Design and Development of a Voice Recording Device for People Suffering from Alzheimer's Disease

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Design and Development of a Voice Recording Device for People Suffering From Alzheimer's Disease

Master's degree in Electronics and Information Technology Engineering, option information and communication technology systems

Lucas PRIEËLS 2022-2023

Abstract

Alzheimer's disease, the most prevalent form of dementia worldwide, is projected to affect over twice as many individuals by 2050. Most of those people are facing memory and autonomy loss affecting the patient. Their caregivers are them becoming mentally and physically overloaded by the growing assistance they are giving to the patient. This thesis focuses on designing a device alleviating the effects of memory loss among people affected by an early stage of Alzheimer's disease while minimizing the negative environmental impact underlying the production of a device. The device is developed using a user-centered design approach and uses Bluetooth Low Energy tags to trigger audio prompts based on the user's location and time. The theoretical development of the device involves careful selection of electronic components and thoughtful proximity detection mechanisms to optimize cost, size, weight, and power consumption, and fulfill requirements listed in collaboration by future users. Ethical and sustainable considerations led to choosing to manufacture in Europe, and selecting environmental friendly materials and manufacturing processes. Finally, a prototype was developed for validation and testing purposes. It highlighted possible improvements to the device and proved the feasibility of its main features. Validation of the theoretically designed device and user feedback showed it fulfilled the listed requirements. It is a promising chance to alleviate the effects of loss of autonomy among those affected by Alzheimer's disease and their caregivers, while contributing to some of the United Nations' Sustainable Development Goals.

Keywords: Alzheimer, Bluetooth Low Energy, proximity detection, audio prompts, user-centered design methodology

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I am grateful to Sara, Clara, and Tanguy, my TRIAXES+ teammates. Our countless work sessions, collaborative efforts, and shared enthusiasm have made this journey not only productive but also enjoyable and fun. Each team member's unique strengths and perspectives have contributed to the success of our project.

Thank you to the whole TRIAXES+ staff: Jean Paternotte, Olivier Witmeur, Julien Cabay, Raoul Sommeillier, Sylvain Busine, Chloé Smeekens, Lucas Secades, Aurore Lambert, and Sam Wattenbergh. Their regular feedback, constructive criticism, and ideas made this project continuously improve over time.

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Contents

Foreword: TRIAXES+ program

This Master's thesis has been written as part of the TRIAXES+ program. This program consists in forming multidisciplinary teams of 4 Master's students: they are students in industrial design, business, law, and engineering. Each of them brings his own specific expertise to jointly work on a project involving all 4 aspects. Throughout the year, each team is tasked to find a problem faced by some people, propose a product idea, and turn it into a pre-industrial prototype accompanied by a business and intellectual property plan. The only requirement is that the product has to be a 3D device, not a software or an application.

The core values of the TRIAXES+ program are collaboration and user-centered *design thinking*.

Collaboration and interdisciplinarity

While recognizing the importance of individual contributions, the program promotes a collaborative and interdisciplinary mindset among students. At the start of the program, students come together as a team to collectively decide on the problem they want to address. Then, they leverage the work done by their fellow students in their respective fields, using their expertise as the basis of their own contributions.

A key aspect of collaboration in TRIAXES+ is the mutual exchange of knowledge and interdisciplinary learning. To actively collaborate, students dive into the theoretical and practical aspects of fields outside their own, broadening their perspective, and learning valuable skills. They communicate by simplifying sometimes complex concepts to ensure that their work is understood by others. Moreover, regular meetings allow students to support the progress of their teammates, providing valuable insights and feedback from a different perspective.

Each student is particularly focusing on his own area of expertise. The industrial designer is focusing on the user experience: understanding the needs of the user, and ensuring that the device fulfills these needs, is ergonomic, user-friendly, and good-looking. The business student ensures that the conceived device is commercially viable by estimating the market size and penetration, balancing the profits and losses, and setting up a business plan. The law student is making sure the device meets all legal requirements and protecting the intellectual property of the device. Finally, the engineering student is taking care of the technological aspects of the device, constructing an initial prototype, and preparing the production phase of the device. These roles are shown on Figure 1.

Rather than juxtaposing the individual contribution of the teammates, collaboration and interdisciplinarity allow to use the collective intelligence and various backgrounds and perspective from each student, while ensuring the work is carried out in line with the requirements of each field of study.

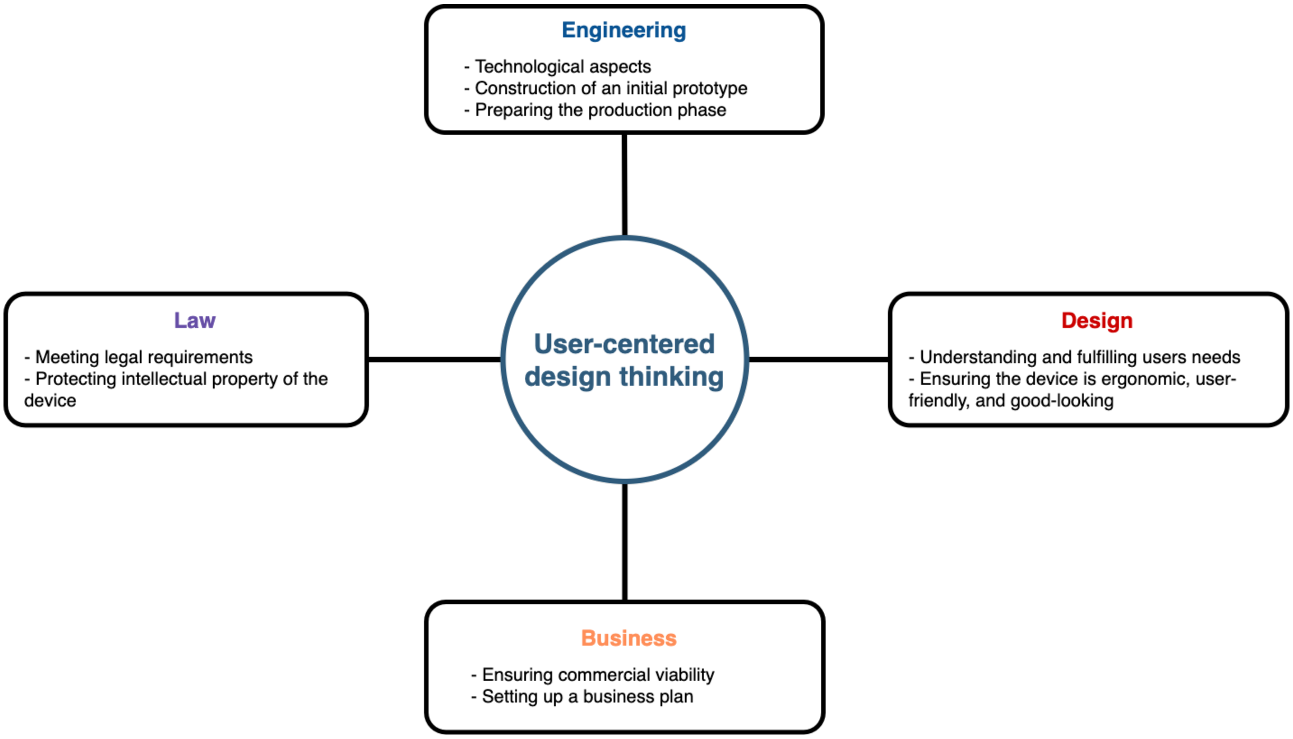

Figure 1: Roles of each student taking part in the TRIAXES+ program

This Master's thesis is presenting my own work: the engineering aspects of this project. Of course, because of the collaborative nature of TRIAXES+, design, business, and intellectual property aspects are also considered at many steps of this process. In this thesis, contributions performed by my teammates are duly highlighted as not being my own work.

User-centered design thinking

The TRIAXES+ program is based on a conception approach called *design thinking*, focused on the user during all stages of the design: from setting up the requirement list to preparing large-scale production. The first step of this approach is to identify a problem and the *persona*, a typical person who might need a solution to this problem. Students then take part in an extensive fieldwork, contacting many experts and users to make sure their needs are understood and fulfilled. During the design steps, multiple concepts of solutions are assessed, and one of them is chosen thanks to the input of the experts and users. The chosen solution is then developed, always taking the user into account for all choices.

This approach allows students to empathize with the users and develop a solution that truly addresses their needs. Throughout the design process, teams iterate on their ideas to refine it and improve it thanks to the feedback given by future users. This ensures that the final device is relevant for them and increases the chances that it becomes a commercial success.

Timeline

The TRIAXES+ program dedicates a large amount of time for the formation of the teams, the search for a problem, and to get confirmation from the fieldwork that this problem is not only important for the involved people but also manageable to tackle in a limited time. To take this time into account, the program is starting earlier than usual Master's thesis.

The selection of students is performed in January, more than a year before the deadline for handing the thesis. Students get to know each other and the TRIAXES$+$ staff, and they form team in March. They then start looking for multiple problems they could tackle, their corresponding personas and start their fieldwork to choose the most promising problem to address by May. They start the main part of the work, which is finding solutions tackling the considered problem, in September after the holidays.

In the case of my group, the problem we chose in May was the accessibility of the digital world to blind and visually impaired people. It was a promising problem because it is faced by almost the entirety of visually impaired people and our initial fieldwork confirmed that this was an important issue for them. All the people we met were very enthusiastic with our work. Our goal was to find a way to represent digital data in a physical way, using some of the 4 other senses blind people have. However, we realized while considering different concepts of solutions that they were too optimistic to realize by our inexperienced team in the quite short time available. Following the advice of the TRIAXES$+$ staff, we chose to completely switch of topic in the end of October towards the topic addressed in this thesis. Our focus became to develop a device improving the quality of life of people suffering from Alzheimer's disease and their caregivers. November was a very anxious and difficult moment for our team as we had to start the work all over again, but we are very proud of the work we achieved in only 6 months, between November and April.

Chapter 1

Introduction

1.1 Alzheimer's disease

1.1.1 Introduction of Alzheimer's disease

Alzheimer's disease is a neurodegenerative disease, meaning that it is caused by dysfunctions and loss of neurons in the brain and the nervous system. This type of disease is first noticed because of mild cognitive loss, but it progressively worsens as more and more neurons are lost.

Although it is possible to relieve some of the symptoms caused by neurodegenerative diseases, it is today not possible to cure them, or even to slow their progression down. These diseases are fatal [2, 3].

Neurodegenerative diseases most often follow a mechanism of loss and dysfunctions of neurons due to aggregation of proteins in the brain. However, these diseases notably differ in the type of aggregated proteins as well as in which parts of the brain are affected. For example, Parkinson's disease is characterized by the aggregation of proteins called α-synuclein, and mostly affects the basal ganglia, the part of brain that controls movement. In result, Parkinson's main symptoms are tremors and muscle stiffness [4, 5]. Alzheimer's disease is on the other hand aggregating 2 types of proteins called Amyloid-β and Tau, and primarily affecting the hippocampus, which is handling memory tasks [4, 6, 7].

It is important to remind that, even today, mechanisms underlying neurodegenerative diseases are not fully understood. In particular, the exact cause of the disease is not known, even though it is believed to be a combination of many factors including the environment, genetics, and lifestyle [15].

Dementia is a general term describing the loss of cognitive abilities beyond what is usually expected because of ageing. It includes many different diseases, such as neurodegenerative diseases, but can also be due to strokes, alcoholism, physical injuries, or some infections such as HIV. According to the World Health Organization, Alzheimer's disease is the most common cause of dementia in the world, accounting for 60 to 70% of the cases [1].

The primary risk factor for Alzheimer's disease is age: in 2015 the worldwide incidence of dementia doubled with every 6.3 year increase in age [8]. In 2020, there were over 55 million people living with dementia worldwide, most of them being aged 65 or more. As the population of elderly individuals increases, the number of people with dementia is expected to increase to 131.5 millions in 2050, as shown on Figure 1.1. This increase is particularly driven by low and middle income countries, but this increase occurs in high income countries as well.

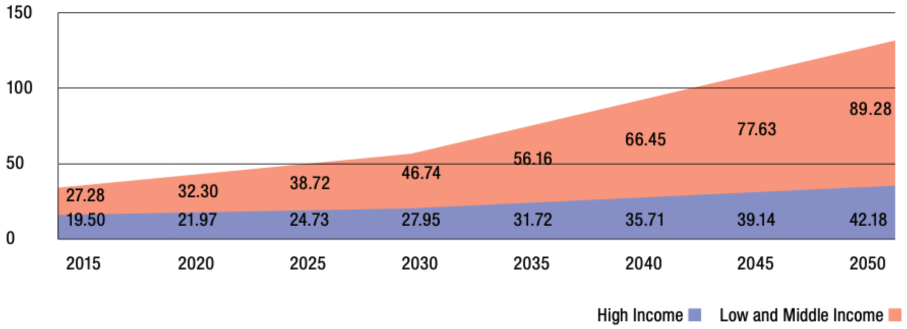

Figure 1.1: Prediction (made in 2015) of the number of people with dementia in millions, in high income and low and middle income countries [8]

In Belgium alone, $137\,800$ individuals are affected by Alzheimer's disease, 70% of them still living at their home [9]. It is the third disease removing the most years of life to the Belgian population ($97\,369$ years of life lost, after lung cancer and heart diseases) [10]. Since 2019, dementia is even the leading cause of death in Belgium: while only 5% of deaths were due to dementia in 2004, it increased to 9% in 2019 [11]. In the mean time, the number of deaths due to all the others main death causes of death were decreasing, as shown on Figure 1.2.

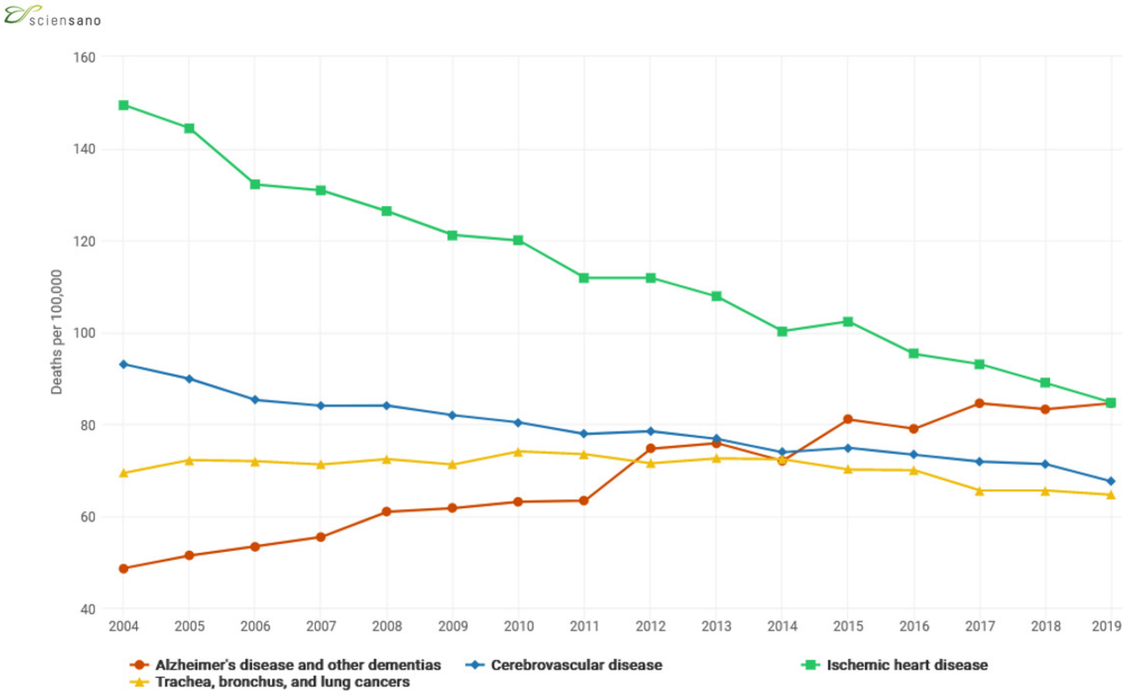

Figure 1.2: Evolution of the main causes of death in Belgium between 2004 and 2019, in deaths per $100\,000$ people [11]

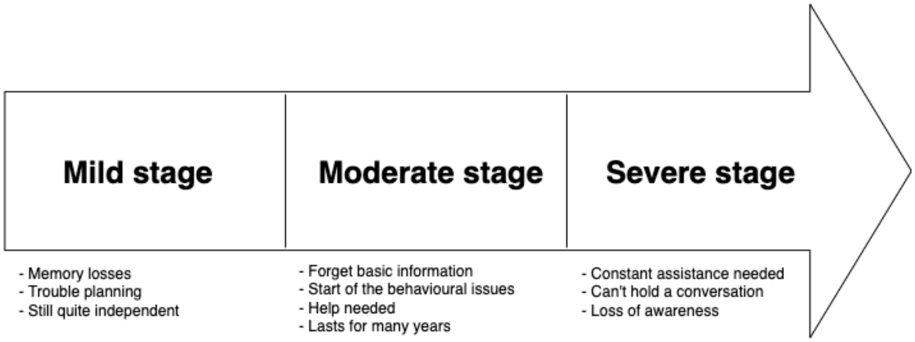

Figure 1.3: Timeline of the successive stages in the evolution of Alzheimer's disease and their most common characteristics

1.1.2 Stages of the disease

The evolution of the disease is most often considered in 3 different stages, which are described in this section. However, each individual has a unique experience of each of these stages, depending notably on which part of their brain is damaged first. These stages only represent the most common evolution of the disease [12, 13]. They are summarized on Figure 1.3.

Mild stage

During the first stage of the disease, the hippocampus is most often the only area of the brain affected. The patient starts having memory loss, mostly about recent events. He starts forgetting words, names, losing objects, experiencing trouble planning or organizing. These symptoms start worrying the patient and his or her relatives, and that's most often the stage during which Alzheimer's disease is diagnosed. However, the patient can still live well and quite independently at this stage.

It is thought that the brain changes causing these symptoms are beginning at least 20 years before symptoms start [14].

Moderate stage

During the moderate stage, memory loss is becoming more and more problematic for the patient: one starts forgetting his personal memories or important information such as their own address or telephone number. The rest of the brain is also affected, which starts causing disorientation, confusion and anger. It becomes difficult to follow a routine without help and at this stage, it is advised to use written reminders if the patient can still read. This stage is often the longest one and can last many years.

Severe stage

During the last stage, patients need constant assistance. They are not able to carry a conversation anymore and eventually lose control of their movements. They lose awareness about their environment and stay mostly in bed until end of life.

1.1.3 Memory loss and decrease of autonomy

One of the major issues raised by patients suffering from Alzheimer's disease as well as their relatives and caregivers is the progressive loss of autonomy due to the symptoms or their disease, particularly their memory loss.

Already in the mild stage, patients are losing objects or forgetting appointments more and more often. In the beginning of this stage they can still manage it but as the disease progresses they become reliant on their caregiver to find lost objects or remind them about visits and appointments. In later stages, recent memories are more affected: patients need frequent reminders and almost constant help especially to plan and structure their day. Objects and tasks typically forgotten by patients are the following:

- Losing objects
- Eating and drinking regularly
- How to use electronic objects in their everyday life
- Hygiene (showering, changing clothes, teeth brushing)
- Taking pills and medication
- Appointments and visits
- Turning off appliance (oven, stove etc) after using it
- In an a quite advanced stage of the disease, patients get lost in their own home

However, it is important to note that each person is affected differently by the disease and might forget different things. For example, it is common for them to regularly move an object to a location, always the same, then lose it because they don't remember they moved it.

The loss of autonomy experienced by people suffering from Alzheimer's disease is not limited to memory loss. As more parts of their brain are affected by the disease, patients may also experience difficulties to make decisions or to perform basic tasks such as dressing or cooking. This can make it increasingly challenging for them to live independently and carry out daily activities without assistance.

Losing autonomy can lead to feelings of frustration, helplessness, and a sense of being a burden on others. In this context, the role of caregiver for the patient is increasingly important to help and assist him. The caregiver needs to take on more responsabilities and to spend more time helping their relative. This can be overwhelming for the caregiver, and his well-being might be strongly affected by the condition of his relative.

1.1.4 Well-being of the caregiver

Even though the caregiver may be a professional such as a nurse, it is most often a relative who is taking the burden of assisting the patient on a regular basis. In the United Kingdom only, approximately 9 million adults are considered to be *informal caregivers*, i.e. individuals who provide unpaid and long-term assistance to someone suffering from a chronic condition, disease, or disability [16]. Most often, these informal caregivers are relatives of the assisted person.

Caregivers suffer from the difficulty of seeing the mental and physical state of a loved one worsen with no perspective of long-term improvement since the disease is not curable. Knowing that Alzheimer's disease is fatal, caregivers often start grieving for the loss of their relative from the moment they learn about their condition until their death. In addition to that, since people having Alzheimer's disease are suffering from mood disorders, they sometimes commit psychological or physical aggression on their caregivers.

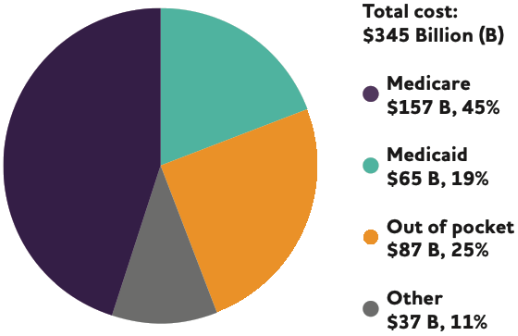

Figure 1.4: Costs of care for Americans aged 65 and older having dementia in 2023, depending on the payment source [14]

Multiple studies show that caregivers are themselves suffering from the condition of their relative: they are notably experiencing a decreased capacity to act and difficulties in balancing their time and financial resources with the help they are providing [17].

High levels of anxiety and distress are measured with the patient but also with their caregivers [16]. A meta-study made by Pinquart and Sörensen [20] shows that caregivers are suffering significantly more from depression and stress than other people. Their subjective well-being is significantly worse, and even their physical health is slightly worse. As the disease progresses, this becomes an increasingly important difficulty for caregivers

The majority of current caregivers have provided help at least for the last 4 years [18]. A study covering France, Germany and the United Kingdom shows that each Alzheimer's patient requires 2.7 to 3.7 hours of daily informal care in mild stage, and 4.4 to 6.3 hours in moderate stage [23]. Not only do they spend a lot of time giving care, but they also spend money because of this condition. Depending on the stage of the disease and on the choices of the caregiver himself, many types of expenditures can take place such as hiring a housekeeper or a home nurse or paying for a nursing home. Depending on the country in which the patient is living and on the coverage of social security, expenditures might also include appointments with doctors, medication, or other kinds of treatments. In the United States for example, where social security is not universal, a quarter of the total costs of care for Americans over 65 years with dementia were paid out of pocket by the patient or their relative, as shown on Figure 1.4. This will account for an estimated total of 87 billion US dollars in 2023. Even people who are covered by the Medicare or Medicaid social securities have to pay a part of the treatments out of pocket: $10\,241\$$ in average per year [14].

1.2 Problem statement

The problem which is tackled in this Master's thesis is two-fold. For the person suffering from Alzheimer's disease on one hand, it relates to the issue of their loss of autonomy due to the effects of their disease. For the caregivers on the other side, it relates to relieving their mental load by ensuring that the patient receives help on a daily basis. In the context of this Master's thesis, it has been chosen to restrict this problem statement to the mild stage and the beginning of the moderate stage of the disease, because patients are still able to perform most tasks independently but need regular assistance for others. Moreover, most of those patients suffer from memory loss but not yet of major behavioral issues that could prevent them from efficiently using the device that will be introduced later. This problem is summarized in Table 1.1.

Alzheimer's patient: Loss of autonomy	**Caregiver**: Decline of well-being
▪ Memory loss	▪ No perspective of long-term improvement
▪ Frustration and helplessness	▪ Anticipated grief
	▪ Anxiety, distress, and depression
	▪ Time spending
	▪ Financial spending

Table 1.1: Summary of the problem

Problem statement
People suffering from an early stage of Alzheimer's disease lose autonomy, mainly because of memory loss, and their caregivers are mentally and physically overloaded by the growing assistance they are giving to the patient.

The goal of this thesis is of course not to fix entirely this problem, this would be way too optimistic, but rather to provide a solution allowing to somewhat improve the quality of life of both the patients suffering from Alzheimer's disease as well as their caregivers. As further explained in section 1.3 detailing the scope of this work, the goal of this Master's thesis is to design a device that somewhat alleviates the loss of autonomy faced by the patients suffering from Alzheimer's disease and improves the well-being of the caregiver, in order to improve the quality of life of both.

Although each country has particularities, these struggle of loss of autonomy and well-being of the caregivers are faced by most Western countries, as illustrated with the various figures from the United States, United Kingdom, France, and Belgium shown in the previous paragraphs. In non-Western countries, loss of autonomy does not have the same cultural context and may not be as prominently addressed or recognized. For example, in Asia, ethics are based on duties and obligations rather than autonomy and freedom of choice [21]. However, this does not imply that loss of autonomy is entirely absent in non-Western cultures. Moreover, informal caregiving has a larger relative important in those countries, as social security is less common and professional and costly caregiving is less widespread [8]. It is important to approach this issue with sensitivity and acknowledge that the perception of loss of autonomy varies across different cultural contexts. While the perception of Alzheimer's disease and loss of autonomy may differ from country to country, the emotional, psychological, and physical impact on patients and caregivers is still important.

1.3 Research question and scope of the work

The considered problem statement is quite broad as there are many ways to consider autonomy and well-being. This problem needs to be refined into a precise research question to be thoroughly studied in this thesis. Moreover, as explained in the foreword, in the context of the TRIAXES+ program a device is to be designed to tackle this specific issue. The research question should therefore relate to how a device could contribute to solve the problem.

It has been decided that the work of our TRIAXES+ team will focus on the memory loss caused by Alzheimer's disease instead of other behavioral issues. This is one of the main causes of loss of autonomy among individuals suffering from Alzheimer's disease, especially among those in the mild or early moderate stage. We chose to focus on this stage of the disease because most of these affected individuals have no or only few behavioral problems yet. This eases the conception of the device because it is less likely that users might be distrustful of the device and refuse to use it. Memory loss mostly affects patients at their home, where they are most often located, therefore this is where the device will be the most effective.

Therefore, the goal of the device to be designed is to alleviate the effects of memory loss among early stage Alzheimer's disease patients. Its goal is to improve their autonomy and the well-being of the caregivers thanks to this help. The resulting increase in quality of life should be the main objective of the device, but many others goals have to be considered for the device to be *sustainable*.

On a social aspect, if the device is effective but can only be used by a minor fraction of the intended population, it is not a satisfying solution. The device should notably be easy-to-use by many, affordable, and safe.

On the other hand, the positive social impact of the device should not be balanced by other negative aspects, such as on the environment. The production and usage phases of the device should minimize the impact of the device on the climate (greenhouse gases emissions, water and other material usage, pollution of natural environments, usage of resources etc). It also has to be recyclable, or at least disposable in a clean way.

Finally, financial impacts have to be taken into account. If the device is effective enough to allow to decrease the number of hours of informal care, it has a positive impact on the finances of the caregiver as well as of the society in general. This is even more true if the improvement in the well-being of involved people is such that they require less medication or care provided by the society. This is far from being a negligible amount of money: the global cost of dementia is estimated to 1300 billion US dollars in 2019 by the World Health Organization (1.3% of the global Gross Domestic Product), half of it being directly caused by the cost of the time spent for informal care. It is increasing to an estimated 2800 billion US dollars by 2030 [24].

The ideal solution to the problematic should be in line with some of the Sustainable Development Goals (SDG) introduced by the United Nations (UN) as part of its action plan for 2030. The most relevant SDGs for this problem are shown on Figure 1.5 and are the following [22]:

- SDG 3: "*Ensure healthy lives and promote well-being for all at all ages*"
- SDG 8: "*Promote inclusive and sustainable economic growth, employment and decent work for all*"
- SDG 9: "*Build resilient infrastructure, promote sustainable industrialization and foster innovation*"
- SDG 10: "*Reduce inequality within and among countries*"
- SDG 12: "*Ensure sustainable consumption and production patterns*"

Figure 1.5: Sustainable Development Goals introduced by the United Nations which are the most relevant to keep in mind while designing a device solving the problem statement: number 3, 8, 9, 10, and 12

All these impacts should be considered as a whole, in a systemic way, to ensure the device has the best possible overall impact on society. These aspects are taken into account and summarized in the research question of this Master's thesis:

Research question statement
Which device could alleviate the effects of memory loss at home among people suffering from an early stage of Alzheimer's disease, maximizing its positive social impact while minimizing its negative environmental impact?

The scope of this Master's thesis does not include the development of a fully-working device ready to be mass produced and commercialized. Instead, the scope is limited to creating a Proof of Concept based on 3 deliverables:

- A pre-prototype demonstrating that the technology considered to solve the research question is working as expected in a context similar to the common usage of the fully-working device
- A draft of the production plans for the final device: concept of solution, choice of materials and manufacturing processes, choice of electronic components, estimation of production costs
- An analysis on how the proposed device meets the requirements and needs raised by experts and future users during our fieldwork

1.4 Approach

To achieve the Proof of Concept which is the deliverable of this Master's thesis, the design thinking methodology introduced in the Foreword is used. The first step is to define the problem to solve. This involves understanding the needs and challenges of patients with Alzheimer's disease and their caregivers. Through this process, the problem statement introduced in the previous sections is defined.

Once the problem is defined, the next step is to set up a requirements list. This includes identifying the key aspects and requirements for the solution to meet in order to address the problem effectively. The requirements list is a reference ensuring that the solution is aligned with the needs of the users.

The next step is to generate and compare different concepts, which are sets of blocks achieving selected functions. Multiple ideas of possible solutions are listed and compared to the light of the requirements list and their feasibility. The most promising concept is selected during this evaluation. Once a concept

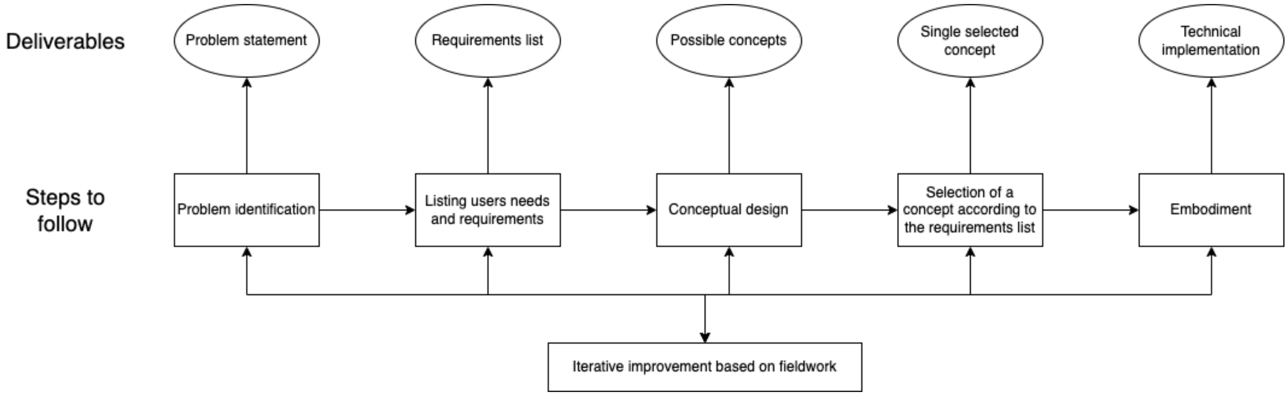

Figure 1.6: Summary of the design thinking methodology procedure

has been chosen, it is embodied: this consists in translating the functions which are part of the selected concept into a detailed implementation.

Throughout this process, feedback and opinions from stakeholders are gathered and used to iteratively improve the requirements list, the concepts, as well as the embodiment. The process is not linear, but allows to ensure the considered solution is at all time in line with the needs of their future users. The design thinking methodology is summarized on Figure 1.6.

The structure of this Master's thesis follows a similar pattern. This first Chapter is introducing the context behind Alzheimer's disease and how it is affecting patients and caregivers. A specific problem statement is identified, and a resulting research question statement is raised, to improve the identified problem while taking into account social, economic, and financial aspects.

Chapter 2 introduces the current state-of-the-art: the existing devices and solutions, including the business competitors identified jointly with my team, and how well they answer the research question. Chapter 3 clarifies the task by setting specific quantified requirements. These requirements are used in many occasions to justify design principles and choices. A solution device is considered as satisfactory if it fully complies with these requirements.

In Chapter 4, some possible conceptual designs are introduced and compared based on the requirements list set up in Chapter 3. The most promising concept is selected and Chapter 5 details how all its features are implemented in practice. It also presents how the user interacts with the device, as well as how it will be manufactured.

Chapter 6 finally validates the designed device. First, a pre-prototype is implemented to verify the core features of device and ensure they are working as expected. Then, the chapter analyses the embodiment and the prototype to show they are fulfilling the requirements list. Finally, legal and commercial aspects are considered to ensure the viability and the intellectual protection of the designed device.

Chapters 5 and 6 thus present the main deliverable of this this Master's thesis, which is a theoretical design of a fully-working device, and a physical implementation of a prototype that includes the main features of the device. Chapter 7 concludes by reflecting on the initial objective of this thesis and on how it has been achieved. It also highlights the future work left for further studies before having a fully-working device ready to be mass-produced.

Chapter 2

State of the art

The context of the thesis have now been introduced, the problem is stated, and the approach is presented. The next step is to study possible solutions of the research question. To perform this, existing solutions and the current state of the art are first analyzed and compared to understand which needs of the public are already fulfilled and which weaknesses a new device should tackle. This is the subject of this chapter. These existing devices have been identified jointly with my team.

2.1 Existing devices and solutions

Sticky notes (Post-it) and whiteboards

Sticky notes like shown on Figure 2.1 are the most natural tool to set reminders for most people, including those affected by Alzheimer's disease and their caregivers. They are easy to use and cheap. One of the main advantages of sticky notes is that they can be placed in a location relevant with respect to the reminder itself. For example to remind to turn off the oven after using it, it is natural to place the note on the oven. They rely on their color and location to catch the attention of the user.

Sticky notes are flexible and versatile: they can be used to remind many different types of actions. Reminders are adapted by the caregiver to be relevant specifically for the patient depending on their specific needs [29].

Figure 2.1: Example of sticky notes usage: this can be overwhelming, especially for people suffering from Alzheimer's disease [30]

They however suffer from multiple drawbacks. It might be difficult for some elderly people to read and even more to write notes [46]. They have to be placed in locations where they can easily be seen, which can be difficult if the user has a visual impairment. A significant portion of individuals affected by Alzheimer's disease have some visual impairment: between 28 and 50% depending on the study and the definition of visual impairment [28, 36]. This can be due to normal aging process or to the impact of the disease on their brain. Even for those who are not visually impaired, routinely seeing the same note in the same place can lead to not paying attention to it anymore.

Moreover, the quantity of information a note can hold is limited, which might lead to lack of context for the user to understand what is reminded. Moreover, they can slip or fall down, especially when they are used for a long time, and they need to be regularly changed to contain up-to-date information. Seeing many notes around their house at all times, even when they are not relevant, can also be quite overwhelming for people suffering from Alzheimer's disease. Finally, sticky notes are most often single-use and this can have a significant impact on the environment if they are frequently replaced.

Whiteboards have mostly the same advantages and drawbacks than sticky notes. Their main differences is that whiteboards are more difficult to place at specific locations, but they are on the other hand less likely to fall down. The advantages and drawbacks of sticky notes and whiteboards are summarized in table 2.1.

Advantages	**Drawbacks**
▪ Natural and easy to use	▪ Difficult to read and write, and not compatible with strong visual impairment
▪ Cheap	▪ Becomes un-noticed because of routine
▪ Flexible and versatile	▪ Limited quantity of information displayed
▪ Placed in a relevant location	▪ Can fall down
	▪ Can be overwhelming
	▪ Environmental impact

Table 2.1: Advantages and drawbacks of both sticky notes and whiteboards to alleviate memory loss among individuals suffering from Alzheimer's disease. Items above the bold horizontal line relate to both sticky notes and whiteboards, the one below only relate only to sticky notes

Augmented sticky notes: eSticky

A paper published in April 2023 introduces an augmented version of classic sticky notes called eSticky, and shown on Figure 2.2. These electronic notes display text but also images and are updated remotely. They can contain a button for the user to acknowledge the corresponding action has been performed. They are connected to a base station using the Bluetooth Low Energy technology, the base station being itself connected to the Internet using Wi-Fi. Thanks to the usage of e-paper, the low-power screen technology notably used in e-readers such as Amazon Kindle, an extensive autonomy of 3 to 6 months is foreseen for each eSticky. This device is still in prototyping phase [31].

Although this high-tech device is promising to allow caregivers to remotely update reminders and to get feedback from the acknowledgment button, it does not really solve the drawbacks associated with sticky notes shown in Table 2.1. On the contrary, it involves supplementary drawbacks such as needing a connection to the Internet and requiring the caregiver to be comfortable enough with technology to

Figure 2.2: eSticky screen design [31]

update the messages remotely. Even if it highlighted that the device will be affordable, no indication on the price is given.

Home assistants

Vocal assistants such as Google Home or Alexa can be beneficial for people suffering from Alzheimer's disease by playing audio reminders on specified dates or times. Reminders are planned in advance and even remotely, and they can be repeated if the user does not reply. Some assistants like Alexa have features intended specifically for people affected by Alzheimer's disease to remind appointments or to take medication for example. They are interactive and allow the user to ask further questions, like ask where his medication is located. Moreover, they are cheap - as low as 25€ for low-cost ones - and the caregiver can receive feedback about interactions between the user and the device. Finally, they can be integrated with Internet of Things (IoT) devices such as sensors to check the fridge door has been closed or that the oven is turned off for example.

However, home assistants also have many drawbacks. They are most often difficult to set up and interact with for technologically inexperienced people, and require an Internet connection. Elder people sometimes struggle to articulate enough to be understood by the device. Some individuals, and particularly those affected by Alzheimer's disease, might be distrustful of the device and suspicious that it will record everything they say. Repetition of messages can have adverse effects, making the user take his medication multiple times for example. On the contrary, if messages are not repeated they can be missed if the user did not hear it or was not home at the time it was played. Finally, vocal assistants have robotic and unfamiliar voices which may be unpleasant to hear for some people.

To summarize, home assistants might be an appropriate solution for tech-savvy elder people, but it is not an ideal solution for most people suffering from Alzheimer's disease because of their many drawbacks. Those advantages and drawbacks are summarized in Table 2.2 [25, 26, 27].

LiNote

The LiNote device shown on Figure 2.3 is a connected tablet created for elder people. It contains a single application and a few simple features to be as easy to use as possible: video calls, digital photo frame, agenda, clock, and message receiving. Even though it is not specifically intended for individuals affected by Alzheimer's disease, a caregiver can send reminders as text messages, and they are then shown on

Advantages	**Drawbacks**
▪ Can be planned in advance and remotely ▪ Reminders can be repeated ▪ Allows interaction and further questions ▪ Cheap ▪ Combine other features and sensors ▪ Feedback and information can be received by the caregiver	▪ Difficult to set up and interact with ▪ Require an Internet connection ▪ Struggle to articulate and communicate ▪ Distrust of the device ▪ Adverse effects of reminders repetition ▪ Reminders can be missed if the user is not present ▪ Robotic and unfamiliar voices

Table 2.2: Advantages and drawbacks of the home assistants device to alleviate memory loss among individuals suffering from Alzheimer's disease

the screen along with a ringtone [32]. The advantages and drawbacks of this device are shown on Table 2.3.


Bon appétit ! N'oublies pas de prendre tes médicaments !

Il est 12h00, mardi 16 août

Figure 2.3: LiNote tablet displaying a reminder sent by a relative to the elder person [32]

Advantages	**Drawbacks**
▪ Reminders can be planned in advance and remotely ▪ User-friendly, intended for elder people ▪ Contains other features (video calls, digital photo frame etc) ▪ Caregiver can receive feedback on whether a messaged has been read based on a motion detector	▪ Device can only be rented and subscription is quite expensive: 38 to 50€ per month ▪ Requires an Internet connection, it can include a 4G connection but more expensive ▪ Reminders can be missed if the user is too far to hear the ringtone ▪ Reminders need to be read, not compatible with strong visual impairment ▪ Limited quantity of information displayed

Table 2.3: Advantages and drawbacks of the LiNote tablet for elderly to alleviate memory loss among individuals suffering from Alzheimer's disease

Smartwatches

Some smartwatches are specifically designed for elder people. They often include a limited number of basic features to be user-friendly, such as counting steps, weather, clock, and SOS button. Some of them like the Medical Guardian MGMove also include a reminder application particularly useful for people affected by Alzheimer's disease [33]. This watch is shown on Figure 2.4 and its advantages and drawbacks are summarized in Table 2.4.

Advantages	Drawbacks
▪ Easy to wear and carry	▪ Expensive: one-time fee of 200 US$ and mandatory subscription of 40 US$ per month
▪ User-friendly, intended for elder people	▪ Requires an Internet connection, it can include a 4G connection but more expensive
▪ Contains other features (text messages, weather, step tracker)	▪ Battery life of less than 24 hours
	▪ Limited quantity of information displayed

Table 2.4: Advantages and drawbacks of the Medica Guardian MGMove watch for elderly to alleviate memory loss among individuals suffering from Alzheimer's disease

Figure 2.4: Example of smartwatch designed specifically for elderlies: Medical Guardian MG-Move and its reminder feature [33]

Figure 2.5: Bracelet of the TagMe project [34]

TagMe project (MIT)

The TagMe project (Figure 2.5) was an innovative idea introduced by researchers at MIT. It consists of an RFID bracelet interacting with RFID stickers placed on objects to recognize them. When the user touches the object, the bracelet detects the proximity of the RFID sticker and trigger a corresponding action. This prototype can be used for many usage scenarios including reminding to take pills if the bracelet did not detect the proximity of the pill box sticker yet, or reminding to close the door of the fridge a few seconds after detecting the fridge sticker. This project was only a Proof of Concept, and was stopped in 2018 before bringing a device to the market [34].

Voice recorders

Voice recorders can act as reminders for individuals with Alzheimer's disease. One advantage is that they play audio messages, making the message more engaging then a written note. The recorded voice is familiar and personal, making it easier for the individual to connect with the message. Additionally, voice recordings are flexible to focus on specific needs of the user. Voice recorders are also portable and convenient, allowing reminders to be accessed anywhere. However, a fundamental drawback is that the person must remember to play the audio message themselves, as the device does not remind them automatically.

Reminder apps and alarms

Reminder apps and alarms on smartphones are a convenient solution to help individuals affected by Alzheimer's disease remembering tasks and appointments. These tools allow to set multiple reminders, schedule regular alerts, and specify written messages along with the reminder. They are increasingly used among these people, but they are also described as cumbersome to use [46]. It is important to consider that the usage of these apps requires the individual to have access to a smartphone and be comfortable using it, which is quite uncommon among people with Alzheimer's disease.

Augmented Reality system

A promising Augmented Reality (AR) system is in development at University of Regina, Canada. A paper published in 2021 [35] presented this device, called the My Daily Routine. It is based on a Microsoft HoloLens AR device and sends different types of reminders (text, images, videos, voice messages etc). These reminders can be played based either on voice commands or on automatic recognition of objects and people, even though only recognition of objects was yet implemented at the time of publishing of the paper. It is customizable using a web interface, and allows to show holograms to help the user, for example for indoor navigation It has the potential to become at some point a disruptive solution to radically change the daily life of people affected by Alzheimer's disease. However, it is still in development and far from being fully-working, even as a prototype. Many features are not yet implemented, computing performances are limited, and it is based on a 579g heavy AR display [35]. It also requires users and caregivers to be confident with complex technology. Since it is still in early stage of development and a lot of information is missing, the My Daily Routine system will not be considered in the comparison between existing solutions presented in the next section.

2.2 Comparison of existing solutions

Table 2.5 details a comparison between all the devices introduced in the previous section. It shows that no device is significantly better than others: they all have important weaknesses which makes them unsatisfying for people suffering from Alzheimer's disease. According to our fieldwork, most of the people we met choose to use either sticky notes for location-based reminders, or alarms for time-based reminders, or a combination of both, because of their simplicity. Elder people who are comfortable with technology might consider using home assistants despite their weaknesses such as not being able to play reminders depending on the user location in his home, or their robotic voice, but this does not represent the majority of those people.

As part of the TRIAXES+ program, the goal of our team is to develop a device combining the advantages of technological solutions (play messages depending on the location and the time) and voice messages, while being easy to use and not requiring any action from the user.

Criteria / Device	Easy to use	Price	Remote config	Uses location	Uses time	Quantity of info	Internet	Feedback to caregiver	Other advantages	Other drawbacks
Sticky notes	Easy	Cheap	No	Yes	No	Small	Not required	No		▪ Becomes un-noticed ▪ Can fall down ▪ Can be overwhelming
eSticky	Setup: difficult Use: easy	Unknown	Yes	Yes	Yes	Small	Required	Possible		▪ Becomes un-noticed ▪ Limited autonomy ▪ Prototype stage
Home assistant	Quite easy	From 25€	No	No	Yes	Large	Required	Possible	More features	▪ Distrust ▪ Robotic voice
LiNote	Easy	50€/month	Yes	No	Yes	Small	Required (4G possible)	Possible	More features	
Smartwatches	Variable	Expensive	Yes	No	Yes	Small	Required	No	More features	▪ Low battery life
TagMe project	Setup: difficult Use: easy	Unknown	No	Yes	Yes	Variable	Not required	Possible (if Internet)	More features	▪ Battery life unknown ▪ Abandoned prototype
Voice recorder	Easy	Cheap	No	No	No	Large	Not required	No	Audio messages	▪ Playing audio isnot automatic
Reminder apps/alarms	Easy	Free	No	No	Yes	Small	Not required	No		▪ Requires a smartphone

Table 2.5: Detailed comparison of currently existing devices and of some selected prototypes to help alleviating the effects of memory loss among people suffering from Alzheimer's disease

Because of intellectual property reasons, chapters 3 to 7 have been removed from this Master's thesis as they contain confidential material. Don't hesitate to reach out to Vocomemo if you would like to know more about it.

Chapter 7

Conclusion and future work

This thesis introduced the design and the development of a device called Vocomemo aiming at improving the quality of life of people suffering from Alzheimer's disease and their caregivers. Reminders are triggered depending on the current time and the user location, which is determined using proximity detection of Bluetooth Low Energy tags. Rather than reducing caregiver-patient interaction time, the device aims to enhance the quality of their time together, fostering conversations and discussions. A device has been theoretically developed, which involved careful selection of electronic components to optimize cost, size, weight, and power consumption. Ethical and sustainable considerations led to manufacturing in Europe, prioritizing environmental regulations, quality control, and local job creation. A prototype was also developed for validation and testing, providing insights for device improvement and confirming the feasibility of key features. The goals of this thesis have therefore been achieved because a theoretical device has been designed, a prototype containing its most important features has been implemented, and it has been verified that the theoretically designed device fulfills requirements listed with users and the UN Sustainable Development Goals.

The next steps to take to continue the technical development of the Vocomemo device is to create a new prototype, based on a PCB and mostly using components chosen in Chapter 5. This will allow verifying the functioning and compatibility of the components and whether the quality of the audio signal is as good as expected. In parallel, the 3D model of the device case should be molded to verify its quality, check whether future users like it, approve its size and check the two parts of the case are closing well. Once a fully-working prototype and case are created, they can be tested in real-life conditions with user to make final adjustments before starting mass production.

Depending on the users feedback, new features could be implemented in the Vocomemo, like the possibility to connect the device to the Internet to record messages remotely and check which messages have been played. The accelerometer which is already integrated in the device could then be used to monitor whether the user fell and warn its caregivers. However, the additional energy consumption caused by this connection should be assessed to measure its impact on the battery life. We were also asked to add a feature allowing the caregiver to localize the user using its Vocomemo. However, this causes ethical issues, and the user might refuse to wear the device if he knows that it is tracking him.

This Master's thesis presented the development of a device which has been shown to fulfill the vast majority of its requirements. Some still requires further validation and tests, and it is expected that new issues would arise during the continuation of its development. However, this thesis shows that this device is very promising and could help improve the lives of thousands of people suffering from Alzheimer's disease and their caregivers.

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