréscimo na esperança de vida e a um decréscimo nas taxas de natalidade. Assim, a medicação está a tornar-se uma parte cada vez mais prevalente em adultos sénior. No entanto, como acontece com a população em geral, é fácil esquecer-se de tomar a medicação. Este esquecimento pode trazer muitas consequências, especialmente em adultos sénior. Isso se deve à sua saúde fragilizada e às complexidades inerente à sua medicação, resultando numa menor qualidade de vida e um maior número de visitas hospitalares.

A não adesão à terapêutica é o resultado de 3 fatores principais: fatores do paciente, fatores da medicação e fatores dos prestadores de cuidados de saúde. Estes entrelaçam-se adicionando à complexidade do problema, porém podem ser corrigidos.

Soluções tecnológicas foram desenvolvidas ao longo dos anos, algumas academicamente e outras estão disponíveis no mercado atual. No entanto, como todas as soluções, há sempre margem para melhorias.

Este documento recolhe as necessidades dos adultos sérnio, em relação à sua medicação, e revê os sistemas desenvolvidos até ao momento,com o objetivo de idealizar um sistema inovador capaz de reponder às necessidades dos adultos sénior, construindo sobre os sistemas atuais. Para isso tomou-se uma abordagem sistemática, adaptando metodologias adequadas de desenvolvimento de produto, lineares e mais tradicionais, *State-Gate*, e cíclicas e mais inovadoras, *Lean*.

Isto resultou na idealização de um sistema orientado para o futuro que tenta abordar o problema da não adesão à terapêutica como um todo. A partir desta idealização foi possível desenvolver e construir um protótipo que demonstrasse suas principais funcionalidades.

Contents

List of Tables

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List of Figures

Part I

Introduction and Background

Chapter 1

Introduction

Older adults' population is growing at a higher rate every year. Between 2015 and 2050, the proportion of the world's population over 60 years will nearly double from 12% to 22%. It is arguable that this is only an important subject in rich countries, like the ones in the EU, nevertheless the same is happening is poorer countries, where in 2050, 80% of older people will be living in low and middle income countries [Organization 2019]. Nonetheless, higher income countries, in the EU are predicted to age quickly. Predictions for 2100, in Figure 1.1 show a very unbalanced population pyramid, where older population outweighs younger population.

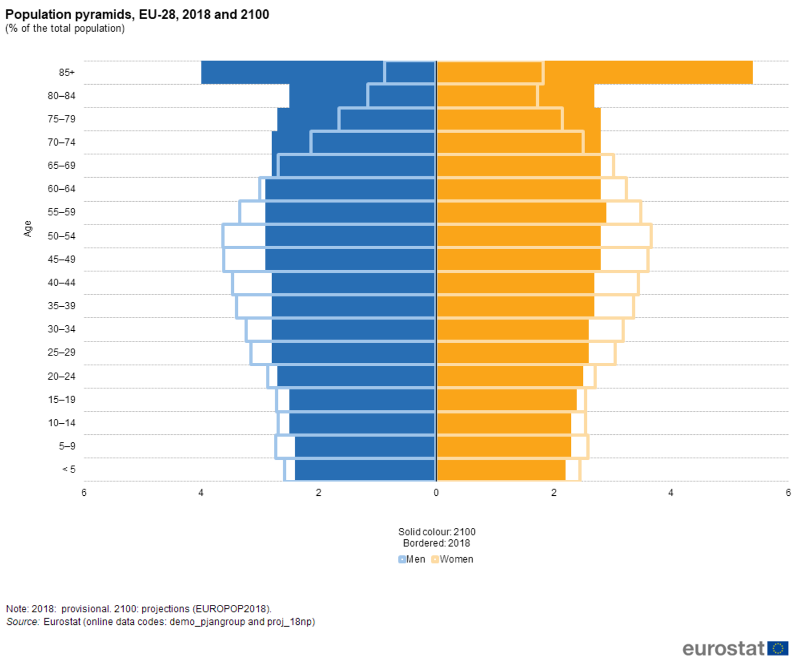

Figure 1.1: EU population from 2018 – bordered color – and the prediction for 2100 – full color [eurostat 2019].

Additionally, EU's population ageing rate is rising, as shown in Figure 1.2.

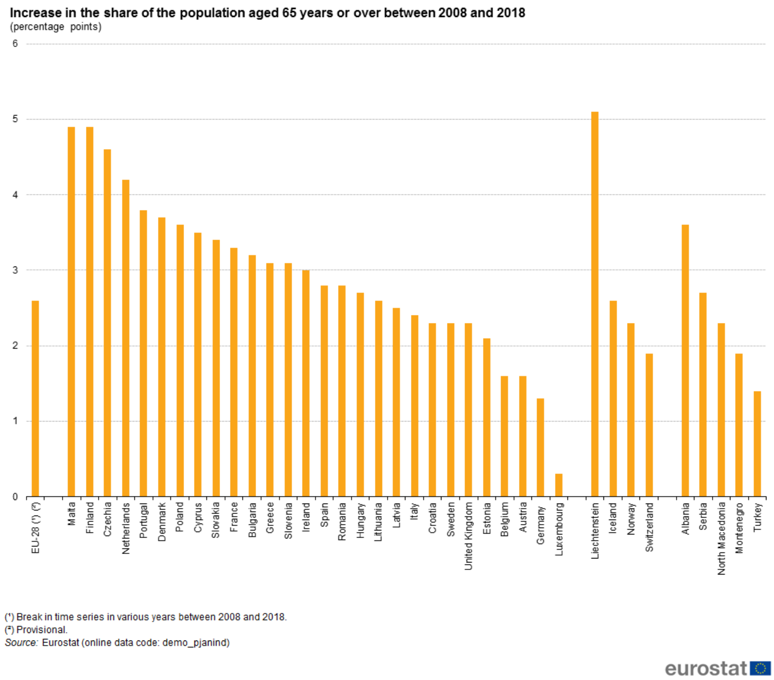

Figure 1.2: EU population ageing rate from 2008 to 2018 [eurostat 2019].

This creates a scenario where everywhere in the world population is getting older, whether it due to a drop in birth rates virtually everywhere or people are living longer lives, because of better healthcare, diet and several other factors, such as technology improvements [Pierson and Castles 2006]. This brings us to a state where sooner or later all people will have to deal with the consequences. Some consequences, are already being experienced, specially in countries like the USA. Here, healthcare expenditure exceeds the $2.7 trillion, of which between $100 and $300 billion dollars were exclusively spent due to medication nonadherence complications [Iuga and McGuire 2014].

This costly healthcare expenses come with the need to treat an older population, which tends to have a polypharmacy regimen – multiple kinds of medications taken by a patient – which consequently leads to higher risk of nonadherence. Nonadherence results in more hospital visits, deterioration of health and morbidity, leading to higher health expenses [Angela Frances Yap 2016, Erika Zelko 2016, Xiaoping Toh 2016].

With this problem in mind, the researcher will develop a system capable of solving some of the difficulties associated with the nonadherence, more specifically regarding the older adults' population, where the consequences are the most notable.

However, before setting off to the system's development, a deeper understanding of the target population, in this case, older adults' population in polypharmacy regimen, is needed. This means understanding their difficulties/problems, routines and healthcare framework of their daily lives. Moreover, it makes no sense to develop a system which already exists, meaning whether it was previously developed in academic work or it is, or was, commercialized, making it important to conduct a good state of the art research in order to understand benefits and downsides of current solutions.

1.1 Motivation

The motivations are based on the new reality of society and are mainly the following:

- Firstly, all people will eventually reach old age, which brings the same problems and affects us all in the same way. This is also when we are less capable of solving problems like this, since our prime abilities are no longer with us.
- Secondly, it is mutually agreed that an active, healthy and dignifying ageing should be a granted element of life. As described in the previous section, one of the most prominent factors for a quality ageing, is correct medication adherence.
- Another motivation is the change is family structure. Nowadays families are not as fixed in the same place as previous generations, making it harder to be able to support old adults, since it might be might difficult to travel to their location.

Personally, there are other reasons that motivate the researcher to further this project. The personal interest in this project is the love for problem solving, which is exactly what this project is about. Also a big driver for the researcher is the fact that the project combines engineering with the medical field. Something that he is passionate about, combining two areas with great impact and use them as an advantage to solve a big problem.

1.2 Why a technology based solution?

There are many factors that influence nonadherence and although it is possible to manually monitor the medication adherence, this requires a lot of effort from the patient's part. For example, direct biochemical approaches are possible, however they require the patient to report to a clinic for fluid testing.

Smart monitoring devices, as the one proposed, have been proved to improve medication adherence, when compared to manual approaches. And Internet of Things allows for tracking devices at low cost while allowing for caregivers' supervision [Aldeer *et al.* 2018, Xiaoping Toh 2016].

1.3 Methodology

In general, when conducting an experiment or project, researchers stand on shoulders of giants and make use of tools like the scientific method. In the dictionary this is is described as : "A method of procedure that has characterized natural science since the 17th century, consisting in systematic observation, measurement, and experiment, and the formulation, testing, and modification of hypotheses." [Oxford 2019].

Recently product development and management have evolved immensely, leading to several methodologies that are based on the cyclical nature of the scientific method and the improvement of linear, more classic, methodologies. The most common product development and product management methodologies are [Brunski 2017, Muslihat 2018]:

- **Agile** is excellent for small increment team focused projects that need a lot of flexibility, specially in software development [Beck *et al.* 2001];

- **Scrum** is similar to Agile, however is more suited for bigger and more complex projects. It also involves more structure supervising each cycle [Sutherland *et al.* 2018];

- **Kaban** is similar do Scrum, however if focuses on self managed teams. It is governed by 6 practices: visualization, limiting work in progress, flow management, making policies explicit, using feedback loops, collaborative or experimental evolution. This methodology originated in industrial optimization in Toyota, by Taiichi Ohno [Ohno 1988];

- **Lean** is a cyclical methodology, essentially a simplified scientific method based on: build-measure-learn. It focuses of minimal waste, high speed and learning. One of the best practical references for this methodology is Eric Ries' book, The Lean Startup [Ries 2011];

- **Waterfall** is unlike the others above, since it is based in a more traditional linear methodology based on an article from 1970 [Royce 1987]. Its core is based on the following phases: system and software requirements, analysis, design, coding, testing and operations. Although is was proposed for software development, it can be easily extrapolated to hardware product development: system requirements, analysis, design, prototyping, testing and maintenance. This is however better suited for large and complex products;

- **Stage-Gate** works as Waterfall, however between each stage, there are gates. This gates are meetings to ensure that the project is apt to follow to the next stage [Shohet 2007];

- **Six Sigma** is suited for larger companies and organizations that want to improve quality and efficiency through a data-driven methodology. It aims to improve quality by reducing the number of errors in a process by identifying what is not working and then removing it from the process [Mikel Harry and Schroeder 2006];

- **PMI/PMBOK** (Project Management Institute/Project Management Body of Knowledge) is a project management methodology based on 5 key steps: planning, executing, monitoring and controlling and closing [Institute 2019].

Not all of these methodologies are a fit for this project, however they all have key elements that can be extrapolated into a better fitting methodology for an academic project, taking into account the business/market aspects. Having said this, this project will use a combination of Stage-Gate and Lean methodologies, which are believed to be the best practice in this case. This means:

- Focus on the consumer and their needs – trough cyclical research and possibly interviews, in order to fully gasp the users needs and characteristics;

- Identify opportunities and holes in current market – through cyclical researching what has been done, why it works or why not;

- Explore new concepts – through cyclical innovation and following the needs and characteristics of the target audience;

- Prototype and experiment – through building a prototype product and learning with it;
- Systematically follow the strategy in the development [Cooper 2011].

It is important to add that these steps will be done in an linear fashion, and not cycle through them, as some of the cyclical methodologies, due to time constrains. Although, if it would be done with a go to market strategy, it would be important to cycle through the steps in order to get quick customer feedback and learning [Ries 2011].

1.4 Objectives

The main objective of this project is to build a system that aids older adults with their medication.

This objective is meant to be carried through following an existing up to date methodology or a mix of methodologies, which is the case. More specifically, the objective of this project is to research about old adults and what characterizes them as users and what their needs are – regarding medication taking; explore existing solutions for the problem of nonadherence and look for their downsides; idealize and develop a holistic system that goes towards what older adults need and that is not being fulfilled by the current solutions; and finally to explore the system's limitations and what can be improved in the future.

1.5 Document structure

The structure of this document should reflect the methodology used in the project as well as telling its story. Therefore, the first part includes the introduction followed the state of the art, where it is highlighted the characteristics and needs of the target audience, older adults, and a highlight of the pros and cons of current market and academic systems. This allows for a more sound development of the system at hand, setting the stage for the second part, the development. Firstly, requirements and considerations are presented, based on the first part, secondly the idealization of the system and finally the development of its hardware and software. In the third part, a conclusion and overview are presented, in order to look back on what has been done and see how it could be improved, as "criticism is the backbone of the scientific method" [Oxford 2019].

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Chapter 2

State of the art

State of the art is "the most recent stage in the development of a product, incorporating the newest ideas and features" [Oxford 2019]. That is the goal of this chapter: review the literature available on older adults about their medication and specific characteristics; review the literature on existing systems with the goal to solve the same, or similar, problem; and research existing products in the market.

Therefore, the next sections correspond, respectively, to the different needed topics of the state of the art.

2.1 Target population

2.1.1 Understanding older adults

Older adults are considered to 60 years old or more, but this may vary according to literature. Age itself is a marker for behavioral changes in people. Therefore in this section it will be described the specific characteristics that happen during the ageing process and that are prevalent in older adults [Czaja *et al.* 2019].

Ageing has at least three dimensions: biological, psychological and social. The level of ageing in each dimension ultimately depends on the person and their age [Czaja *et al.* 2019]. Given the fast changes occurring in older adults, the characteristic can not be generalized for age 60 to 100 plus. Therefore, researchers set out in distinguishing different categories of older adults. One of the categorizations divides older adults into three different groups: from 65 to 74 the young-old adults(YOA), from 75 to 85 the old-old adults(OOA) and above 85 the oldest-old adults(ODOA) [Veloso 2014].

Another important aspect of ageing is the active ageing. This is a term used to refer to a healthy and full filling ageing. Active ageing is set on three pillars: health, security and social engagement [Veloso 2014].

In the next section, it will be explored the characteristics of older adults having in mind a product development centered in the users, the older adults.

Characteristics of older adults

The following characteristics are based on the book*Designing for Older Adults* [Czaja *et al.* 2019], where the authors explains in detail the characteristics of an older adult user. These are split in 3 categories: sensation and perception, cognition and movement control.

- **Sensation and perception**
  - Taste and smell show age-related declines.
  - Changes in haptics result in increased perceptual thresholds for temperature and vibration and may make older adults more susceptible to falls.
  - Auditory declines are common, especially for older men, and especially for high-frequency sounds.
  - Vision declines for many older adults; visual acuity declines begin to be noticeable around age 40.
  - Glare is more problematic for older, relative to younger, adults.
  - Other aspects of vision also show age-related declines: dark adaptation slows, breadth of visual field decreases, visual processing speed slows, and perceptual exibility declines.
- **Cognition**
  - Memory is a multifaceted construct; only some aspects show age-related declines:
    - Working memory (i.e., the ability to hold and manipulate information) declines with age.
    - Semantic memory (i.e., acquired knowledge) shows minimal decline with age although the ability to access information may be slower and less reliable.
    - Prospective memory is remembering to do something in the future. Age-related declines are less evident if people have strong cues available as reminders (e.g., take medication with dinner).
    - Procedural memory is knowledge about how to do something. Well-learned procedures are maintained into old age and, in fact, are difficult to inhibit. Older adults are slower and less successful at acquiring new procedures, relative to younger adults.
  - Attention is a multifaceted construct; only some aspects show age-related declines:
    - Selective attention (i.e., searching a visual display) and dynamic attention (reorientation of attentional focus) both show age-related declines.
    - Older adults can benefit from cues to orient and capture their attention.
    - Age-related differences in rate of information processing increase with task complexity (i.e., attentional demands).
    - Older adults perform less well than younger adults when required to coordinate multiple tasks, either by dividing attention or switching attention.
  - Spatial cognition (i.e., maintenance and manipulation of visual images) declines with age.
  - Language comprehension remains intact if older adults can capitalize on their semantic memory; impairments are observed when inferences are required and working memory is overloaded.

- **Movement control**
  - Older adults respond more slowly than younger adults. In general, an older adult will take between 1.5 and 2 times longer to respond than a younger adult.
  - Movements made by older adults tend to be less precise and more variable than those made by younger adults.

2.1.2 Importance of adherence

In Chapter 1, it was highlighted the importance of patient's adherence to medication. Non adherence is mainly due to poly pharmacy and the complexity and individuality of medication-taking [Jim Mitchell 2001, Erika Zelko 2016]. This can affect the patient's health greatly, leading to an increase in morbidity and mortality, with higher chances of hospital emergency visits, hospitalizations, a lower quality of life and costly healthcare expenses [Jim Mitchell 2001,Rajesh Balkrishnan 1998,Erika Zelko 2016,Angela Frances Yap 2016, Yap *et al.* 2016].

In this research, it is believed that this main factors should be enough to highlight the importance of the adherence to medication. Broadly, they can be summed in two: quality of life and healthcare costs.

Quality of life is important for every human being, however one of the most fragile times for every one of us, comes as people grow older. Not sticking to medication when one is "healthy", may not carry too many consequences, nonetheless when one is older, this might determine the quality of living for the rest of their lives.

Regarding health care costs, it has been highlighted the amount of money wasted in avoidable health situations. This affects wellfare institutions, the government and consequently all of us.

2.1.3 Non adherence factors

The reasons for non adherence are not always clear. However, they can be categorized in three categories:

- Patient factors;
- Medication factors;
- Health care providers factors.

Although studies like Sek Hung Chau's [Sek Hung Chau 2016] present an in depth listing of the factors leading to medication non adherence, the presented ones will be the most important and the ones which are closely related to the project at hand.

For this project, focusing on all factors is important. Resulting in a solution with higher chances of effectively solving the problem of non adherence and not having any factor as a bottleneck. In a nutshell, trying to solve the problem as whole and not just a part of it.

Patient factors

The patient's main categories for non adherence are:

- **Living alone**: this is a great predictor for medication non adherence, since they have no one to help them manage the medication [Rajesh Balkrishnan 1998, Angela Frances Yap 2016];
- **Income level**:this it affects the willingness/possibility of older adults to buy the medication [Rajesh Balkrishnan 1998];
- **Health situation**: this is a huge factor in non adherence. There are two separate reasons though: their actual health and the beliefs about their health. Regarding their health situation, old age, lower cognitive function, poor memory, poor dexterity, frequent hospitalization, among others, are important factors that heighten the chance of non adherence. Moreover, the patient believing that they are well and not sick anymore, leads to a premature abandoning of the medication [Rajesh Balkrishnan 1998, Angela Frances Yap 2016, Sek Hung Chau 2016];
- **Medication misinformation/beliefs**: most patients are not fully aware of what their medication is doing [Rajesh Balkrishnan 1998] or may have wrong assumptions/beliefs about their medication [Angela Frances Yap 2016]. Moreover, it may have not been fully clarified or even the patients did not understand the technical language used by the medical professional [Renata Mazaro e Costa 2008]. Poor health literacy highly impacts medication adherence and consequently quality of life [Manafo and Wong 2012].

Medication factors

Managing a patient's medication is not an easy task. The behaviour of taking medication is extremely complex and individual, which requires taking into account a lot of different factors and strategies to make sure the patient takes the medication as intended [Erika Zelko 2016]. However, drug dosing is just one of the difficulties when talking about medication factors.

The more medication a patient takes, the harder it becomes to manage theirs effects and to promote medication adherence. Most older adults are able to stick to their medication, due to habit. When the habit changes, the new drug taking regimen is much harder to reintroduce it into their lives. This is why changing the drug regimen can alter medication adherence so much [Angela Frances Yap 2016].

Finally, a factor regarding the problems of old age is the drug handling. Many older adults have poor dexterity, as mentioned in the sections 2.1.3 and 2.1.1, which means that if the medication packages are hard to handle, they can be problematic for the patient [Angela Frances Yap 2016].

Health care provider factors

The last of the non adherence factors is related to the health care providers. Even though their job is to make sure that the patients' health is assured, that is not always easy to accomplish. The factors mentioned below affect how patients take their medication, influenced by health care providers' behaviour. It is mostly unintentional, but a result of several subjective factors.

Two very big factors affecting patients' adherence are the contact and careful explanation, or lack of it [Rajesh Balkrishnan 1998, Erika Zelko 2016, Angela Frances Yap 2016]. This means that better clarification and attention to the patient will improve their medication adherence. Overworked caregivers and lack of medication review also result in poor adherence [Erika Zelko 2016, Angela Frances Yap 2016].

Factors not entirely related to health caregivers, but to the health care system are also worth mentioning. Poor health literacy [Manafo and Wong 2012], follow up, medication schedule and not enough professionals to help medication management contribute to higher medication nonadherence [Angela Frances Yap 2016].

2.1.4 Drug Related Problems

It is also important to note that in the literature there are extensive analysis of which are the most common problems related to drugs.

According to Rajesh Balkrishnan's work [Rajesh Balkrishnan 1998] the most frequent drug related problem is its under and over dosing. Additionally, the 3 drugs classes associated with most problems are: drugs for peptic ulcer and gastro-oesophageal reflux disease; antithrombotic agents; and lipid modifying agents.

Sek Hung Chau [Sek Hung Chau 2016] has also compiled the main medication factors that affect patient's medication adherence, present in Table 2.1.

Table 2.1: Medication factors affecting medication adherence [Sek Hung Chau 2016].

Factors	Ref
Drug	
Formulation	37
Packaging	38
Drug storage issues	40
Drug handling	
Lack of use of medication boxes	39
Necessity to cut tablets	39
Difficulty opening containers	36
Drug regimen	
Polypharmacy	40
Medication regimen changes	23
Complex dosing regimen	16
Others	
Costs and lack of insurance coverage	17
Adverse drug reactions	39
Drug-drug interactions	42
Poor labeling instructions	36
Short-term medications	50
Lack of immediate consequences of missed doses	31

Renata Mazaro and Costa [Renata Mazaro e Costa 2008] went through another route, highlighting the side effects of certain medication that might affect older adults. For example, benzodiazepines can cause memory and balance problems, when taken incorrectly, more specifically when taken longer than recommended, leading to accidents and a lower quality of life. This when more than 20% of older adults make use of this drug in their daily lifes.

2.2 Academicaly developed systems

In this section, academically developed systems will be presented. When introducing the systems is important to be consistent, this means following the same presenting rules for each system, in order for them to be easily compared between each other.

The following topics will be the base for inducing the systems throughout this section:

- **System description**: explain how the system works generally and its important features.
- **Pros**: which part of the system addresses the problem and has the characteristics presented in the section 2.1.1 taken into account.
- **Cons**: which parts of the system deserve improving.
- **To whom**: based on the section 2.1.1 indicate who is the specific target group for the system.
- **Cost of the system**: based on the material composing the system, what is the predicted price-point it would have: low cost(0-$150), medium cost(151-$300) and high cost($301+).

2.2.1 Older Adults' Medication Adherence Monitoring with the Internet of Things

A team of researchers from Singapore developed a simple IOT system consisting in a box with a microcontroller and a magnetic switch in the lid. The box used what a plastic container with different compartments, for different medications as seen in Figure 2.1. When the user opens the box, the microcontroller sends the information to a hub in the house. This hub then sends the information to a web platform, which can be consulted by different stakeholders, for example caregivers [Xiaoping Toh 2016].

(a) Single-compartment. (b) Three-compartments.

Figure 2.1: Medication box configuration [Xiaoping Toh 2016].

According to the researchers, the system was successfully adopted by the old adults, after some necessary convincing. The information given by the system allowed for a good tacking of the medication, impeding patients' health deterioration [Xiaoping Toh 2016].

A good characteristic was that users liked it was customizable.

However, this systems has some downsides. There is not an alarm system to remind the users to take the medication, caregivers called in case forgetfulness. Additionally, the system is blind regarding the amount of medication taken.

Many older adults had concerns with the energy consumption of the system, even though the system had very low power. There were times when the users themselves took the power plug off the wall to turn the system off. Moreover, they would forget to close the box, leading to the drainage of the battery. Caregivers would call to remind the users to close the box.

Another problem was the difficulty to match the system with the users' lifestyles. Some of the older adults had active lifestyles, which led to higher medication irregularity. This is important, given that active ageing lifestyle is becoming more prevalent.

The users in the study ranged between 69 to 81 years old, and each of them is diagnosed with three to eight chronic illnesses. Each old adult consumes four to ten types of medication, and daily medication intake frequency ranges between one to three. This concludes that the systems is prepared to be used by users of any age.

The system is composed of very simple components– a micro controller, a simple hub and simple switches– which makes it low cost.

On a final note, other systems were developed with similar functionalities, which are not worth going into detail given their similarities and similar findings, these are [Marcelo Parra *et al.* 2017].

2.2.2 ElderlySafety

The system developed by Bárbara Martins [Martins 2015], ElderlySafety, is a dispenser plus tracking software. The dispenser's hardware is controlled with an Arduino Uno, connected to an LCD, which displays useful information for the patient, a step motor, which controls the circular pill tray, Figure 2.2, and a Bluetooth module, which allows the communication between the hardware and the tracking software. It is possible to see the system's schematics in Figure 2.3 – at the right top corner, the motor that moves the pill tray, in the center in blue, the microcontroller, and at the bottom in green, it is the LCD for displaying information.

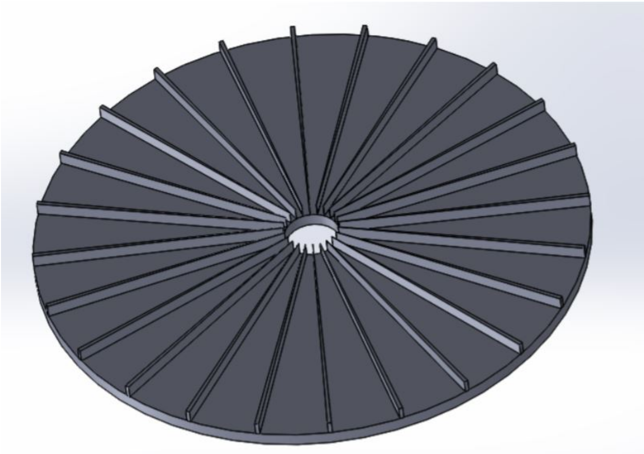

Figure 2.2: ElderlySafety's pill tray [Martins 2015].

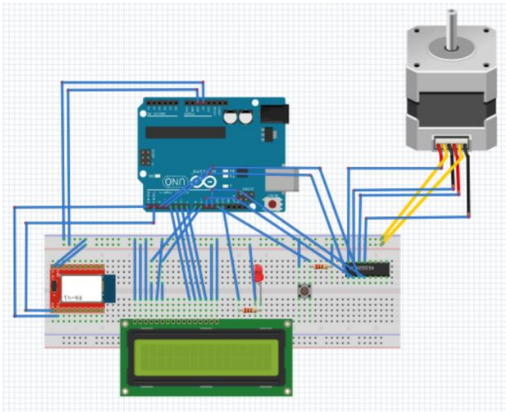

Figure 2.3: ElderlySafety's system representation [Martins 2015].

The system is able to always deliver the correct dosage to the patient, given that the medication loaded in the tray is the correct one. Additionally, the tracking software allows patient's stakeholders, like family members and care takers, to access the patient's medication information.

The alarm system helps reminding the patient of their medication. Moreover medication taking flow is not compromised with this system.

However, the pill setup has to be made entirely by the care taker, from loading the pill tray to setting up the software with the pill schedule. This may increase the cost of the patient's health, given that the system is not portable and need a caretaker to properly run the system (it is not easily set up).

The display of the system is not older adult friendly, as its dimensions are not according to what display design for older adults dictates. [Pak and McLaughlin 2011].

The tests made with the system were made with 4 older adults from 73 to 82 years old. However, this systems can easily be used by YOA.

Even though the system overall is simple, if turned into a product it needs modifications, therefore its price lays between the low and medium cost range.

2.2.3 Teng Cao

The design work of Teng Cao [Cao 2010] is an interesting take on modular portable pill dispensers/pillbox with a ring to easily reminding the patient of the medication. The whole system can be seen in Figure 2.4. On the left are the pill bottles, where the pills can be stored. On the right of the pill bottles, are the pillboxes, which can be be opened when the patient has to take the medication. On top of each compartment there is a sticker with the medication's information is, except on the bottom one, which controls the whole system, has a screen to display medication information and communicates with the ring. This ring helps reminding the patient that he has to take their medication 2.5.

Figure 2.4: Teng Cao's whole system [Cao 2010].

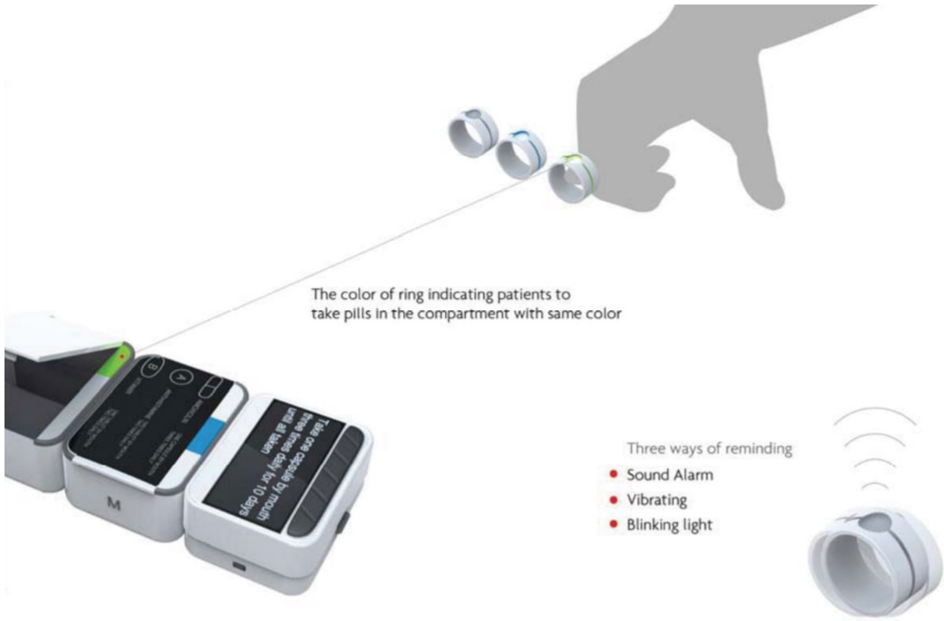

Figure 2.5: Teng Cao's pillbox concept [Cao 2010].

This system is very portable, which goes with the growing needs of active ageing. Additionally modularity allows for customization, which is important for old adults 2.2.1. Moreover, it allows to display information about the medication, an important factor for adherence, as seen in section 2.1.3. Finally, the ring is a good alarm system to help older adults to remember the medication, since hearing deteriorates with age, section 2.1.1.

Unfortunately it requires manual pill loading into the pillboxes, which is not easily accomplishes by every old adult. Small letters in the medication information labels is also not indicated for old adults [Pak and McLaughlin 2011]. Additionally, the small compartments of the pillbox are difficult to be handled by OOA and older, given less movement and hand control degeneration, section 2.1.1.

Given the different characteristics described in section 2.1.1 and the pros and cons above described, this system, as it is, is indicated for YOA and OOA.

The complexity of the system puts it in the most expensive side of the spectrum, high cost. It involves an ecosystem of products to work seamlessly, which as a product is expensive.

2.2.4 Pill Dispenser with alarm via smartphone notification

This is a prototype model of an older adults' pill dispenser equipped with am alarm sent to their smartphone. It is controlled with a microcontroller and an infra-red sensor controls the medication dosage which also measures the duration of the medication intake. The systems has an LCD and buttons for configuration, as seen in Figure 2.6. To dispense the pills it uses a servo and vibration motor to help the medication fall out off the container. The information is sent to a hub, that re-transmits the information to the smartphone. The alarm notification is a popup in the smartphone, *Instapush*, sent when the medication is due [Othman and Ek 2016].

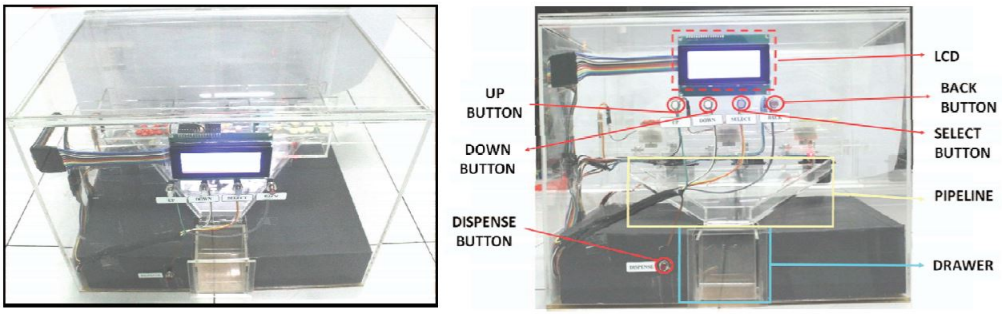

Figure 2.6: Pill dispenser system with smartphone notifications [Othman and Ek 2016].

This system has four advantages: it allows for caregiver control, since the notifications can be configured for more than one smartphone; it solves the problem of older adults not hearing the alarm, which happens due to age-related hearing loss, section 2.1.1; the medication is dumped into containers, not needing an exhausting manual load up into different small containers. The latter one encourages independence of the older adult; and is an almost closed system – the user has no control over the main system's decisions – however since the medication is not automatically updated in the system, gives the user some control over it.

One of the downsides of this system is the increased technology in the system, the smartphone notifications. This is a known barrier for older adults, due to age-related changes and challenges [Fischer *et al.* 2014]. Moreover, the LCD screen and controls are not designed for older adults [Pak and McLaughlin 2011]. The others are: is not modular, portable nor customizable, important aspects seen before [Xiaoping Toh 2016].

Given the need for smartphone adoption, this system is more suited for YOA and some OOA.

The complexity of the systems, even though the researchers refer as a low cost system, can be projected to a low to medium cost, given the complexity needed for a market product like this.

2.3 Commercial products and services

In the medical industry there is a large variety of products and services, specially when it comes to older adults' care and people with serious/chronic problems. The goal of this chapter is to gather information regarding commercial products, services and both – products that are sold with/as services – in a systematic way.

Concrete examples of companies will be given, so that scalability and the economical point of view are also taken into account. This sets a more realistic perspective, insuring that the product development goes hand in hand with a sustainable business. Obviously that not all product development has the goal of maintaining a profitable business, however it is an important aspect and it should not be ignored.

There are several sensor-enabled medication boxes, these are costly and most not easily adopted by older adults. Most of these are known to be inflexible and bring recurring costs [Xiaoping Toh 2016].

Just like the previous section 2.2, every system will follow a similar set of rules to insure consistency:

- **System description**: explain how the system works generally and its important features.
- **Pros**: which part of the system addresses the problem and has the characteristics presented in the section 2.1.1 taken into account.
- **Cons**: which parts of the system deserve improving.
- **To whom**: based on the section 2.1.1 indicate who is the specific target group for the system.
- **Market acceptance**: important information about how the market is adopting the system.
- **Cost of the system**: the market price will be divided in 3 categories: low cost(0-$150), medium cost(151-$300) and high cost($301+).

2.3.1 Products

In this section products that are bought as a one time purchase, with no fees or recurring costs, will be reviewed.

Tricella

Tricella is a pillbox/dispenser, Figure 2.7, that allows for Bluetooth connection with a smartphone app and senses whether or not the pills have been taken. This allows tracking and surveilling patients who need it, alerting caregivers in case of a missed dosages [Tricella 2019].

It is advertised to have arthritis friendly design and drawers. Amazon reviews shined a better light on its functionalities like the ability to block individual compartments to avoid opening them before the medication is due, the ability to take one individual box when sleeping out one night, ability to have the light on for the compartment of that day and the ability to have the history of when the dosages were taken, in the family app.

However, there are downside for this system too. It needs to be refilled every time, which needs a fully capable older adult or a caregiver to do it for them. This brings recurring costs and reduces autonomy. Some users complained that the app is not useful. It should give a log of when the compartment are opened, but it fails to do it occasionally. Moreover, several users complain about battery and connection issues.

It is important to notice that each Tricella allows only one daily dosage, therefore the user needs to purchase on Tricella for each dosage that they take a day.

It is reported that it is suited for all kinds of users, YOA, OOD and ODOA. However, as discussed before, the need for adopting a smartphone as a hub for the system can be a bottleneck for some users. Having said this, the system is more adequate for YOA and OOD.

The system is sold online and come American stores, like Target. It is not sold in health specialized stores, like pharmacies. Mostly, this product is bought for the customer's parents, in order to help them better take care of the user.

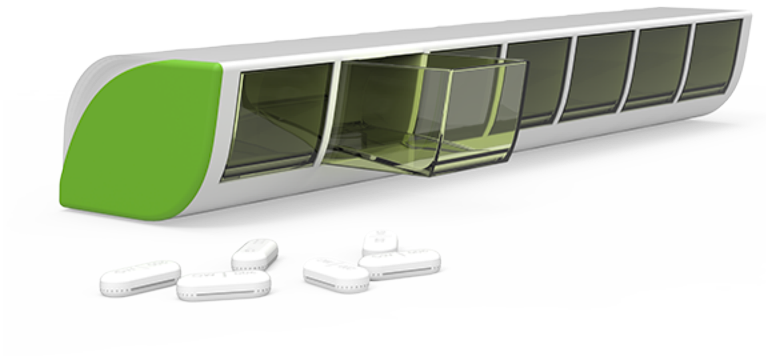

Figure 2.7: Tricella Smart Pillbox [Tricella 2019].

This is a low cost product, around $100, however this covers only one daily dosage. The user would have to buy a Tricella for each daily dosage it usually takes.

Medissimo iMedipac

Medissimo iMedipac is a smart pill-tray, Figure 2.8. The pill-tray needs to be filled in, by hand, by the pharmacist. Each compartment has a sensor that detects when the user took the pills out. Overall, this product is a simple pill-tray with the detection of when the patient takes the medication. Additionally, it is complemented with a software that tracks the medication taken and its information can be shared with other stakeholders, caregivers and health professionals [iMedipac].

It is a simple system, which is fortunate for older adults. Moreover, it tracks the necessary information to ensure the user's good health. Another positive aspect is that it essentially is a closed system, where the user an little control over errors in medication and dosage.

However, it requires an initial pill setup, which does not promote the patient's independence, since it needs to be set up by a pharmacist. Even though it is portable, it is not the most easy to transport, since it is briefcase size. Another important aspect is the lack of easy access to medication information by the patient. Additionally, the price does not make the system easily accessible for every older adult. Finally, the small compartments of the iMedipac are difficult to be handled by OOA and older, given less movement and hand control degeneration, section 2.1.1.

This system is advertise for every type of older adult. Given the simplicity of the

Figure 2.8: Medissimo iMedipac system [iMedipac]

product, there is no literature that objects this affirmation.

This product is mainly sold in the french market and according to the information available by the company, it works in par with pharmacies. This leads to the conclusion that there needs to be a partnership between the company and pharmacies, restriting its use to where this partnerships exist.

The price of this product is around $400, setting the price range into the high cost spectrum.

PillDrill

PillDrill is a smart system that tracks, reminds and notifies medication intake. The systems, in Figure 2.9, has a main hub, where the NFC tags can be scanned. The Figure 2.10 shows the NFC tag scanner (NFC antenna). The tags are available in stickers, attached to elastic bands and in the bottom of each compartment of the pill strip. Additionally it includes an app that can be set up with the system, for caregivers and/or personal use, depending on the familiarity with technology of the user [PillDrill 2019].

This is a clever systems due to its human centered approach, where it tries not to modify habits, but to be as hassle free as possible in the medication taking flow as possible. Moreover, it allows for portability with its pill strips, making it easier to fit into more active routines, which some older adults have. The containers are also claimed to be easy to open. Finally, the screen is suited for older adults [Pak and McLaughlin 2011]. good screen design

The system has some downsides. The system is of difficult set up, which requires manual pill distribution and the inability to scan medication intakes on the go. Moreover, it is not motioned that the hub can show any kind of medication information, an important aspect covered before, section 2.1.3. The system is not a closed system, it is actually fairly customizable, which can be an advantage for some users, however in old adults the medication should be automatically set by the system, in a closed system, in order to reduce human errors.

Figure 2.9: PillDrill Hub, 2 pill strips, 12 scanning tags, 3 elastic tag holders, the mood cube [PillDrill 2019].

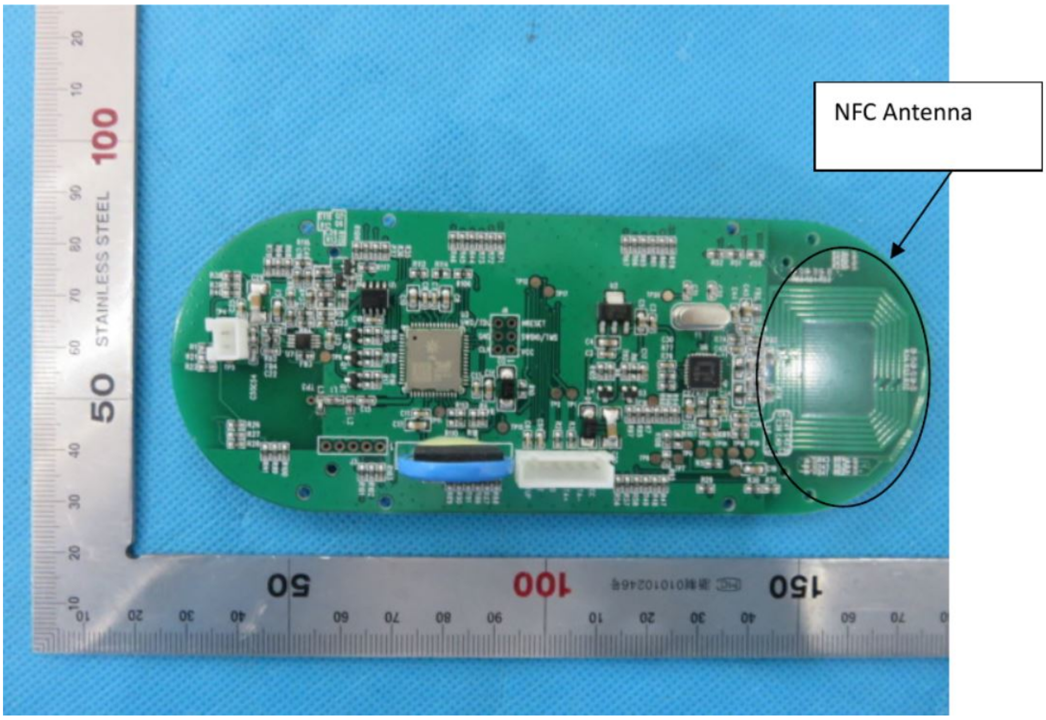

Figure 2.10: PillDrill internal with highlight on the NFC antenna [FCC].

PillDrill is claimed to be for all ages, however a part of the system can be complex enough to be of difficult adoption by certain older adults, as OOD and ODOA.

The system can be only bought through their website [PillDrill 2019]. Several reviews indicate that it works well and the GooglePlay App Store shows that it has 500+ installed apps, which helps estimate the number of users using the system.

The system costs $279, setting the prince in the medium cost category.

Ellie smart pill box

This smart pill box works as a pill tray that reminds the user when, what and how many pills to take. The system is in Figure 2.11, which is the pill box and the app, that wirelessly connects to it [Grid 2019].

Figure 2.11: Ellie smart pillbox and app [Grid 2019].

The pill tray is fairly simple to use and portable due to its size.

However, it is enable to track the amount of pill taken and, specifically for older adults, the only way to check and manage the medication is through the app, which can be an obstacle. Additionally there is no way to show medication information to user. Finally, it is not a closed system, which can lead to medication error and wrong dosages.

Given the fact that the only way to control the product is through the app, this system is mainly for more tech savvy users. Having said this, it is more suited for YOA.

Just as the previous system, the product can only be bought through their website. The complementary app, in the GooglePlay app Store, shows to have 100+ installs, which gives an estimate of the number of users using the system.

The system costs $149, which positions itself in the low cost category.

Reizen's AutoPill

AutoPill is the most simple smart system for medication tracking. It is possible to see in Figure 2.12 that it is similar to the system developed in section 2.2.2, with a circular pill tray and featuring alarms to remind the patient about the medication.

The simplicity of the product allows for an easier adoption in older adults [Fischer *et al.* 2014]. It is also portable, an important aspect mentioned in section 2.1.1.

Being simple has its downside though. It lacks a lot of important features that better the medication taking flow and still requires a time expensive manual setup. Additionally,

Figure 2.12: Reizen's AutoPill [MaxiAids 2019].

it has no tracking information about missed dosages, an important fail safe in case the patient did not take it, nor access to more information about the medication. Finally its medication set up is manual, being a burden on caregivers and makes it an open system, which leaves room for human error, as discussed in previous products.

Given its simplicity, it can be assumed its adaptability for any kind of user and older adult.

From the information available it is inconclusive what is the market's adoption of this product

The system costs $64.84, which puts it in the low end of the spectrum of low cost systems.

AdhereTech

AdhereTech is a smart pill bottle . The way it works is: the patient takes the pills normally and the bottle sends the medication taking information directly to the company. This information is integrated with the pharmacy's system and it is real-time. The patient receives a notification when they miss the dosage, through a text message or a call. Additionally, when the patient needs, they receive medication refills and support [AdhereTech 2019].

This is one of the few systems that requires no setup from the user. It is highly portable, an upside of the system. The pill bottle is of very simple use, suitable for an user with any level of technology literacy.

Unfortunately it does not measure the amount of pills taken by the patient, which can lead to dosage errors. The alarm system, apart from phone notifications, is only the light on the bottle seen on Figure 2.13. Finally there is no medication information available for the end user.

Figure 2.13: AdhereTech intelligent pill bottle [AdhereTech 2019].

Given the simplicity and hassle free product, it suitable for any older adult.

The product is still under testing, therefore having no available information about the market adoption.

Since it is currently under testing, there is no price available on the system, however given its characteristics it will most likely fall in the low to medium cost categories.

Pillsy

Pillsy has the same concept as the product in 2.3.1, however instead of a bottle is just the cap of the pill bottle and a complementary app. It can be seen in Figure 2.14 [Pillsy 2019].

According to the GooglePlay app store, the complementary app has 1000+ downloads, which gives a rough estimate of how many users are using this product.

Its cost is $44.95+, setting the price in the low cost category.

2.3.2 Products and services

In this section it will reviewed systems that are sold as a product with a service, which brings recurring costs.

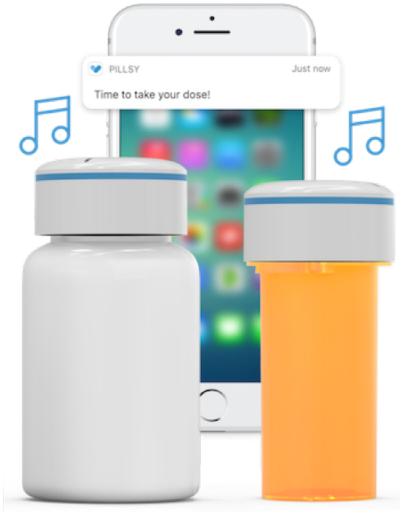

Figure 2.14: Pillsy bottles and app [Pillsy 2019].

Hero – $399 + $39/month

The Hero system, Figure 2.15, has a main hub and an app for medication management. It automatically dispenses the medication, thanks to its pill rotating holder, which can hold up to 10 different kinds of pills, Figure 2.16. It supports medication management, alarms and reminders, through the hub and the smartphone app. A normal usage for this system is, first set it up in the app and then every time medication is due, click the middle button and the medication is dispensed [Hero 2019].

A positive aspect of this system is the automatic sorting of the medication. The trays only need to be filled up, as you can see in the Figure 2.16 and 2.17. It is also easy to use, which simplifies medication taking flow.

With information in the website, the app is required to manage and use the system. Additionally there is no medication information available for the end user and it is not a closed system, susceptible to medication errors, as discussed before. Finally, the system is not portable in any way, which can affect adherence in older adults with active lifestyles.

The system is advertised to every age. Given that a caregiver can help setting up the system, it is indeed suited for every old adult.

According to Google Play app store, the app has 500+ downloads, giving an estimate of current users using the system.

Hero is a high cost product, costing $399 plus a $39 monthly fee. Assuming a 5 to 10 year system usage, adds to the system from $2340 up to $4680.

2.3.3 Services

The goal of this section is to review systems sold as a service.

Figure 2.15: Hero system [Hero 2019].

PillPack

PillPack is a full package service pharmacy and care-taking service. Each month, customers receive a personalized roll of pre-sorted medications along with a convenient dispenser and any other medications that cannot be placed into packets, like liquids and inhalers, Figure 2.18. Additionally it has a managing platform, PharmacyOS, that besides managing each costumer's medication, puts them in touch with health professionals, to help them with the medication [PillPack].

Considering the engineering aspect, it is not the most interesting service, however it lays the ground for other possible services that take advantage of a more human-centered design [Bhattacharyya *et al.* 2019]. There is no need for any kind of medication sorting. Finally, it is a portable system, since every pack can be separated and later opened.

Unfortunately, even though it has a platform, the end user does not have direct access to medication information. Also it does not support medication alarms nor tracking. It is an almost closed system, however there are downsides to it, mentioned above, which can affect medication adherence.

Given that there is no reminding system, this should be for old adults with high memory capability, section 2.1.1, mainly YOA.

The company did not disclose the number of customers it serves, however after being

Figure 2.16: Hero pill holder [Hero 2019].

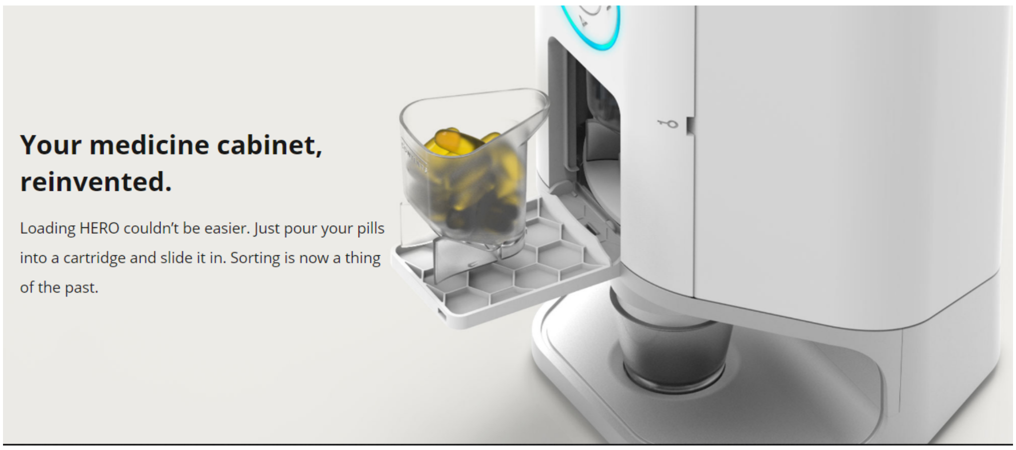

Figure 2.17: Refilling Hero [Hero 2019].

sold to Amazon for 753 million dollars it is safe to assume the high number of customers the company has. Additionally, it is known that PillPack's customers reside between 50 and 60 years old [CNBC 2019].

The system is sold along health insurance packages, which may vary the prices.

Figure 2.18: PillPack slot holder and one medication example [PillPack].

MedMinder

It serves as a pill box with a few smart features, present in Figure 2.19 [MedMinder 2019], these include sounds alarms, blinking the specific compartment needed for the dosage and medical alert with the push of a button.

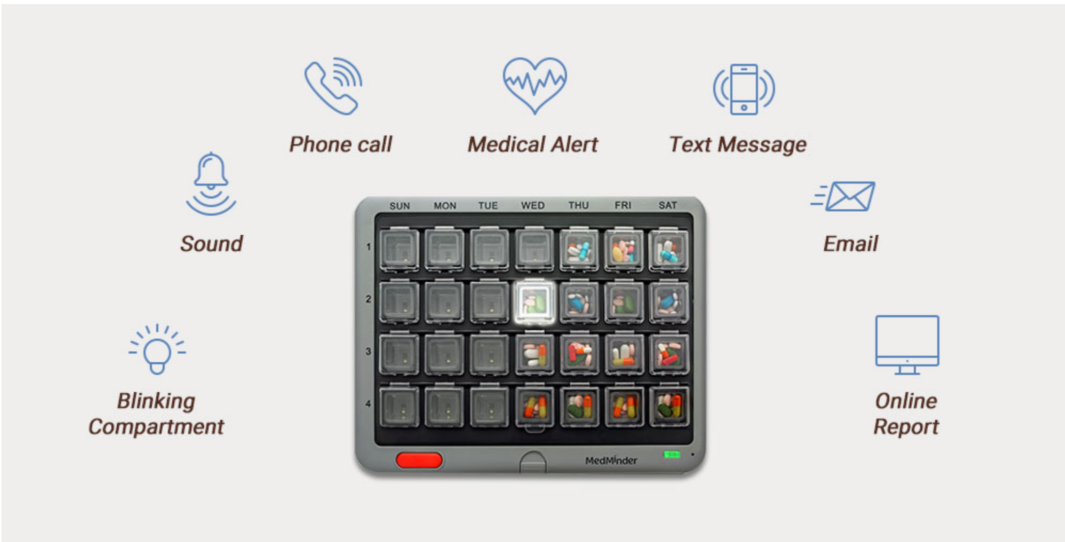

Figure 2.19: MedMinder pill dispenser with the different features [MedMinder 2019].

All the features mentioned above are positive aspects of the system. Additionally it has a 24/7 help department available to the user.

Even though it is an upgrade of a normal pill box or dispenser, it lacks important features that users need/require. Just like other systems, a manual set up is required and portability is an issue given its size. Additionally, being this a service, it is subject to recurring cost that quickly add up to a more expensive system than others presented in this document. Finally, the small compartments of the MedMinder are difficult to be handled by OOA, given less movement and hand control degeneration, section 2.1.1.

This product has overall useful features for every kind of older adult.

From the information available it is inconclusive what is the market's adoption of this product.

MedMinder is a service with 4 different plans, Figure 2.20, built up on a smart pill dispenser, Figure 2.19. These range between $39.99 up to $64.99 a month. Assuming a 5 to 10 year use of each system, this prices the system between $2399 and $7799. This however includes the 24/7 support. To conclude, this system is in the high cost category.

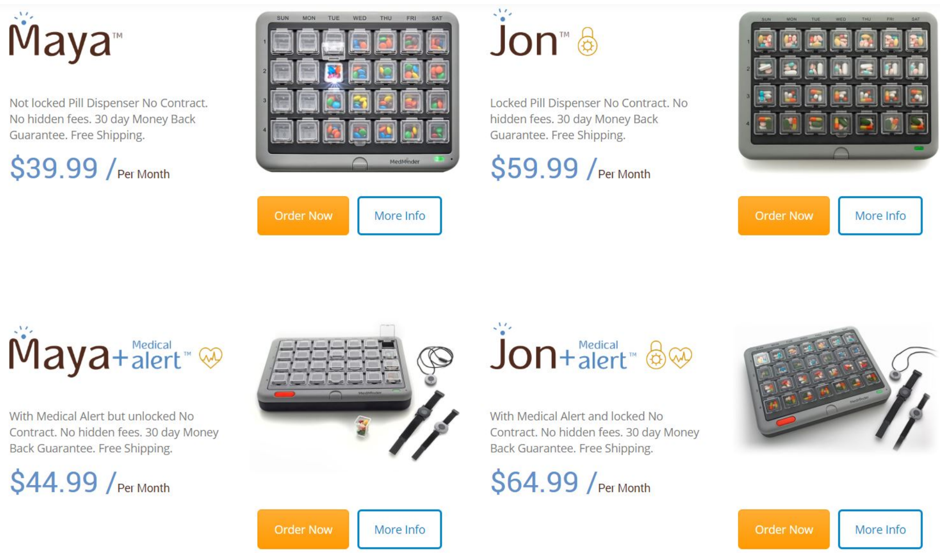

Figure 2.20: MedMinder's different services [MedMinder 2019]

MedaCube

This service comes after the section 2.3.2, **Hero** system, due to their similarities, refraining from repeating the same features and downsides of the system. Moreover, it is possible to see the system on Figure 2.21 [MedaCube 2019].

The system can be considered a service since it charges $99 per month, but can be bought as an unique purchase for $1499, setting the system in the high cost category.

Stihi's Pill Dispenser – From Rs 3500 ($45) to Rs 5000 ($64.50) per month

Just like in the previous section, this service, based on the product present in the Figure 2.22, is similar to the on the one present on the section 2.3.2 [Stihi 2019].

This system is sold as a service ranging from $45 up to $64.50 per month. Following the same logic as the section 2.3.3, this system is a high cost system.

2.4 Systems' summary

The goal of this section is to summarize every system presented in the previous sections in a global table for quick overview and consulting.

Figure 2.21: MedaCube system [MedaCube 2019].

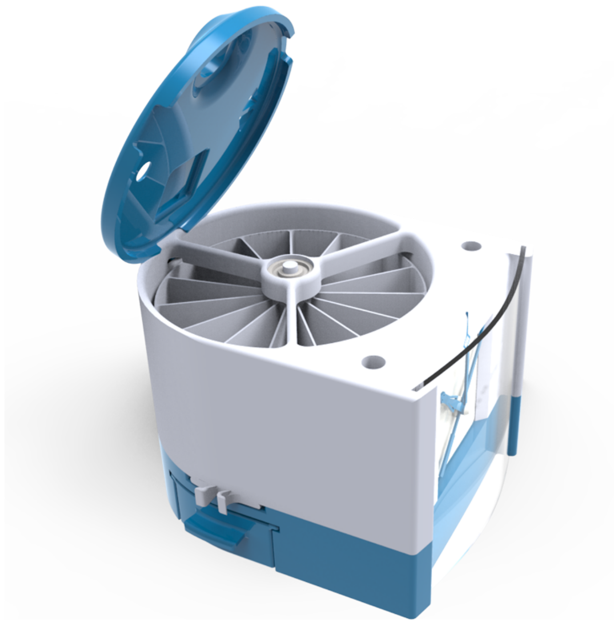

Figure 2.22: Stihi's pill dispenser [Stihi 2019].

Additionally, this serves as an easier and systematic way of identifying opportunities and current market holes, which fail to address older adults' necessities or to tailor the systems to their unique characteristics.

Table 2.2: Systems' summary(1/2).

Name	System desciption	To whom
Older adult's medication adherence monitoring with IOT	Senses when medication box is opened and conveys that information	All old adults
ElderlySafety	Circular pill tray dispenser	All old adults
Teng Cao	Modular portable pillbox	YOA and OOA
Pill Dispenser with alarm via smartphone notification	Hub automatic dispenser withsmartphone notifications	YOA and OOA
Tricella	Portable pillbox with app	YOA and OOA
Medissimo iMedipac	Smart pill tray with managementplatform	All old adults
PillDrill	Smart system with hub, tags, appand portable pill strips	YOA
Ellie smart pill box	Smart pill tray with app	YOA
Reizen's AutoPill	Simple smart dispenser	All old adults
AdhereTech	Smart pill bottle with managementplatform	All old adults
Pillsy	Smart pill bottle cap with app	All old adults
Hero	Home hub pill dispenser withapp for management	All old adults
Pillpack	Full package online pharmacy	YOA
MedMinder	Smart pillbox with important features	all old adults
MedaCube	Home hub pill dispenser withapp for management	All old adults
Stihi's Pill Dispenser	Home hub pill dispenser withapp for management	All old adults

Table 2.3: Systems' summary(2/2).

Name	Pros	Cons	Market acceptance	Cost
Older adult's medication adherence monitoring with IOT	CostumizableReal time information	No alarm Some problems with usability Not portable Medication dosage errors	–	Low
ElderlySafety	Automaticly dispenses	Manual pill set up Poor display No medication information	–	Low to medium
Teng Cao	Portable Good alarm system Customizable Has medication information	Manual pill set up Labels too small Small compartments	–	High
Pill Dispenser with alarm via smartphone notification	Good alarm system Information for the caregiver Pills are loaded, no set needed	No medication information Poor LCD and controls Not portable	–	Low to medium
Tricella	Blocks compartments Lights the right compartment Information for caregivers in the app	Manual pill set up No medication information	1000+ Sold online and retail stores	Low
Medissimo iMedipac	It is simple Almost a closed system	Manual pill set up No medication information Small compartments	Sold in partnership with pharmacies	High
PillDrill	Very good medication taking flow Good screen	Manual pill set up No medication information	500+ Sold online only	Medium
Ellie smart pill box	Simple Portable Pills are loaded, not set up	App is required No medication information Does not mesure dosage	100+ Sold online only	Low
Reizen's AutoPill	Simple Portable	Manual pill set up No medication information Does not track missed dosages	Inconclusive	Low
AdhereTech	Simple, no set up Portable Tracks medication Phone notifications	Does not mesure dosage No medication information No alarm, only light on the bottle	Under testing	Low to medium
Pillsy	Simple, no set up Portable Tracks medication Phone notifications	Does not mesure dosage No medication information No alarm	1000+ Sold online only	Low
Hero	Automaticly dispenses Easy to use after set up	Difficult set up, only with app No medication information Not portable	500+ Sold online only	High
Pillpack	Pre sorted medication Portable	No medication information No alarm Does not track missed dosages	High adoption Cutomers between 50 and 60 years old	Price varies with insurance
MedMinder	Good alarm system Locks wrong compartments Lights right compartment Medical alert	Not that portable Manual pill set up Small compartments	Inconclusive	High
MedaCube	Automaticly dispenses Easy to use after set up	No medication information Not portable	Inconclusive	High
Stihi's Pill Dispenser	Automaticaly dispenses Easy to use after set up	Difficult set up, only with app No medication information Not portable	Inconclusive	High

Part II

Development

Chapter 3

System's idealization

3.1 System requirements

This section is meant to take the section 2.4 into account and take the positive aspects of the existing systems, as well as the negative, and give overall requirements that improve the system's capabilities. This is meant to take every information from Part I chapters and learn from them, creating a new system, hopefully, better than all current ones.

1. Portable in some way – easier to fit every older adults' lifestyle.
2. Maintains medication taking flow – less habit disruption.
3. Automatically distributes the medication – less error and more independence.
4. Information display about the medication – one of the factors is medication beliefs.
5. Real-time information for caregivers.
6. Customizable – makes for easier adoption by older adults if they like the system.
7. An internal UPS like battery – in Xiaoping Toh's system [Xiaoping Toh 2016] the elderly would often turn the system off.
8. As less tech savvy as possible in order to use it.
9. As closed system as possible – least amount of room for error as possible.
10. An adequate alarm system, given older adults' characteristics, section 2.1.1.
11. An adequate display, given older adults' characteristics, section 2.1.1.

3.2 General considerations

- The system is used in a country where medication is given out in bottles, for example the USA.

This project's system is meant to hold up for the future. This means it should follow a the sensible trend of market's development. All distribution is being optimized, which need to incorporate automatic processes. For automatic processes to be reliable and cheap, they need uniformity and scalability. As mentioned above, the USA is one of the countries where this is implemented, that is why the system should be considered to work with this kind of distribution process.

- It is assumed the user has access to power.

3.3 Idealization

As described in section 1.3, an idealization of the system is required. This allows for a starting point before setting out to build the system. As mentioned in the same section, the idealization is where new concept systems are explored.

In order to not extend the document unnecessarily, the final proposed idealized system is the one here presented.

In order to have as few medication errors as possible, the system needs to be a closed system. This means that medication information should come directly from a database when the medication is scanned in the pharmacy. Additionally, the medication, at the user's home, needs to be automatically sorted, by a hub, so that dosage is consistently correct.

Other important features should be included. Portability has to be included in the system, with a portable pillbox, Figure 3.4. Additionally, the hub should have a big screen [Pak and McLaughlin 2011], with the information of the medication displayed, due to health literacy, section 2.1.3. The feedback information about the user's medication habits should be transmitted back to a managing platform available for all stakeholders, like caregivers. Finally, the controls from the patient's end should be as simple as possible.

The Hero dispenser, section 2.3.2, is a very good example of a hub that automatically dispenses the pills. The MedaCube, section 2.3.3, is more adequate, given its screen for showing information, however it is a very small screen [Pak and McLaughlin 2011].

In order to make the whole system closed, the idea of tagging the medication automatically has been done by the system PillDrill, section 2.3.1, however the medication should be automatically be written with the medication code directly in the pharmacy. This way, as PillDrill reads the tags and identifies the medication in the hub, it could read the information about the medication directly from a database, where the system would know the dosage, scheduling and its information.

For a more intuitive understanding Figure 3.1 represents the flow chart of how the systems works in general.

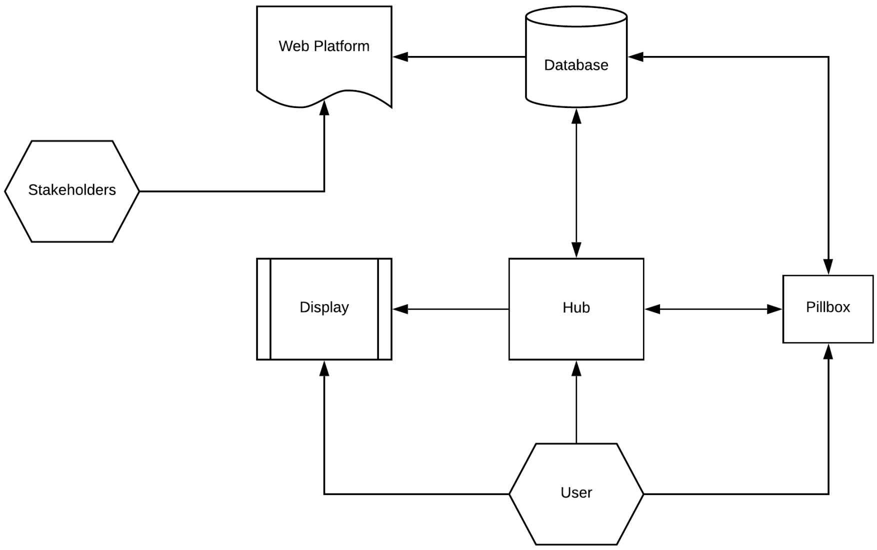

Figure 3.1: System's flow chart.

Having said this, in order to maintain consistency with the sections 2.2 and 2.3, it will presented a rough initial design of the system and it will presented using the same set of rules used by the section 2.2 given its academic nature.

3.3.1 Presenting the system

The most intuitive and insightful way to understand and improve a product is through customer journey/experience [Kalbach 2016]. This way, the system's description will be made using this method, where it will be shown how an hypothetical user would use this system and how it would fit in his life.

When the user goes to the pharmacy, it brings the bottles to be refilled/switched with the new medication. This bottles are filled up and the pharmacist when scanning the medication in the cashier, tags the medication code embedded in its cap, writing the medication information directly.

The user goes home and pushes the bottle in into the bottle into the designated place in the hub, Figure 3.2. The hub reads the tag from the cap, filling the appropriate section in the pill tray. After, the hub dispenses the medication, accordingly to the dosage and the information. In case the user needs to go out, they click on the screen to inform the hub and the pillbox comes out, Figure 3.3. Both the hub and pillbox have SIM, for real time communication with the database, feeding real time information. When medication is due, the correct compartment of the pillbox lights up and unlocks, Figure 3.4, while the others stay locked. When medication is due, depending on the user, the alarm can be on the phone or on the hub/pillbox to warn the user. When the pill box in the hub, the hub asks if information about the medication the user is taking is needed and if so, a simple menu with the important information is shown.

In the web platform, stakeholders, like caregivers or pharmacists, can help the user set up the medication schedule, as well as consult the information about the medication.

Figure 3.2: System's CAD render.

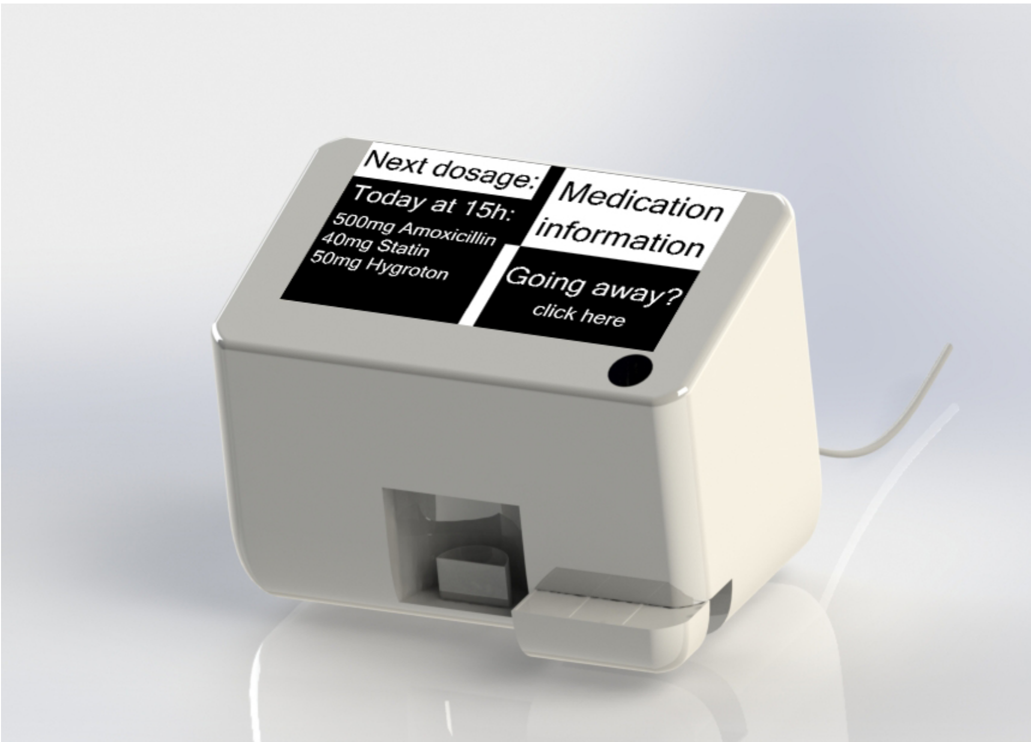

Figure 3.3: System's CAD render, with pillbox opening.

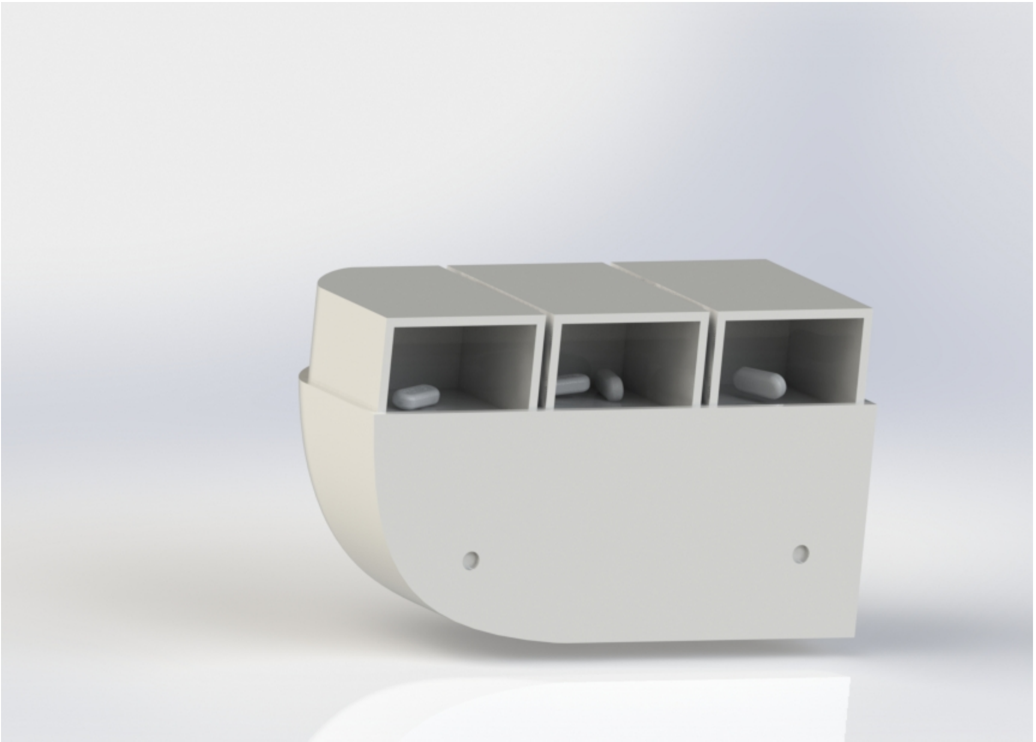

Figure 3.4: Pillbox's open CAD render.

Just like PillDrill, section 2.3.1, for medications that are not in the usual bottle pills, like sensitive medication or inhalers, tags are provided and attached to the medication directly in the pharmacy.

As one should expect, this system brings a variety of positive aspects, according to the old adult characteristics, section 2.1.1. The most important of all is that it is a closed system, drastically reducing margin for errors. Additionally it allows for portability, fitting perfectly into every kind of old adult's lifestyle. The big screen allows for better readability by old adults and for useful medication information, which can be key for medication adherence. The interface design should be designed according to users goals and expectations in order to work more fluidly [Czaja *et al.* 2019]. The fact that uses SIM connection allows for higher reliability and real time feedback information for the database, where it can be consulted in the web platform by authorized stakeholders. Moreover, locking the wrong compartments, while lighting up the right one, grants quicker access and better usability. Finally, power failures can happen, whether is the home power or power concerns of the user, as see in section 2.2.1, therefore the hub has an UPS like battery in order to maintain its good functioning, as well as giving an alert to the user and the stakeholders.

Unfortunately, for this system to work seamlessly, partnerships with pharmacies and with medication information providers had to be made, which is not entirely easy to do.

This system is meant to be suited for every age older adult.

The system comprises additional logistics and complexity as of other existing systems, however its hardware is not more complex than any other, setting its hypothetical price in the medium to high cost.

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Chapter 4

System's prototyping

The goal of this chapter is to explain how the system was brought to life, based on the previous chapter, Chapter 3. To put into context how this was done, the section 1.3 explains the methodology it is being used and what set of rules dictate the decisions.

The prototyping phase means that a prototype should be built. Seems obvious, however the word prototype has a lot of meanings and levels. Prototype needs a more specific definition, based on the methodologies chosen in the beginning. The book *The Lean StartUp* [Ries 2011] uses the term MVP, Minimum Viable Product, which is a prototype that has the important features of the product to be tested and leaned with. The State-Gate methodology does not indicate any specification regarding what the prototype should be, however it should be enough to be worth moving to the next phase.

In conclusion, the best definition for prototype, for this project and within the time frame, should be similar to the MVP, since it demonstrates its functioning and allows for future learning with the prototype.

4.1 Technology

In this section, it will be presented the technology used in the prototyping of the system, explaining why the choice of the main technologies used. Some simplification will be made, regarding the idealized system, in order to fulfill the project within its timeline, given the previously acquired knowledge and chosen methodology.

4.1.1 Simplifications

Setting simplifications is important in an MVP, for faster iterations. This can be due to familiarity with certain technologies and due to conveying a similar functionality, which all lead to an easier implementation. So, the following simplifications were made.

Even though the system is intended to use SIM connection for better reliability, its technology is not easy to implement. Therefore, connection to WiFi, which can be less reliable, will be used to connect the system to the database.

A web platform is much needed in order to inform other stakeholder about the medication information and medication taking patterns, more importantly caregivers when medication dosage is forgot. However, building this platform is time consuming and for prototyping purposes, sort of an MVP [Ries 2011], a simple database is enough for full functioning.

Locking compartments are very useful to prevent errors in which medication to take. Nevertheless, this feature is not important enough to be necessary for this prototype, therefore it will not be fully built.

The pill sorting mechanism is main advantage for older adults, in order to keep their autonomy as high as possible. This mechanism can complex, in order to consistently deliver the exact medication dosage needed for each compartment. Having said this, attention to details as consistency and exact dispenses will be overlooked, in order to focus on the important features and overall details of the system.

The system's portability allows for the system to match to any lifestyle. The development of the portable pillbox with the SIM connection, or WiFi aspect is, however not part of the most important aspects of the system. With this, it will be developed the simplest aspects of the pillbox.

4.1.2 Overview

Controller

It is used the microprocessor ESP8266 D1 Mini NodeMCU, Figure 4.1 due to the familiarity with it, its capabilities of WiFi connection and small size.

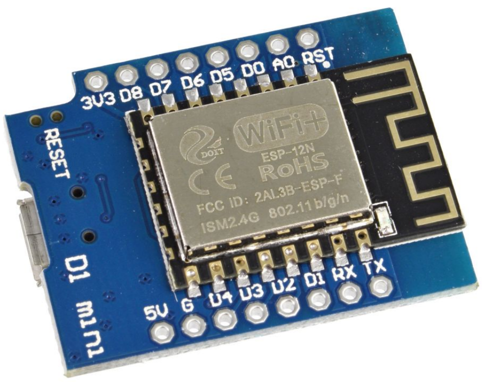

Figure 4.1: ESP8266 D1 Mini NodeMCU.

The ESP8266 is a low cost WiFi, low power and compact microchip with full TCP/IP stack and microcontroller capability. It is programmable as an Arduino, taking advantage of its ecosystem. The code it runs is C/C++ with Arduino and open source libraries [Espressif 2019].

Interface

The user interface is built as a smartphone app, for easier updates, available libraries and support and familiarity. It is built specifically in Android Studio due to development facility and maintenance. Android Studio is an open-source Android application development software created by Google [Google].

Part prototyping

More and more 3D printing goes hand in hand with prototyping. Its use as grown exponentially all over the world. It is a quick and inexpensive way of bringing a design to life through an additive process, in layers, additive process. The most common 3D printing process is plastic printing where a plastic filament is fed to a heated nozzle that melts it and, controlled by motors, creates the layers [Redwood *et al.* 2017].

Having said this, in this project necessary parts will be printed in plastic a 3D printing machine due to its quick time frame, good finish and resemblance with what would be done in a business environment.

Database

Firebase is a Google's ecosystem database. It features easy, free and quick integration with android studio. For this reason and the familiarity with it, the database is built with this platform.

4.1.3 Motor

Step motors allow for higher precision rotation, which help set specific angles of rotation when programming.

4.1.4 Scanning

A very popular technology for quick and cheap code scanning is RFID, Radio-frequency identification. It electromagnetic fields to identify and track tags.

4.2 The prototype

With the simplifications made and the technology to use, it is possible to start building the prototype itself. Even though the prototype is simpler than the the actual final product, mind that an MVP by definition should still represent the main functionalities – or requirements – of the product. These requirements are stated in section 3.1. It would not be following the methodology chosen, if this information was not stated, given the need for a goal to reach at the "gate", in Stage-Gate, and a direction to aim at and learn from, in the Lean build-measure-learn cycle. The latter might be confusing when stated this way, however the Lean build-measure-learn cycle is planned in the opposite way. Stating first what it needs to be learned, how it will be measured, which in the context of this project does not apply, and finally actually building the MVP.

The prototype is divided in 3 main segments: the electrical schematics, the software and the 3D printed parts. Each is responsible for fulfilling some of the system's requirements, section 3.1. In the subsections below, it will be explained what each segment is, how and which requirements it fulfills. In a final note, point 2 of the requirements is fulfilled by the architecture of the whole system and more than one point can need more than one segment to fully fulfill it.

In a final note, it worth mentioning that all of the prototyping elements are product of iterations and brainstorming to accomplish a more polished state, as presented bellow.

This iterative process is accomplished with software testing, talking with experienced professionals, 3D test printing and assembling.

4.2.1 Electrical scheme

Building on the section 4.2, the electrical part of the system fulfills the points 3, 4, 5, 7, 9, 10 and 11.

As a general requirement for the electrical scheme, it needs a microprocessor, section 4.1.2, and a power source.

For point 3, are needed 2 things: a step motor to spin the pill container to the right one when refilling and another for dispensing; and an RFID, section 4.1.4, to automatically read the medication code.

For point 4, 5, and 11, the microcontroller needs to support wireless communication in order to upload the system's information to the database, for later to be displayed by the screen – an smartphone device in the context of this project.

For point 7, an addition to the power source, it needs a backup battery.

In point 9, the use of the automatic detection of the medication, its distribution and dispense contributes for the closed system.

In point 10, it needs a simple speaker.

To put it all into a simple and easy to understand way, the electrical scheme is present in the Figure 4.2.1.

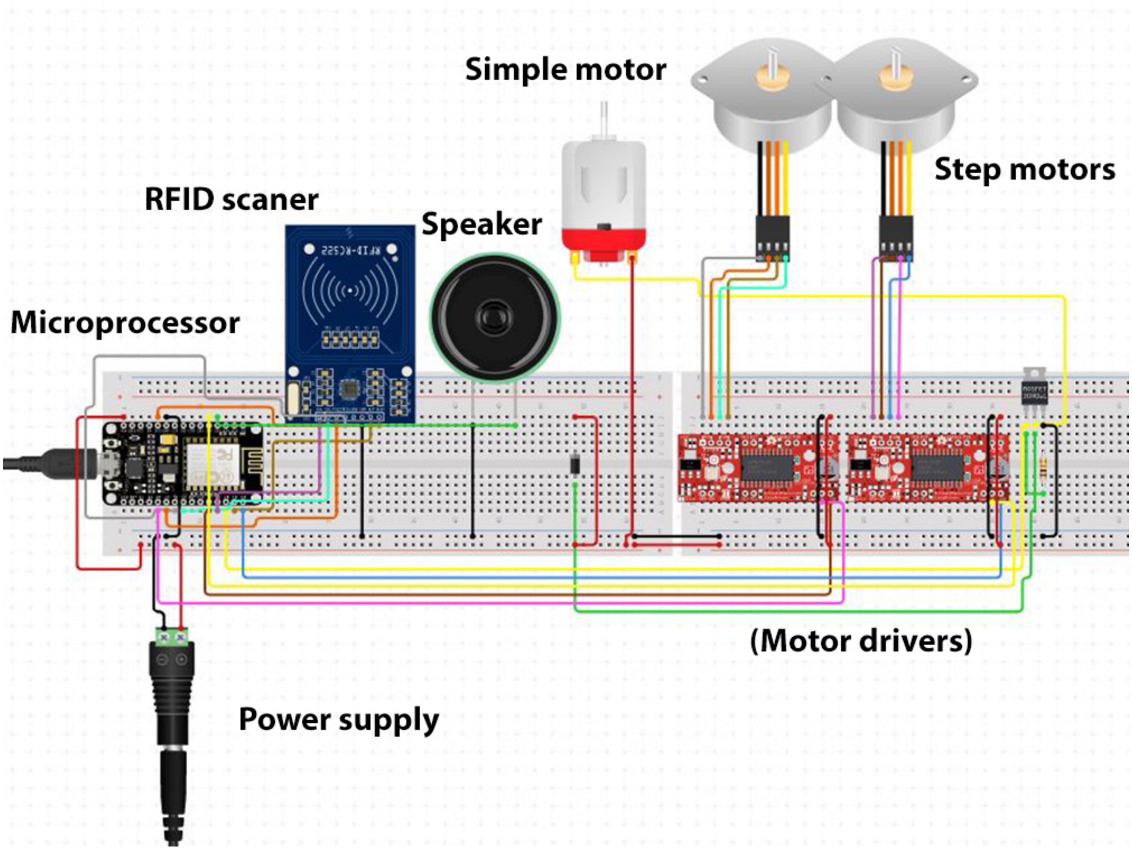

Figure 4.2: Electrical scheme of the system's prototype.

4.2.2 Software

As the previous section, the software of the system fulfills the points 3, 4, 5, 6 and 11.

In the point 3, the software that controls the controller manages the distribution and dispense of the system.

In the point 4, it controls how the medication information is shown in the smartphone.

In the point 5, it controls how the information of the system is sent to the database and to the caregivers.

In the point 6, it manages how the information and medication management is shown. Since it can be updated via network updates, it can be easily customized.

In the point 11, it controls how the display is organized, matching the needed characteristics for older adults, section 2.1.1.

It is important to refer that the software is comprised of 3 different elements: the microcontroller, which controls the electronics; the Android mobile applications, which manage the medication and display the medication information; and the database, which stores the patient and medication information. From these, the most important to go into are the android mobile applications, because they're more in contact with the users and need to follow certain requirements.

An example of how the user's mobile application display should look like is represented in Figure 4.3. There is a lot of contrast, between black and white, big sans serif font to help readability and a simple menu, with only the important information. All this to help matching the display with the old adults characteristics, section 2.1.1, and the guides for designing displays for older adults [Pak and McLaughlin 2011].

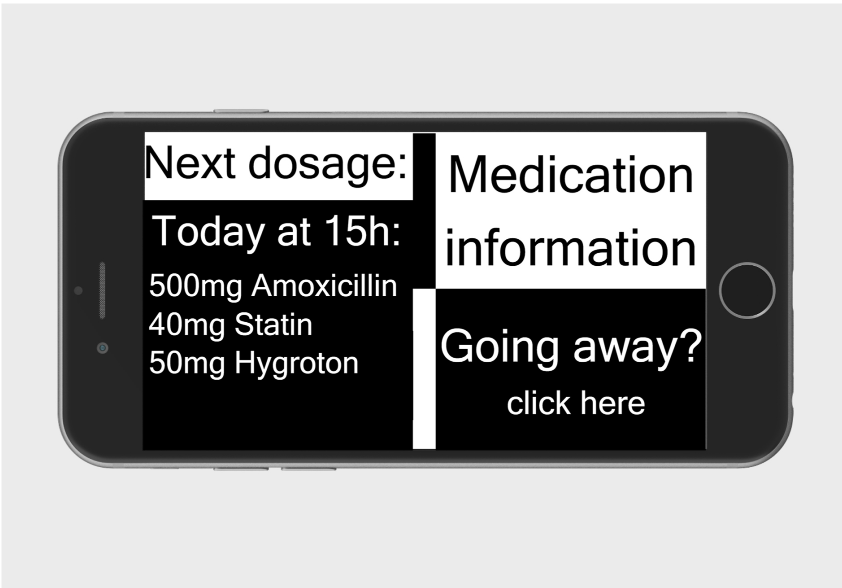

Figure 4.3: Smartphone display example.

The user's Android application developed for this document is present in Figure 4.4 and it can be downloaded at: `http://bit.ly/appsJGV`

The stakeholder's mobile application should be more complete, featuring a more usual configuration. The Android application developed is in Figure 4.5, and can also be downloaded at `http://bit.ly/appsJGV`.

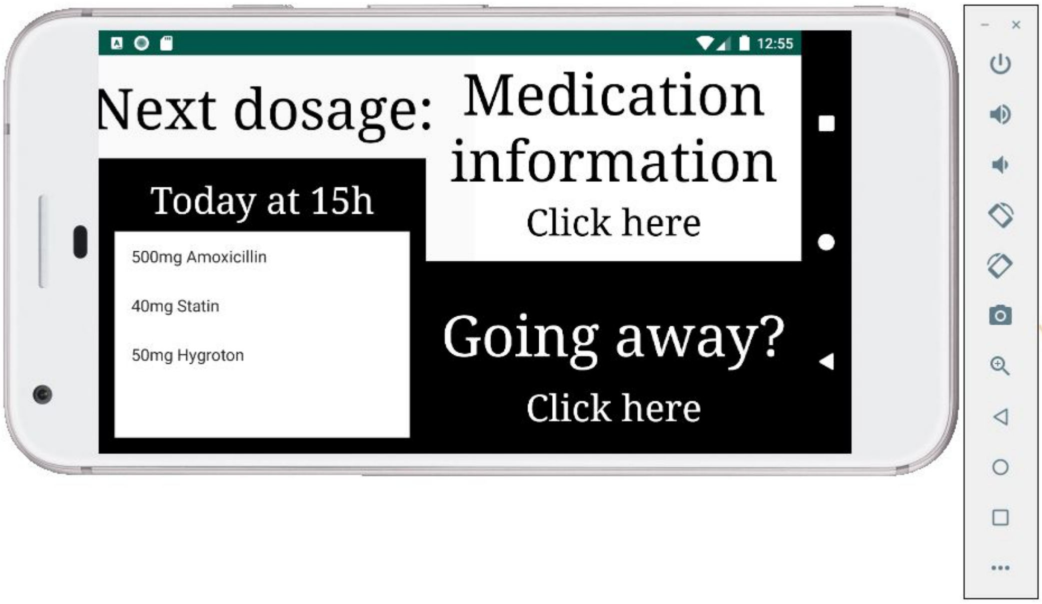

Figure 4.4: User's app.

To better understand the intricacies of the software interconnection, it helps to recall the flowchart in Figure 3.1. The main player is the database, where all the information, regarding the user, the medication and its information are. The hub, in this case a smartphone, receives this information and constantly updates the information shown to the user as well as the information in the database about missed doses, amount of pills in the compartments of the pill tray, among others.

4.2.3 3D printed parts

Following the same thinking as the section above, the 3D printed parts fulfill the points 1, 3, 6 and 9.

In point 1, the portable pill box allows the user to carry medication outside of their home.

In point 3 and 9, the whole distributing system contributes to automatically distribute and dispense the medication while removing possible human errors in the medication distribution.

In point 6, given the quick nature of 3D printing, it is easily customizable according to the liking of the user.

The functional parts are the most important for this prototype, given that they are only that will fulfill the requirements for the system. These can be seen in the Figure 4.6, with each part taking a different color for easier identification.

It is to note that the material used in the 3D printing is PLA (Polylactic Acid), due to its printing facility and availability.

The bright green part is the pill tray, Figure 4.7, which is rotated by one of the step motors and each compartment is filled with pills. It is made to has as little material as

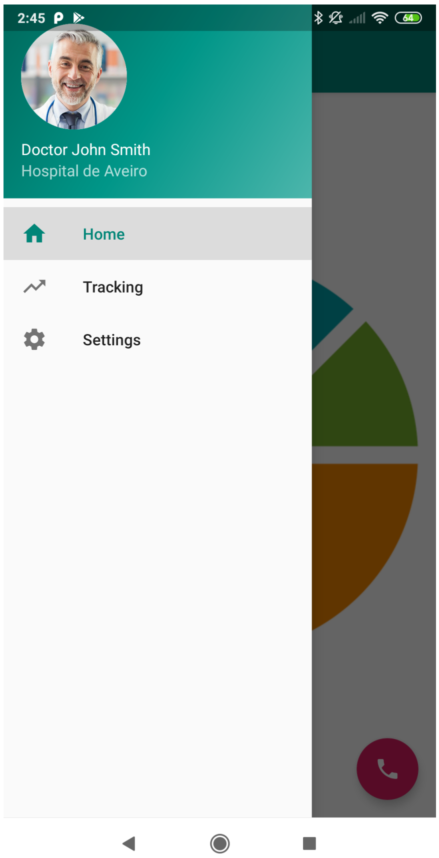

Figure 4.5: Stakeholders' app.

possible to facilitate rotation by a smaller and less powerful motor, making it cheaper. The bottom of the compartments is cut in an angle to allow the pills to slide, with a hole in the end for them to fall off. On the bottom, it features 4 extra bars, which are slightly off center to lock the power transmitting pin

The light blue part is a ring that serves a support for the pill tray, Figure 4.8. It features a ring that prevents pills from falling out of the pill tray, a circular cut out for the dispensing mechanism and a funnel to direct the pill to the correct compartment. Additionally, it has a border to help the pill tray with the circular motion and a hole for the power transmitting pin.

The red part is a disc that attaches to one of the motors and rotates to dispense a pill. The dispense happens when the disc's hole matches with the pill tray's hole.

The dark blue part is the power transmitting pin, Figure 4.10, which when forced down, it locks the ring, allowing the pill tray to rotate freely. When forced up, it frees the ring and makes it solidary with the pill tray. This allows the step motor to do both the rotation of the pill tray to choose the right medication and the pill tray with ring to dispense the pill to the right lane of the pill slide. The vertical movement of the pill is product of the DC motor and the geared mechanism represented in Figure 4.11.

The gray part is the pill slide, Figure 4.12. This is the part responsible for the distribution of the pills through the right compartments in the pillbox.

The part in purple is the base, Figure 4.13. It serves as support for the system and

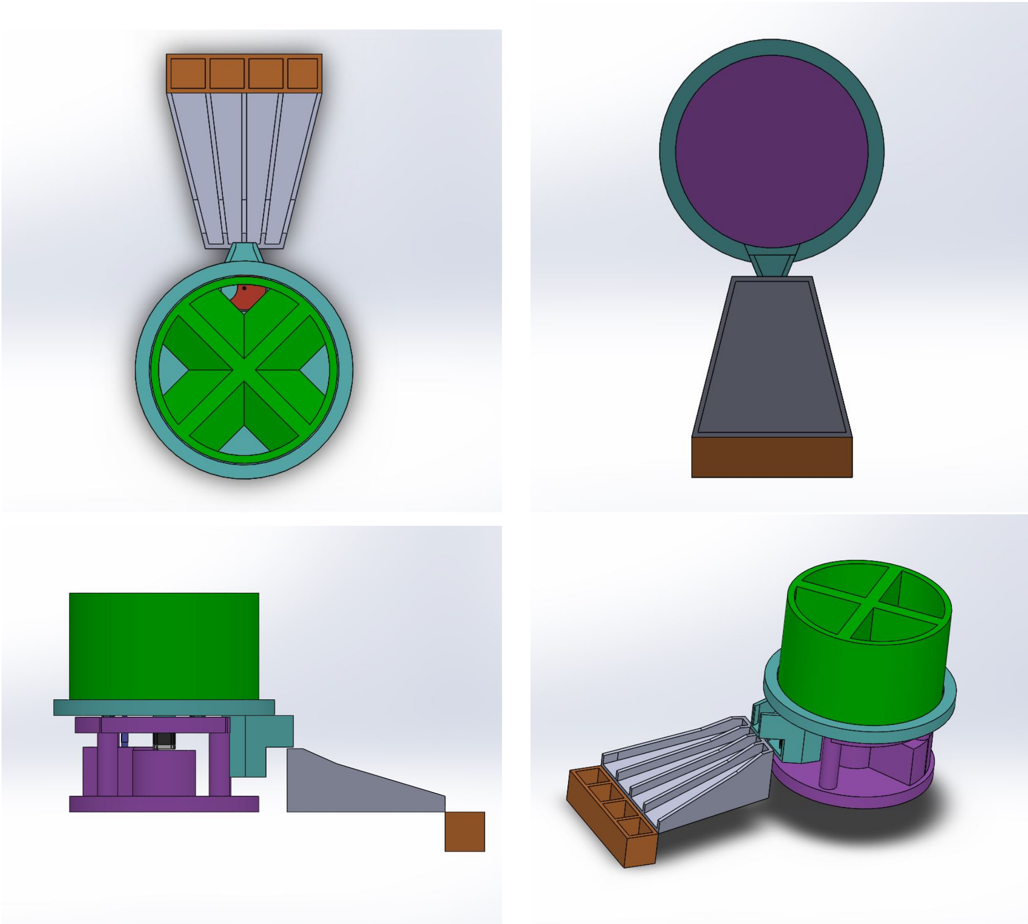

Figure 4.6: Different views of the functional mechanism CAD images.

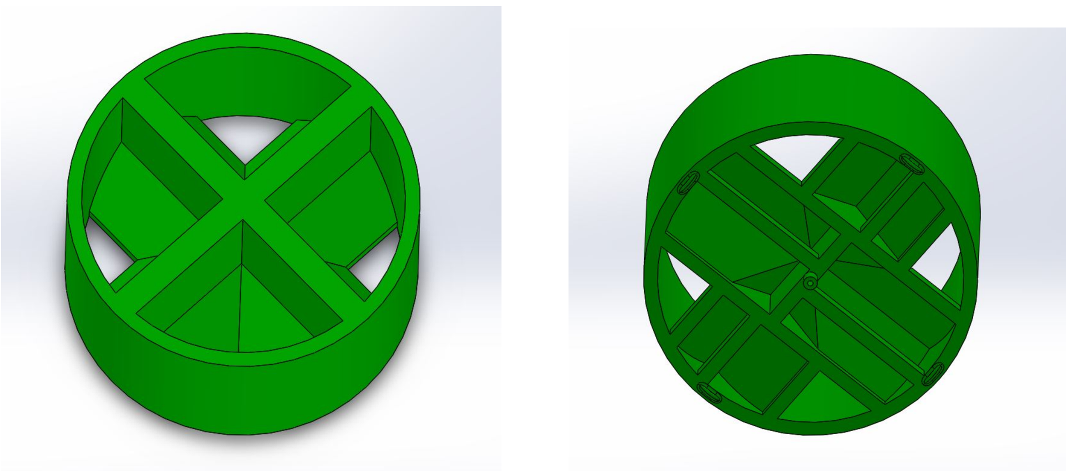

Figure 4.7: Top and bottom views of the pill tray CAD images.

it has 4 different holes for each of the lanes int he pill slide, Figure 4.14. This holes are meant to lock the ring, with the power transmitting pin.

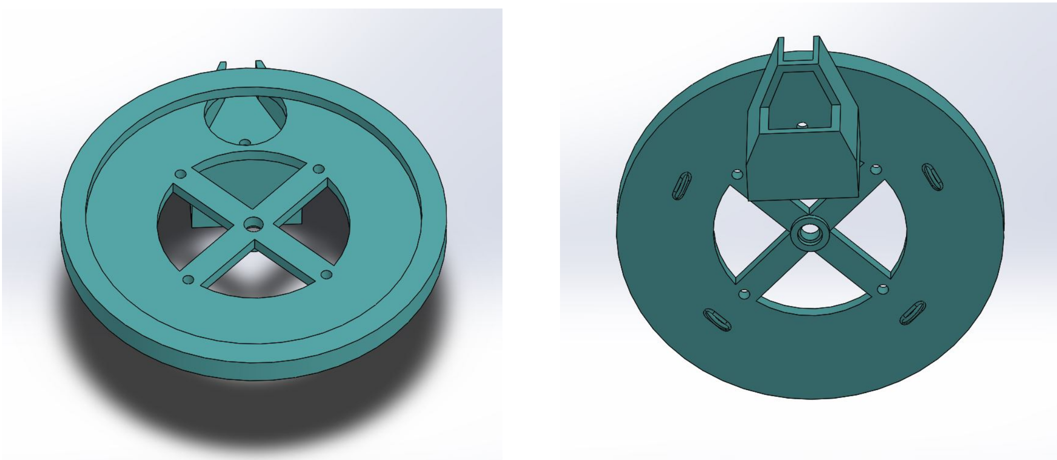

Figure 4.8: Top and bottom views of the pill tray ring supporter CAD images.

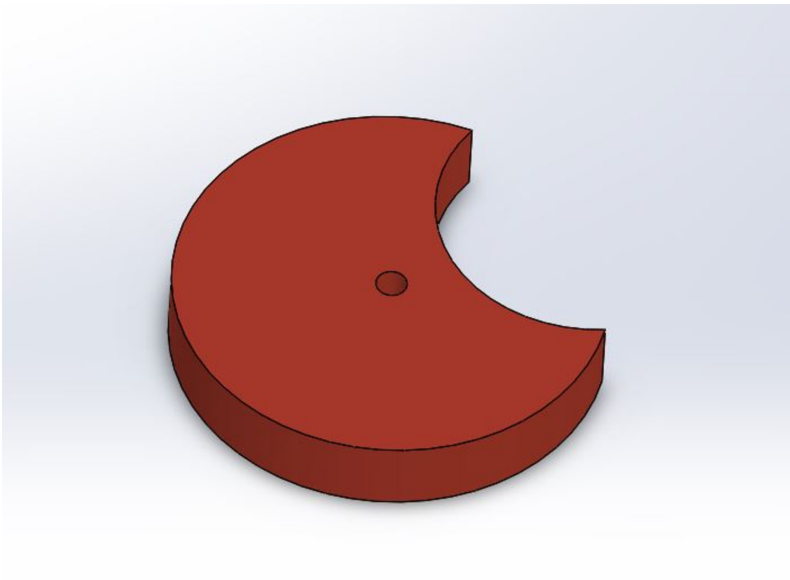

Figure 4.9: Dispensing mechanism part CAD image.

Finally, the pill box in orange, Figure 4.15. This part is how the user can transport pre-dosed medications with them, fulfilling one of the needs many older adults have.

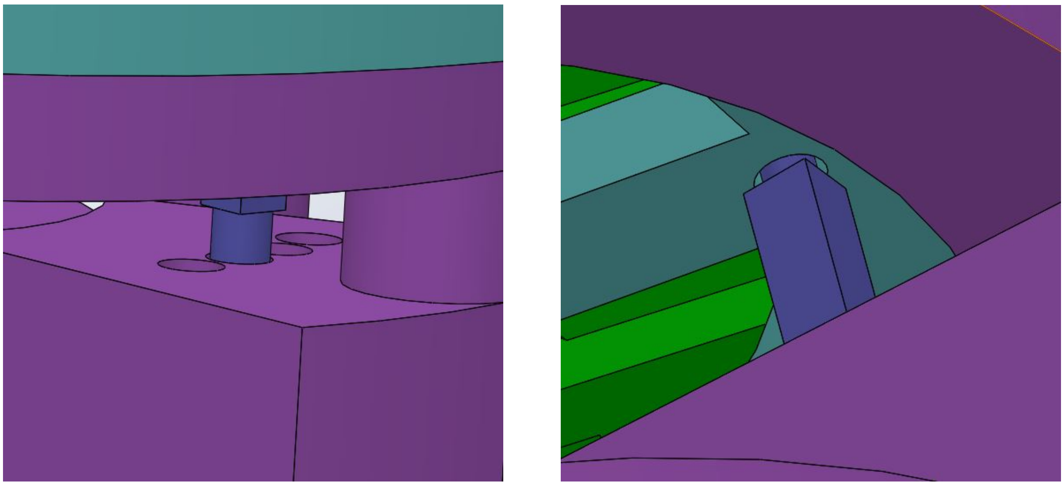

Figure 4.10: Power transmitting pin locking on the base and the ring CAD images

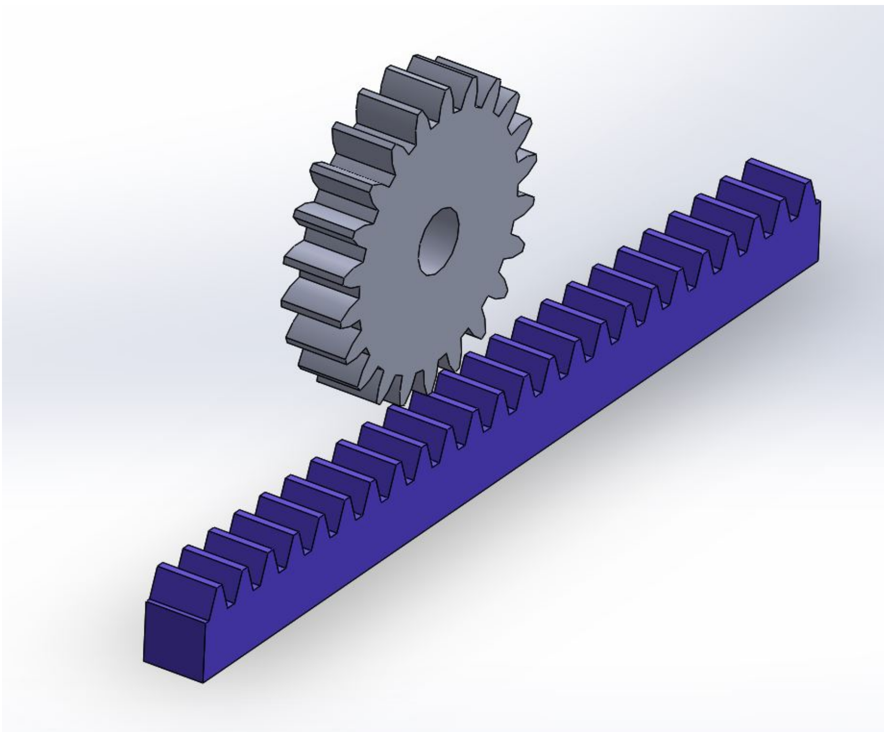

Figure 4.11: Gear mechanism of the power transmitting pin CAD image.

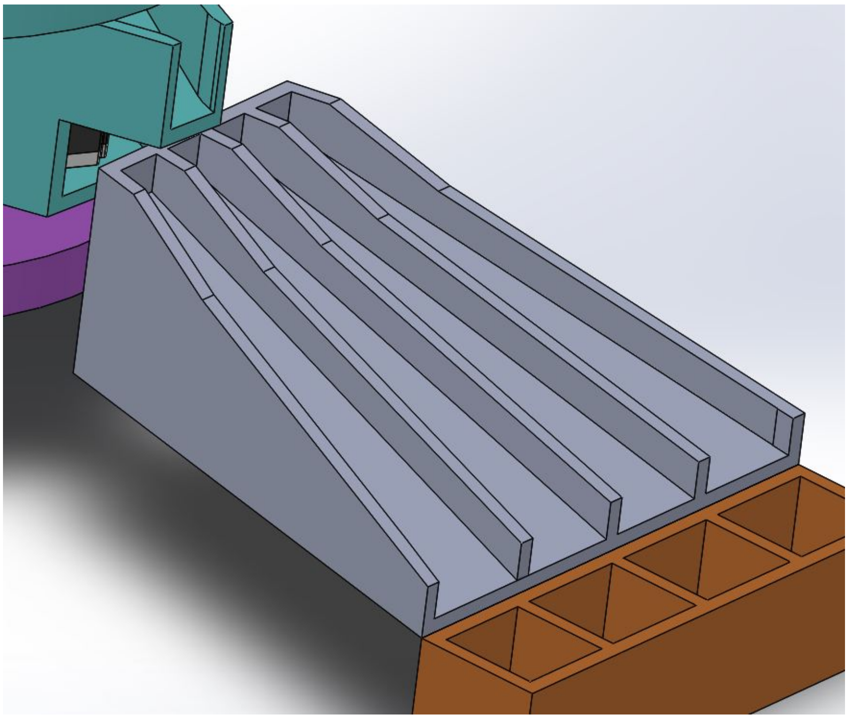

Figure 4.12: Pill slide part CAD image.

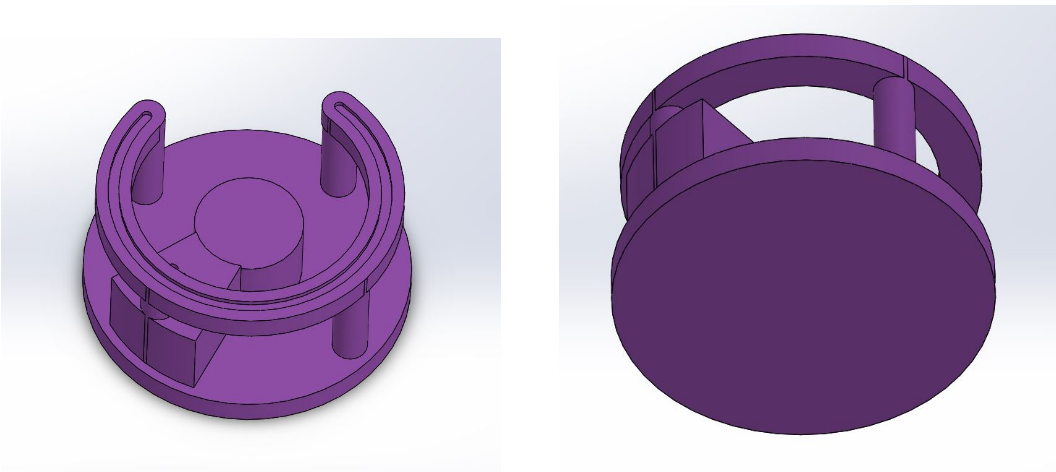

Figure 4.13: Top and bottom views of the base CAD images

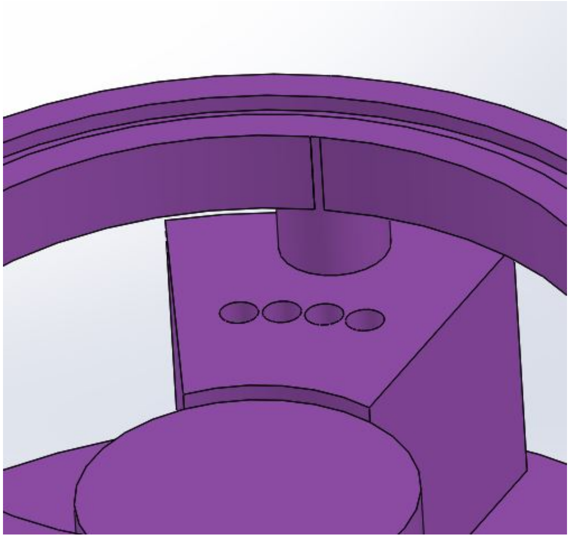

Figure 4.14: 4 locking holes in the base.

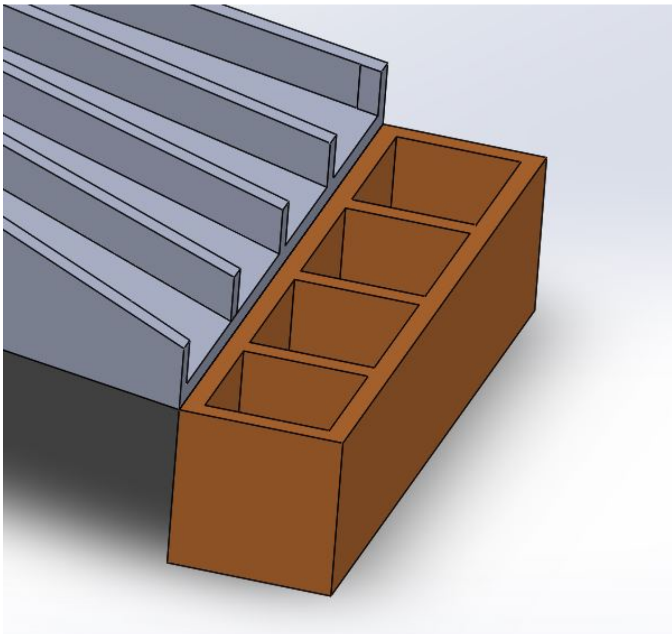

Figure 4.15: Pill box CAD image.

Part III

Final considerations

Chapter 5

Conclusion

5.1 Overview

Over the document the researcher follows a mixed methodology, referenced in section 1.3. In Stage-Gate methodology, vastly used in new product development, it is used gates, most of which are more than relevant and can be adapted to this project:

1. Idea screening
2. Concept screening
3. Business analysis
4. Product prototyping
5. Analyzing the final result

This gates are adapted from an article written to access different evaluations upon developing a new product between Taiwanese and Indonesian manufacturers, [Wang *et al.* 2012]. Looking back on the document, it is possible to see that all points are fulfilled, with the exception of the last one. The first point was completed when the project was chosen. The concept, second point, was was created when the product got idealized, Chapter 3. The business analysis, third point, was completed through a state of the art and market analysis in Part I. The fourth point, was developed in the Chapter 4. Finally, the last and fifth point, is the main goal of this chapter, closing the story promised in the beginning of the document, section 1.5, and completing the adapted methodology chosen for this project.

5.2 Analyzing the final result

To facilitate the readability of this section, the analysis will follow the same structure of the document, beginning with the state of the art and finishing with the system's prototyping, covering both positive and negative aspects, respectively, of the work done.

5.2.1 Strengths

The initial introduction covers broadly the current future trends respective to older adults and general population. Additionally, it is mentioned why the problem this project tries to solve is important, its origins and what consequences it brings to society.

The state of the art is split into 2 parts, covering the old adults and the up to date developed systems, both academically and in the market. Regarding the older adults, there is a fairly deep understanding and categorization of their characteristics and needs as users, for this particular problem. The market research was done thoroughly encompassing academical and actual products, with a consistent analysis of the pros and cons of each systems always based on the needs of the target population.

The idealization used an effective methodology, popular in product developing companies, which is intuitive, easy to understand and based all information collected in the previous chapters.

Finally the prototype was done using cheap technology, with a simple and elegant concept that tackles the problem in all important fronts. It fulfills all minimum required functionalities that important to demonstrate the system's concept and usefulness.

5.2.2 Weaknesses

For a better problem insight, there could have been contact with population experts, specially in the aging and wellfare area. This would verify some possible assumptions the researcher is not aware, solidifying the initial introduction and problem statement.

In the state of the art, regarding older adults, it would have been interesting to interview a dozen of potential users to pick up natural behaviours they tend to do as well as better understanding and documenting their needs as users. Regarding the market research, buying the actual products in the market and put them to test with users, would help to better clarify and perhaps add to the pros and cons of the products.

The idealization could have counted with user journeys, understanding the true possible acceptance and usefulness of the product by the users. In the same note, user tests could have been done with the final prototype, which would help to identify errors and short comings of the concept.

5.2.3 Remarks

Overall it followed a steady and adequate methodology. Even though the stress is made in the State-Gate methodology, the researcher always had in mind the items in the sections 1.3, which also incorporate the Lean methodology. However, it would be a far more compelling and market ready work if there was a greater user involvement throughout the process, a repeated limitation mentioned above.

5.3 Interviewing experts

It is important to review work not only personally, but through other people's eyes. For this section, 2 interviews were made: (1) psychogerontologist and (2) a nurse with geriatric experience.

The interview's goal is to understand each professional's expertise, understand the most important factors in non adherence, explain them the product and finally analyse the product with a SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis and add some additional remarks.

5.3.1 Liliana Sousa

Expertise

Liliana is a psychogerontologist, a psychologist specialized in older adults. Her main focus has been to understand what is really important as we get older. What is well being, how it can be improved and how can still exist development with age. Additionally Liliana tries to understand how it is possible to respectably communicate with older adults, with some degree of mental decline, and their development challenges.

Important nonadherence factors

According to Liliana there are several factors that lead to nonadherence.

The first appointed problem is the lack of patient management by a geriatric specialist, which is proven to greatly improve older adult's quality of life.

Another factor is the different disease mentality, which changed with modern medicine. Before chronic diseases and continued care, people had a symptom, they would go to the doctor, get a medication and solve the problem. Today's reality is different and is not always followed by an adoption of mentality's update. This previous notion leads to a behaviour of abandoning medication when the symptoms disappear, leading to nonadherence.

Finally, the financial situation is not always favourable, which can lead to an inability to buy all the needed medication.

SWOT analysis

Table 5.1: Liliana Sousa's SWOT analysis(1/2).

Strengths	Weaknesses
It saves wasted time preparing medication Brings order to medication in institutions It sounds like a good system	The control over the person needs to be within reason

Table 5.2: Liliana Sousa's SWOT analysis(2/2).

Opportunities	Threats
Use the system for everyone There are some systems that prepare in the pharmacy	In the future, everything being prepared in the pharmacy

5.3.2 João Tavares

Expertise

João is a nurse and Professor in the ageing area, with more than 15 years' experience in retirement homes and old adults' health.

Important nonadherence factors

João believes that most factors are human factors, regarding not understanding the medication that they are taking and its benefits. Additionally, mental decline or pure forgetfullness take a big role in nonadherence.

SWOT analysis

Table 5.3: João Tavares' SWOT analysis(1/2).

Strengths	Weaknesses
Automatic medication assignment Quick and automatic medication distribution Medication management system (refill and others) Medication information for the patient	(considerations bellow)

Table 5.4: João Tavares' SWOT analysis(2/2).

Opportunities	Threats
NAN	There are a lot of dispensers and pillboxes The future is heading towards single dosages Medication storage in the system might be difficult

Considerations

João gave general suggestions/considerations which are worth sharing in the document.

- Automatic unlock of the pillbox for easy removal;
- Allow the system to break pills, since there is some medication that it is taken as half dosage;
- Allow the medication timing to be flexible within meal times, to better fit the patient's schedule;
- Always display audible with visual cues and vise versa;
- Show special medication considerations.

5.4 Future work

It is important to look back on work done and understand what could be added and improved. This section will include a possible direction of work to build on this document, which the researcher believes to be pertinent.

Consulting with expert opinion regarding trends both in the technology and pharmaceutical market was not done in the project. It can be very interesting when building a future proof product. A broad research from current state was conducted, from which conclusions about future trends were extrapolated. However, there is a higher probability of developing a future proof product when based on more solid data.

Another already mentioned limitation of the idealization and the prototype was the lack of user involvement. Interviewing users in order to develop a better idealization of the product and using that information to adapt the concept would improve chances of future market acceptance. The same thing with testing the prototype.

User testing should be done in an iterative fashion, in order to integrate incremental improvements, changing configuration and technology according to the user needs.

Finally, for a true product development, it should feature a cost analysis for bringing this product to market. This should be done in an iterative cycle, as the point above, and in parallel with the point above, in order to match the product price with the user's price expectations.

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