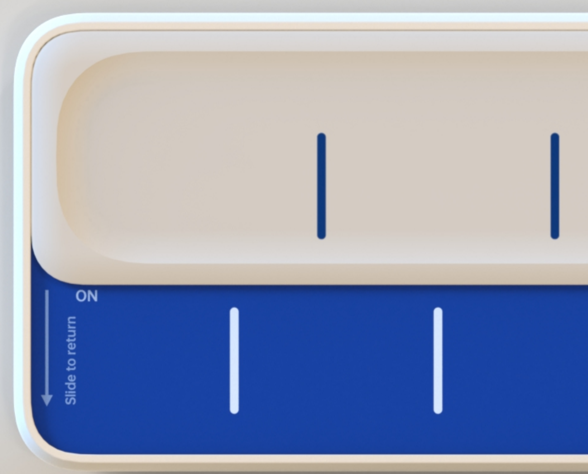
Improving the return rate of a smart pillbox in a circular economy

From product redesign to comprehensive guidelines



Master Thesis
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Digital Health in the Circular Economy

Improving the return rate of a smart pillbox in a circular economy

From product redesign to comprehensive guidelines

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Digital Health in the Circular Economy

(DiCE project)

https://circulardigitalhealth.eu/

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Abstract

This study explores nudging strategies to improve user abilities in order to promote the voluntary return of digital health products, with a focus on the smart pillbox. The two objectives were to create specific design recommendations for the smart pillbox and derive general design guidelines to support a circular lifecycle for future digital health innovations. The study revealed four key design aims: enhancing user abilities, establishing reliable return mechanisms, reducing participation barriers and exploring the wide range of potential applications.

The investigation combined thorough analysis, engaging users and refining designs through iterations. The key findings emphasized the crucial factors of product hardware design and strategic communication in influencing users' abilities and willingness to return the smart pillboxes. Innovations in designing smart pillboxes, such as state switches, clear printed instructions, and digital reminders, have been introduced. Preliminary validations suggest that they are effective, but there is a need for further research to explore their combined impacts. Interestingly, this research highlights the importance of "Returners" as crucial stakeholders in the product return ecosystem. This underscores the need for tailored comprehension and design to meet their unique requirements.

Although the recommended guidelines have the potential to benefit a wider range of smart health devices, it is essential to validate them with more extensive participant groups. It is worth noting that the current research mostly focused on user ability, however, future studies are encouraged to explore the motivation dimension, which participants identify as a critical factor. This would help create a holistic approach to encourage voluntary product returns.

Abbreviation

CE	Circular Economy
DiCE	Digital Health in the Circular Economy
EoL	End of Life
EU-MDR	European Union Medical Device Regulation
FBM	Fogg's Behaviour Model
IoT	Internet of Things
LCA	Life Cycle Assessment
PCB	Printed Circuit Board
R&D	Research and Development
SMS	Short Message Service

Glossary

Collection: The process or system set up to collect and accumulate a particular type of equipment. In the context of this report, it refers to the collection of returned pillboxes or devices.

Divestment: The act of selling or disposing of assets, especially in a planned manner. In the context of the product lifecycle, it can refer to users parting with their equipment, either through return or other means.

End-of-Life (EoL): Refers to the final stage of a product's lifecycle, indicating that the product has reached the end of its useful life. At this point, it's no longer suitable for regular use and is ready to be discarded, recycled or reused.

Medication adherence: The degree to which a patient consistently follows the prescribed dosage, timing and frequency of a medication regimen. This can be critical to the effectiveness of treatments and overall health outcomes.

Return: The process of giving back or sending a product to its place of purchase or manufacturer, especially for reasons of defectiveness, dissatisfaction or a structured recall system.

Returner: An individual or organisation responsible for the act of returning products to their place of purchase or to the manufacturer. In this report, this term could refer specifically to those returning the pillboxes.

Reverse Logistics: The process and operations associated with the return of products from their final destination to recover value or ensure proper disposal. Unlike traditional logistics, it involves operations from the end user back to the manufacturer or similar location.

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Chapter 1
Introduction

This chapter provides an overview of the project by explaining its connection to the circular economy and the end-of-life return of smart pillboxes. It also introduces the results of the background and exploratory research conducted during the primary phase of this project. This encompasses the drivers and barriers in the system for returning and collecting smart healthcare-related devices, as well as the challenges that users face when returning such devices. Ultimately, this chapter defines the objectives and scope of the project.

1.1. Project Context

Waste generation in the healthcare industry is enormous, and existing circular medical products present various challenges, including value, hygiene, requirements, and organizational support structures. (Kandasamy et al., 2022) Healthcare is a resource-intensive and essential system that provides well-being for this and future generations. In addition to non-hazardous wastes, many different types of hazardous wastes are generated, including bodily fluids, infectious waste, pharmaceuticals, sharps, and e-waste from equipment. (Moultrie et al., 2015) The medical device industry leads to a high environmental footprint while maintaining essential social functions (Guzzo et al., 2020). Identifying opportunities for innovation in the circular life cycle of a variety of equipment is therefore challenging.

1.1.1.Circular Economy

A circular economy is an economic system based on the systematic application of strategies to slow, close, or shrink the material and energy cycles to achieve a sustainable future. (Kirchherr et al., 2017). As demonstrated in Figure 1, the World Economic Forum (2014) outlined pathways in which technical materials and value can be returned to users or systems in a circular economy, including maintenance, reuse/redistribution, refurbishment/remanufacturing, and recycling. Regardless of the value recovery pathway, the value and the material need to be collected from end users back to the system. This is reflected in the acquisition and collection of used products during the product journey. By overcoming the challenges of product return and collection, circular economy business models can be implemented more successfully (Kirchherr et al. 2017).

1.1.2.Context: DiCE Project

The Digital Health in Circular Economy (DiCE) project takes a comprehensive approach to the growing challenge of digital health waste (Digital Health in the Circular Economy 2023). It encompasses all stages of the lifecycle of a digital health device, from inception to disposal, with a focus on extending the life of the product. DiCE emphasises the importance of robust testing and implementation of end-of-life strategies that incorporate cutting-edge refurbishment, remanufacturing, and recycling technologies. These methods aim to optimise the recovery of products, components, and materials when reuse isn't an option. Ultimately, DiCE advocates a shift from a disjointed, linear model to a sustainable, circular one that promotes product reuse and component and material recovery. In terms of DiCE's mission, this design project, using smart pillboxes as an entry point, primarily addresses the reverse logistics aspect to increase the return rate of devices for refurbishment or remanufacturing.

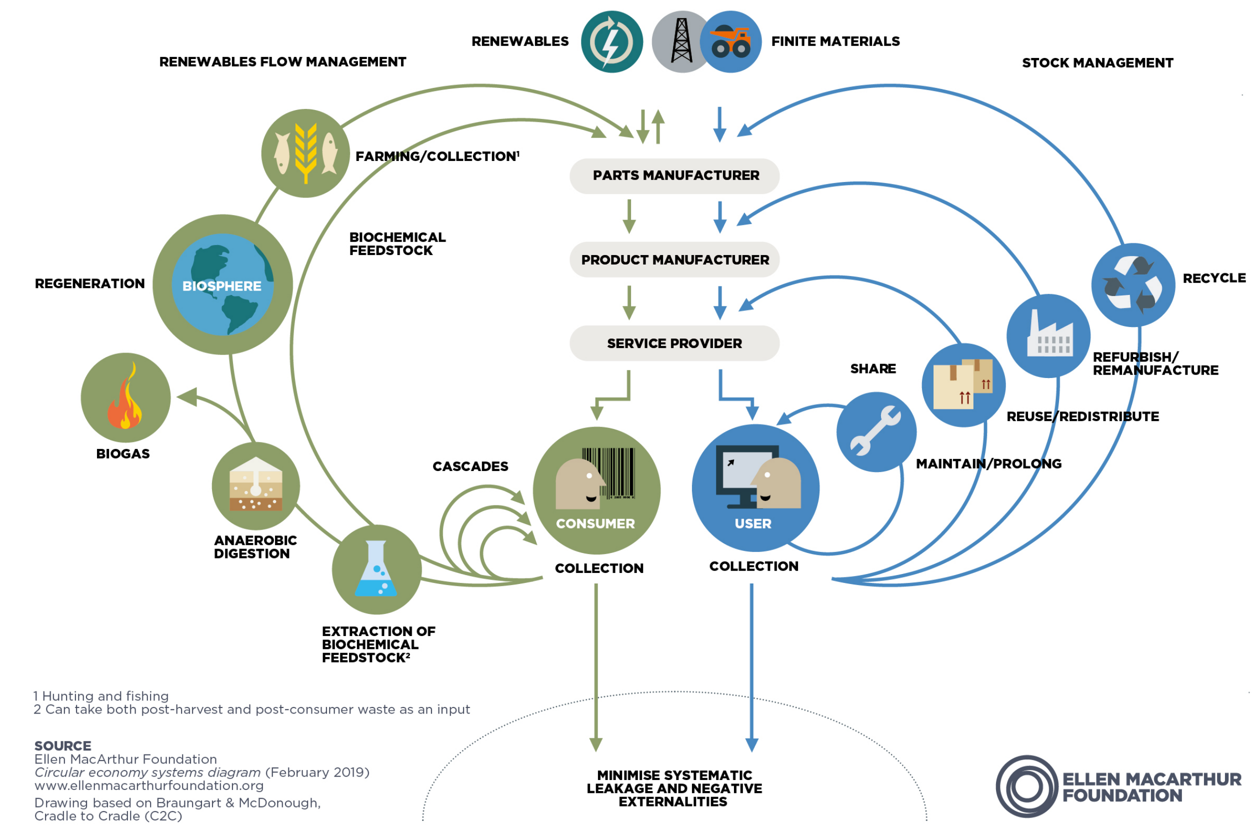


Figure 1 Butterfly diagram (Ellen MacArthur Foundation, 2019)

1.1.3.The smart pillbox

A smart pillbox is selected as one of the four products under investigation in the DiCE project. As represented in Figure 2, designed to streamline medication management, it syncs with a mobile application, leveraging integrated technology to facilitate medication adherence. It prompts users to take their medication, provides dosage instructions, and tracks compliance, thereby making the task of managing medication more straightforward.

The primary materials of the pillbox are polycarbonate, while it features a rechargeable lithium battery, a printed circuit board, and a speaker. The packaging includes a charging adapter and a power cord. By employing a robust return and collection program, vital components and materials of the pillbox can be recycled and reused, effectively reducing the environmental impact.

A smart pillbox can be characterised as a 'borderline medical device' (Medicines and Healthcare products Regulatory Agency, 2021). This underlines its multifaceted nature and the complexity involved in its categorisation. "Borderline medical devices have a clear health-related function but do not meet the conventional definition of a "medical device" within the parameters of the EU-MDR (Publications Office, 2017). Such a position is advantageous for products such as smart pillboxes, as it allows for a more streamlined transition to a circular economy without the burden of strict regulatory compliance face. Such a position is beneficial for products such as smart pillboxes, as it allows for a more streamlined transition to a circular economy without the burden of strict regulatory compliance that these medical devices face.

Figure 2 A representation of a smart pillbox & accompanying App

1.2. Background Research

In order to fully understand the context of the project, background research was conducted at a systems level, focusing on the implementation of circular economy and remanufacturing in industry. This included an examination of the barriers and challenges to the widespread adoption and application of circular economy and remanufacturing principles.

At the same time, an exploratory study was conducted at the user level to understand the mindset that drives end-of-life (EoL) product returns during their journey, as well as the challenges encountered throughout the returns process. This research also included an exploration of nudging strategies as a potential tool to inform and influence subsequent design directions.

1.2.1.Drivers and barriers in the system

Drivers and infrastructures

For manufacturers and stakeholders across the supply chain, the adoption of a circular economy requires incentives for participation. According to Aloini et al. (2020), the driving factors can be categorized into seven dimensions: institutional, economic, environmental, organisational, social, supply chain, and technological. Through the literature review, a total of 12 driving factors were identified, including decision-making drivers and infrastructure required. Table 1 shows the details of these 12 driving factors.

There are many different types of factors and infrastructures that can drive companies into the remanufacturing cycle. The most influential drivers appear to be institutional and economic. Social factors such as consumer awareness and market competition play an increasing role and are positively correlated with firm size (Aloini et al., 2020).

From an R&D and production perspective, efficient supply chain management capabilities and the integration of circular design in the R&D phase may be fundamental to the functioning of the remanufacturing cycle. The unstable flow of critical parts and materials in the remanufacturing cycle poses a challenge to the manufacturing supply chain. Effective management of reverse networks and adaptation to the structure of the supply market can help companies maintain stable production and costs. Lean manufacturing's low inventory levels and ability to adjust production on the fly also contribute to cost control (Ciliberto et al., 2021). At the same time, taking into consideration remanufacturing requirements during the product development phase and adapting remanufacturing strategies during production will be one of the necessary enablers for the manufacturer of the pillbox to move towards a circular economy. User studies have shown that an efficient collection strategy reduces the difficulty of collection for users while increasing their willingness to collect, thus ensuring that critical parts and materials are returned to the system. An efficient collection strategy can therefore be described as a necessary infrastructure for the remanufacturing cycle.

Finally, according to Aloini et al. (2020), the impact of the drivers may also depend largely on the particular environment involved, in this case the marginal medical device industry. Therefore, the specific impact of the driving factors mentioned in the research results on the industry still needs in-depth research to verify.

Dimension	Driving factors	References
Institutional	Government Regulation: policies, laws, directives, regulations, standards, and requirements set by organisations.	(Dijkstra et al., 2020); (Prieto-Sandoval et al., 2018); (Tura et al., 2019)
	Incentives: Tax rebates, funds, low-interest loans, subsidies, incentives, etc.	(Dijkstra et al., 2020); (Prieto-Sandoval et al., 2018);
Economic	Potential to improve cost efficiency and profitability: higher profitability brought about by saving transportation costs, efficient use and recovery of resources, cost reduction and resource recycling, reduced dependence on imports of raw materials, and the impact of fluctuations in resource prices.	(Prieto-Sandoval et al., 2018); (Guzzo et al., 2020); (Dijkstra et al., 2020); (Agyemang et al., 2019)
	Potential for new business development and innovation: Create new value, develop new products, or enter new markets.	(Tura et al., 2019); (Dijkstra et al., 2020)
Environmental	Environmental problems: climate change, energy shortage, resource scarcity, environmental security, and resource limitation.	(Tura et al., 2019); (Govindan & Hasanagic, 2018); (Dijkstra et al., 2020)
Organizational	Strategical concerns: brand reputation and social responsibility	(Prieto-Sandoval et al., 2018); (Tura et al., 2019); (Govindan & Hasanagic, 2018); (Dijkstra et al., 2020)
	Circular Strategies: Efficient collection, inspection, and triage strategy to identify and recover the value.	(Tura et al., 2019); (Bocken et al., 2016); (Dijkstra et al., 2020)
Social	Circular Economy awareness: Stress from the market for green practices from competitors; Environmental awareness, shifting consumer preferences.	(Prieto-Sandoval et al., 2018); (Govindan & Hasanagic, 2018); (Dijkstra et al., 2020)
Supply Chain	Supply configuration: management of reverse network, supply market structure.	(Prieto-Sandoval et al., 2018); (Tura et al., 2019); (Dijkstra et al., 2020)
	Reprocessing system: Cleaning, sterilization, and disinfection processes to ensure the hygiene and safety of remanufactured products.	(MacNeill et al., 2020); (Kane et al., 2018)
	Lean Manufacturing: Reduce inventory, just-in-time manufacturing, and modification; Integration of circularity in the design phase.	(Ciliberto et al., 2021);
Technological	information and communication technology: The use of IoT, RFID and other technologies to assist the collection of information tracking and supply management	(Tura et al., 2019); (Mathews & Tan, 2011)

Table 1 Driving factors in the system.

Barriers in the system

While the goals of a circular economy are constantly being emphasized and adopted as part of future strategies (European Commission, 2014), barriers to shifting to such circular business models remain. Through the literature review , a total of 9 barriers were summarised and grouped into the same dimensions as the driving factors. Table 2 shows the details of the barriers identified.

The transition of products such as a smart pillbox to a circular lifecycle, which incorporates return and remanufacturing, faces a major barrier: the lack of comprehensive support from supply and demand networks. This gap can manifest in several forms, such as insufficient development or input of products or services within the supply chain (Rizos et al., 2016). Challenges may arise in reverse logistics support, inventory management, and supply chain stability, which may increase production costs and required inputs. In addition, capital constraints pose a significant barrier when considering initial investment requirements and potential risks and hidden costs (Rizos et al., 2016).

Manufacturers may also be reluctant to move towards a circular economy, often due to concerns about product sales. Disparate and unreliable information could limit business agility, while fluctuating demand complicates planning (Singhal et al., 2020). Shifting consumer expectations of quality and price add another layer of resistance, fuelled by misconceptions about the quality and safety of remanufactured products (Wang et al., 2018).

Beyond these primary barriers, institutional and structural barriers also play a role, including lack of government support (Rizos et al., 2016) and regulatory complexity (Gumley, 2014). Rizos et al. highlight additional barriers that limit interest in green business initiatives, such as conservative local economic policies and external factors such as economic recession.

In summary , the key challenge in implementing a remanufacturing cycle for smart pillboxes and those digital healthcare devices is the lack of adequate infrastructure. This again reflects the barriers that consumers and users face when trying to participate in returns and collections. This deficiency is reflected in the minimal services and support provided by key stakeholders within the cycle. The underdeveloped state of the circular economy model also affects the infrastructural development of the chain. To overcome these barriers, compelling drivers are needed to catalyse a positive cycle. It's worth noting that barriers can come from both institutional and economic sources. In healthcare-related ventures, such as medication management, institutional pressures and security concerns can create more formidable resistance than in general industry.

Dimension	Barrier	References
Institutional	Restricted from legislation: lack of government support, complexity of laws and regulations	(Rizos et al., 2016) (Gumley, 2014)
	Lack of support from regulators: Lack of technical support for recyclable solutions and financial support for implementation of circular economy practices	(Diabat & Govindan, 2011)
Economic	Lack of capital: early investment, possible risks, and hidden costs	(Rizos et al., 2016) (Govindan et al., 2014)
	Sales concerns: Changed user expectations in quality and price, customers' misunderstanding of the quality and safety of remanufactured products	(Wang et al., 2018)
Organizational	Reduced business flexibility: Unreliable and disparate information, unstable demand, complicated scheduling	(Singhal et al., 2020)
	Lack of effective collection system: Inability to ensure that products are collected from consumers at end of life and continued for remanufacturing	(Kalmykova et al., 2018)
Social	Low interest in circular initiatives: Lack of environmental protection education, insufficient awareness of sustainability, periodic economic depression, and conservative policies of the local sector	(Rizos et al., 2016) (Mishra et al., 2022)
Supply Chain	Lack of support from the supply and demand network: insufficient reverse logistics support, inventory management, and an unstable supply chain	(Rizos et al., 2016)
Technological	Lack of technology for value recovery: Existing systems and technologies resist circular retrofitting; Failure to restore the product to the desired level of performance	(Govindan et al., 2014) (Kalmykova et al., 2018)

Table 2 Barriers in the system.

1.2.2.Behaviour changes and nudging strategies

One of the problems faced today in moving towards a circular lifecycle for smart devices in healthcare is that inactive devices are often not brought back into the system to fulfil their value. For a variety of reasons, users are more likely to leave these devices unused at home, or simply discard them into the waste stream, rather than returning them to the system. To facilitate the CE transformation of such equipment, this user behaviour needs to be changed.

The Fogg Behaviour Model (FBM), shown in Figure 3, is a valuable reference when studying users and other stakeholders' behaviours. Fogg (2009) points out that three elements must converge simultaneously for behaviour to occur: motivation, ability, and trigger . When analysing the reasons for non-return behaviour, the aim is to identify which one or more of the three components is lacking. When providing improvements to the circular lifecycle of this device, it is necessary to address each element of the FBM in order to facilitate the circular behaviour of the users.

Motivation

This refers to the desire to perform a behaviour. According to Fogg, there are three core motivators, each related to pleasure/pain, hope/fear and social acceptance/rejection. Essentially, people are more likely to perform a behaviour if they expect it to lead to positive outcomes and if it is in line with their social context.

Ability

Ability refers to how easy or difficult it is for someone to perform a behaviour. Simplicity is key here - the simpler a task, the more likely an individual is to perform it. Fogg outlines six factors that can affect simplicity: Time, money, physical effort, brain cycles (mental effort), social deviance (going against the social norm) and non-routine (how much the action fits into or disrupts existing routines).

Prompts

A prompt is the cue that initiates the behaviour. Without a prompt the behaviour will not occur, even if the individual is highly motivated and the action is easy to perform. Prompts can take many forms, such as a notification on a phone, a request from a friend, or an internal feeling.

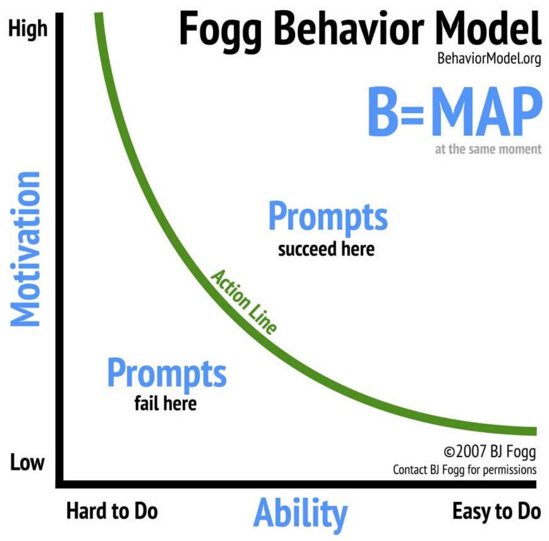


Figure 3 Fogg's Behaviour Model (Fogg, 2009)

6 principles of Nudges	
Incentives	Altering the cost-benefit balance of decisions
Understand mappings	Enhancing comprehension of consequences
Defaults	Leveraging inertia or status quo bias
Give feedback	Providing information about outcomes
Expect error	Designing systems forgiving of mistakes
Structure complex choices	Simplifying decision-making

Table 3 Six principles of nudges (Thaler & Sunstein, 2008)

Nudge, as defined by Thaler and Sunstein (2008), is a method of influencing people's decision-making environment to alter their behaviour. As shown in Table 3, there are 6 principles of nudges which can be applied to the design of the smart pillbox. It is not mandatory and does not restrict people's choices or impose rules or regulations. Nudges guide people towards a desired decision by incorporating cues into the environment (Weßel et al., 2019). By modifying user behaviour, nudge strategies are seen as a potential design reference for edge medical devices such as the smart pillbox, to encourage voluntary participation in product return and collection, thereby advancing the circular economy.

While nudges alone don't guarantee direct action, they can influence user behaviour if they are effectively tailored (Thaler and Sunstein, 2008). By incorporating evidence-based nudging strategies, such as providing clear return instructions or offering incentives, there's potential to make it easier for users to return used pillboxes for remanufacturing. However, it is important to continually evaluate and adjust these strategies based on user feedback and behavioural data to ensure their effectiveness.

Furthermore, the design of nudges is also in line with FBM. For example, nudges can increase motivation by creating positive incentives, such as giving the user a sense of contributing to environmental sustainability by returning the product. Similarly, nudges can improve capability by simplifying the return process, thereby reducing the effort or complexity associated with the task. Finally, prompts in FBM terminology can also be embedded in nudges, alerting the user when it is time to return the product or providing reminders to do so.

Therefore, the implementation of nudging strategies and FBM could facilitate behavioural change towards product return, thereby promoting the circular lifecycle of devices like smart pillboxes. By incorporating nudges into the design, it may be possible to subtly guide users' actions and encourage circular behaviour.

1.2.3.Exploratory Research

A round of exploratory research was carried out as the first phase of this design project. This preliminary phase involved distributing five smart pillboxes to participants who were asked to use the devices for a month. This hands-on approach facilitated the collection of rich, first-hand insights into user experience and return behaviour. Following the trial period, in-depth interviews were conducted, focusing on participants' experiences and perspectives on returning the device. Participants were also asked to rate the effectiveness of various potential nudging strategies. The findings from this exploratory phase significantly influenced the subsequent direction and strategies of the project.

Driving mindsets

The driving mindset is closely aligned with the behavioural component of the Fogg Behaviour Model (FBM) - motivation. The findings from previous research suggest that users have an intrinsic motivation to return the pillbox, albeit conditional. The key condition is that the perceived residual value of the product exceeds the cost of returning it. The assessment of residual value in turn depends on factors such as duration of intended use and environmental awareness.

Short-term users show a higher motivation to return the product due to their higher estimate of the future residual value of the pillbox. This is reinforced by their positive expectation of the product's future value recovery. Their willingness to pass the pillbox on to the next user signals a deeper understanding of the product's utility and its potential for reuse or repurposing.

Environmental awareness also drives the motivation to return. Users who are aware of the potential environmental damage caused by the improper disposal of electronic equipment are naturally inclined towards more environmentally friendly options, such as returning the product. This not only averts potential environmental damage but is also in line with ethical beliefs, thereby reinforcing their motivation to return the pillbox.

In conclusion, users show a degree of motivation to return the pillbox, subject to certain conditions. This motivation, which is deeply rooted in their perception of the product's residual value and their environmental awareness, holds potential for further cultivation through targeted interventions. In particular, interventions that reinforce users' perceptions of the product's residual value and their environmental awareness could significantly increase the likelihood of product returns.

Challenges in the return

The exploratory research has identified key challenges that need to be addressed for the successful return of this device. It was found that users often lack sufficient guidance and information on disposal or return procedures for products. Coupled with a general lack of motivation and ability to seek out this information independently, this is a significant barrier to effective product return strategies.

One of the key challenges is to provide adequate support to users during the collection process. Reducing the costs associated with learning, communication and building trust is an important priority for future strategies. Trust emerges as a critical factor. Addressing users' concerns about potential breaches of personal data stored in the pillbox is essential to building user trust and willingness to participate in the return process.

User behaviour and ingrained habits also pose additional challenges. The research shows that users tend to have established practices for managing similar deactivated smart devices. For example, many participants maintained dedicated storage spaces at home for such devices. Overcoming this behavioural inertia and encouraging users to return rather than store their deactivated devices, is another significant challenge for redesign efforts.

In summary, effectively facilitating product returns requires a comprehensive approach that addresses information deficits, builds trust and challenges ingrained user behaviours. Future redesign strategies should recognise and respond to these challenges in order to improve the return rate of the smart pillbox.

Implement of nudging strategies

Previous research has identified certain promising directions for the application of nudging strategies that could potentially facilitate the collection of this pillbox. These directions were identified through an evaluation process and provide valuable insights for subsequent redesign efforts.

Among the various nudging strategies evaluated, the inclusion of a pillbox deposit was found to be particularly effective. The effectiveness of this strategy may be due to the use of financial incentives in the return process. In addition, the deposit might lead consumers to view the return of the product as a normative expectation, thus influencing them to conform to this perceived rule (Sunstein, 2014).

Providing return information inside the product packaging was also recognised by participants as a useful strategy. This method focuses mainly on effectively communicating the return option. The information, which is present during both the unboxing and disposal phases, can guide user behaviour and decision making. Other well-received strategies included location-based suggestions for optimal return methods and modular design to facilitate the return of electronic components. The main aim of these strategies is to simplify the return process.

It is important to note that the strategies that addressed the 'ability' aspect of the Fogg Behaviour Model (FBM) scored higher overall. Coupled with the understanding that users already have a certain level of motivation to return the product, it seems reasonable to focus the next steps of the project primarily on improving 'ability'.

1.3. Project Objectives

Presently, the smart pillboxes often fail to be returned to the system following their initial use, which results in consequential waste of resources and manufacturing impacts. The primary goal of this project is to enhance the end-of-life return rate of smart pillboxes by evaluating and refining both the product design and system around it. This exploration will culminate in providing comprehensive design guidelines for the circular design of digital healthcare devices, envisaging sustainable solutions for the next 5 to 10 years.

1.3.1.Project Scope

In order to ensure the feasibility and efficiency of the project, it is essential to define the scope of the project as illustrated in Figure 4. In this project, the primary challenge is to stimulate the voluntary return of the product. To achieve this, the project will focus on the use of nudging strategies to encourage user behaviour. In parallel, the project also emphasises the reduction of barriers and the empowerment of users in the return process.

Ultimately, a comprehensive guideline will be delivered in conjunction with the redesign of the smart pillbox. Throughout the process of the project, it may be interesting to look at user habits, application interface, packaging design, and return mechanisms as the need arises.

Certain elements and tasks, such as developing business strategies to incentivise, motivate and design for mass production/remanufacturing, are outside the scope of this project. This ensures that the project maintains a consistent focus on promoting user-initiated product return.

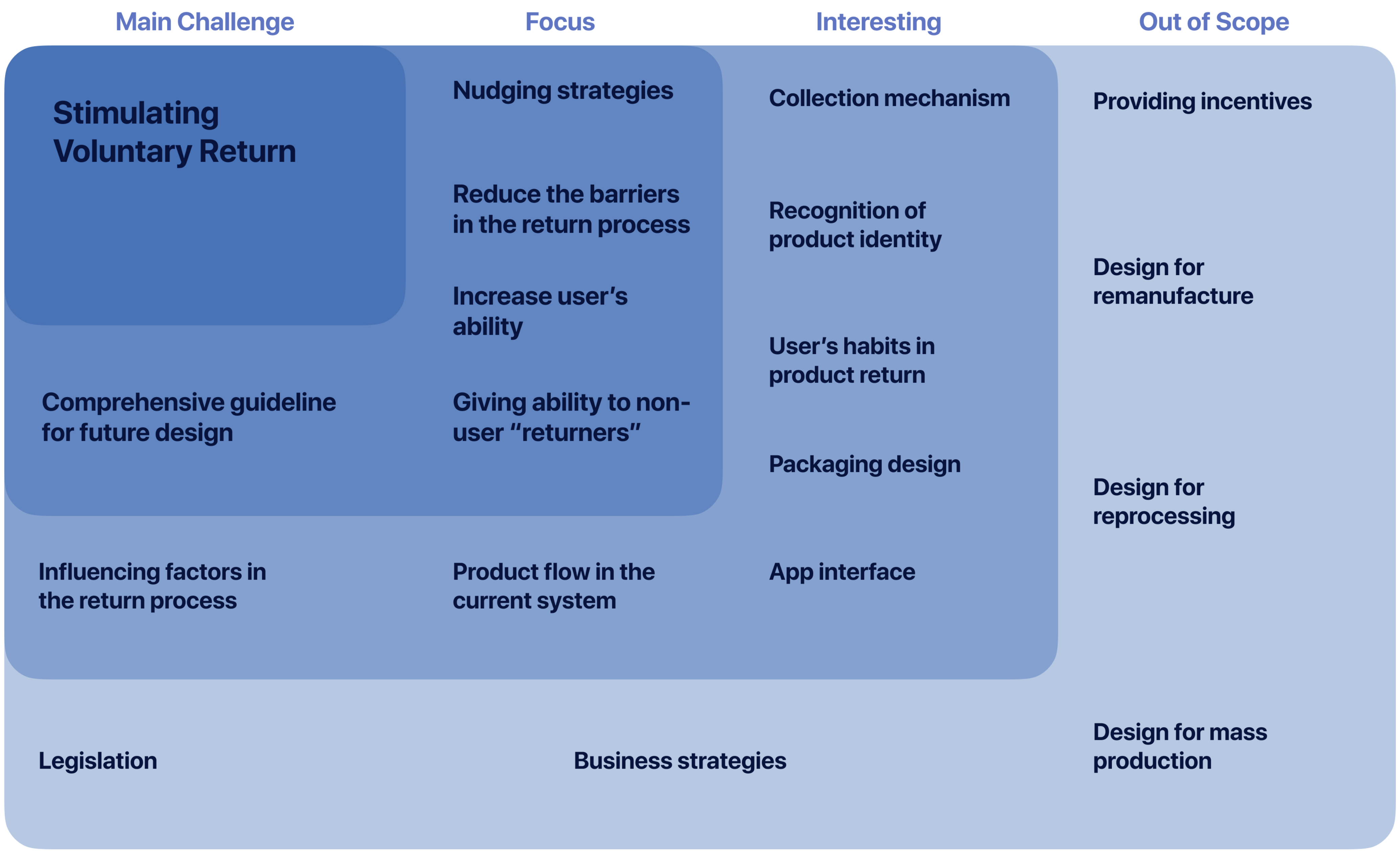


Figure 4 Project scope

1.4. Conclusion

The healthcare industry is a huge contributor to waste generation, highlighting the urgent need to adopt circular economy principles within digital healthcare products for environmental and economic sustainability. However, challenges such as infrastructural limitations and institutional and economic barriers make innovation within the circular lifecycle of such devices complex. A key issue is facilitating the return of products at the end of their lifecycle for reintegration into a circular model.

Users, as the primary return agents, have the motivation but also face challenges. This requires the implementation of various nudging strategies to increase the participation for value recovery and to provide support in the return process in order to increase the return rate of the smart pillbox, thus ensuring a circular economy model.

This project focuses on the application of nudging strategies and the enhancement of user abilities to encourage voluntary returns. It also aims to provide design recommendations and guidelines for future digital health products to ensure a circular lifecycle.

Chapter 2

Approach & Method

This chapter outlines the comprehensive design process undertaken for this project, coupled with a systematic presentation of the research methodologies employed at each stage. The discourse will extend to include a detailed exposition of the research plans, objectives, and pertinent participant information. This aims to illuminate the procedural dynamics behind the project's progression, providing a clear roadmap of the research and design journey.

2.1. Design Process

The design process of this project is shown in Figure 5. It provides a comprehensive view of the project's design process, modelled on the principles of the agile design approach. Agile design was well suited to this project because of its iterative nature and rapid feedback loops. The process was organised into a series of 'sprints', each dedicated to a specific aspect of the design.

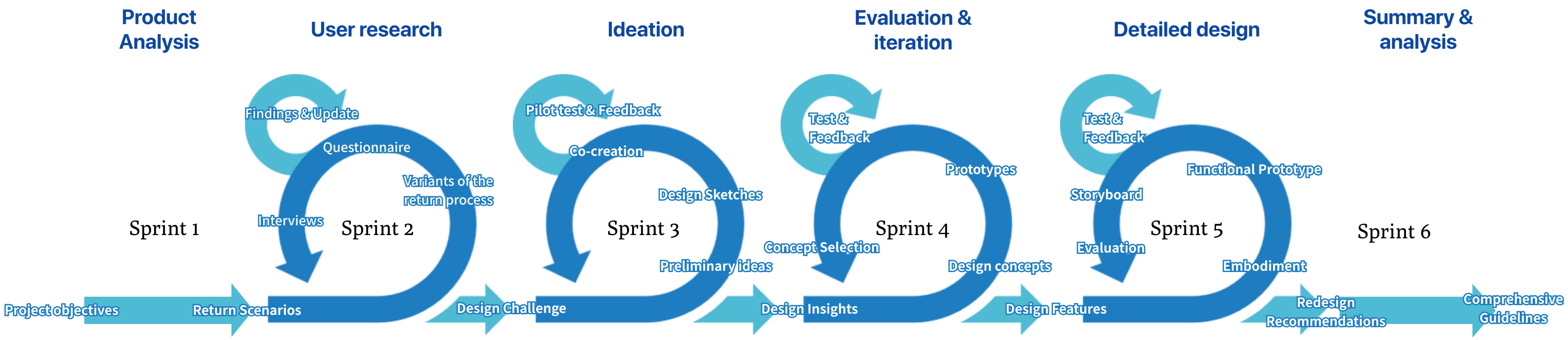
Each sprint in the design phase included a cycle of design and testing. The iterative nature of this process allowed for continuous improvement of design concepts, resulting in refined solutions over time. The results of one sprint, including design challenges and insights, were seamlessly integrated into the following sprint, ensuring a continuous feedback loop and informed progress.

This approach fostered a dynamic process that was responsive to emerging insights and adaptable to evolving design requirements. By adopting this Agile-inspired design process, the project was able to efficiently generate, evaluate and refine design concepts, ultimately leading to a more user-centric solution.

In order to achieve the primary objective, the project first examined the smart pillbox, and the context of end-of-life (EoL) returns in a circular economy, setting the stage for defining the design problem. Once the problem was identified, an in-depth exploration of the key variables influencing the user experience during the EoL return process was conducted, uncovering the main reasons for non-return and the difficulties experienced during the process. These findings helped to identify the design challenges related to user capabilities during the return process.

To address these challenges, preliminary design ideas were generated to stimulate feedback aimed at uncovering user preferences and innovative ideas from participants during co-creation sessions. These ideas were then refined into design concepts and feedback was sought from target users for further development, ultimately leading to the final redesign of the pillbox to improve return rates.

Finally, insights from each stage of the project were distilled into a comprehensive guideline for the future design of borderline medical products, paving the way for more circular solutions.



	Sprint 1	Sprint 2	Sprint 3	Sprint 4	Sprint 5	Sprint 6
Input	• Project objectives • Research result from previous work	• The scenarios of return • Research result from previous work	• Design challenges • How Might We questions	• Insights on the design of return process	• The best concept for development • Design insights	• Integration of design features • Insights from previous testings
Method	• Reverse Engineering • Expert interviews • User journey map	• Inspiring design mapping • Expert interviews • Questionnaires • Interviews	• Brainstorming • Group interviews • Co-creation • Ground-up coding	• Prototyping • Concept selection • Interviews • Value mapping • Ground-up coding	• Prototyping • Rapid testing & iteration • Interviews • Storyboard	• Concept validation • Feedbacks on the design features
Deliverable	• The product flow in the current system • The scenarios of return	• Design challenges • How Might We questions	• Insights on the design of return experience	• The best concept for development • Desired design features	• Redesign recommendations • Prototypes that integrates the desired design features	• Comprehensive guidelines for future design

Figure 5 Overview of design process

2.2. Methods

The research and design methods applied during the project are listed in Table 4.

2.2.1.Literature research

The aim of the literature research was to identify the product flow in the collection and remanufacturing system and to discover the drivers and barriers within it. The research process covered 25 pieces of literature in the relevant fields, focusing on identifying the necessary and potential stakeholders in the collection and remanufacturing cycle, their existing and required capabilities, and the motivations and triggers that could encourage their participation.

2.2.2.Reverse engineering

Reverse engineering was used in the redesign of the smart pillbox to gain a comprehensive understanding of its existing structure, functionality, and user interaction. This approach provided important insights into its adaptability to the circular lifecycle. In addition, reverse engineering allowed the successful elements of the original design to be retained while innovating where necessary, facilitating a balance between familiarity and improvement during the redesign process.

2.2.3.Expert interviews

Expert interviews, which provided deep insight and domain expertise, were valuable in the product analysis and redesign process. A professional from the anonymous pillbox manufacturer provided a wealth of information about the current systems, strategies and users. An expert from a design organisation shed light on the applied health games landscape and shared insights from the 'Nudgingthon', a series of co-creation sessions aimed at improving the circularity of healthcare devices across Europe. This provided valuable perspectives on incorporating nudging values to encourage user participation in the circular economy. The Business Development Officer from a company specialising in smart collection systems, provided insights into the current landscape of smart collection technology, which is essential for the pillbox's return and collection process. Overall, these expert interviews enriched the understanding of the pillbox and its broader context and highlighted meaningful directions for innovation and improvement.

Method	***Stages***	***Research Aim***	***Output***
Literature research	Preliminary Research	To identify the product flow in the collection and remanufacturing system and to discover the drivers and barriers within it.	Lists of drivers and barriers
Reverse Engineering	Product Analysis	To understand the function structure of the pillbox and the app and identify the opportunities.	Product disassembly Interface flowchart
Expert interview	Product Analysis User Research & Scenario Definition	To understand the system around the pillbox and how it flows in the system between hospital, user, and manufacturer. To find out about the collection strategies, and the implement of nudging strategies.	Flow model Nudging ideas
Journey mapping	Product Analysis Ideation	To systematically dissect and evaluate user interactions with the pillbox, shedding light on actions, decisions, and feelings at each stage.	Customer journey map
Stakeholder Analysis	Product Analysis	To understand the stakeholders within the context, especially the possible returner. To find out about what are their goals and abilities.	Goals & abilities Stakeholder map
Inspiring Design Mapping	User Research & Scenario Definition	To generate some brainstorming ideas to identify the variable that can be addressed with the nudging design for the user testing.	Nudging ideas Return process variants
Questionnaire & user interview	User Research & Scenario Definition	To ascertain and analyse the key variables that exert a positive influence on fostering return intentions.	Design challenge Return scenarios
Co-creation	Ideation	To derive evaluations and propositions from user interactions, influenced by their individual capabilities and experiences, in order to uncover user preferences and innovative ideas for the return process.	Design insights on improving user's ability of return.
Concept selection	Evaluation & Iteration	To facilitate the selection of design concepts and gather feedback for further enhancement.	The selected design concept for development. Design insights on improving user's ability of return.
Concept validation	Detailed Design	To validate the effectiveness of the design features in increasing the ability of users to participate in the return and to evaluate how well the design achieves each design objective.	Summary and recommendations for future implementation

Table 4 Design methods involved in this project.

2.2.4.Journey mapping

Journey mapping serves as a powerful tool during the product analysis phase, meticulously dissecting and evaluating the totality of user interactions with the pillbox. This method systematically defines the stages of a user's journey with the product, creating a coherent roadmap of the user experience. It helps to gain insight into the user's actions, the decisions they make and, crucially, the feelings they experience at each stage of the journey. Such a comprehensive view not only illuminates the direct touchpoints, but also highlights potential areas for nudging opportunities, ensuring that design decisions are firmly rooted in the user's experience and needs.

2.2.5.Stakeholder analysis

Stakeholder analysis was an integral part of the product analysis phase and aimed to provide a thorough understanding of the various entities involved in the context, in particular the potential returners of the pillbox. This method is central to identifying and assessing the importance of key individuals, groups or institutions that can significantly influence the outcome of the project. Specifically, the analysis was tailored to elucidate the objectives and abilities of each stakeholder in relation to the product lifecycle. The culmination of this assessment resulted in two primary outputs: a delineation of the goals and capabilities for each stakeholder, and a comprehensive stakeholder map that visually represented the relationships and importance of each entity in the context of the product's lifecycle.

2.2.6.Inspiring design mapping

Inspiring Design Mapping, using the Design with Intent toolkit (Lockton et al., 2010), is a method that facilitates idea generation and mapping in the context of the pillbox's return process. Design with intent toolkits provides strategies to influence behaviour through design by considering the interplay between the user, the product and the environment. It stimulates brainstorming sessions and encourages innovation and diversity of ideas. As demonstrated in Figure 6, through the architectural, error-proofing, persuasive, visual, cognitive, and security lenses, it helped generate creative ideas for nudging the users and returners to return the pillbox along the product journey. The process also helps to identify key design elements that impact the return process, allowing for a more focused approach to the redesign of it. The combination of creativity and systematic analysis embedded in this method makes it a powerful tool for the redesign project.

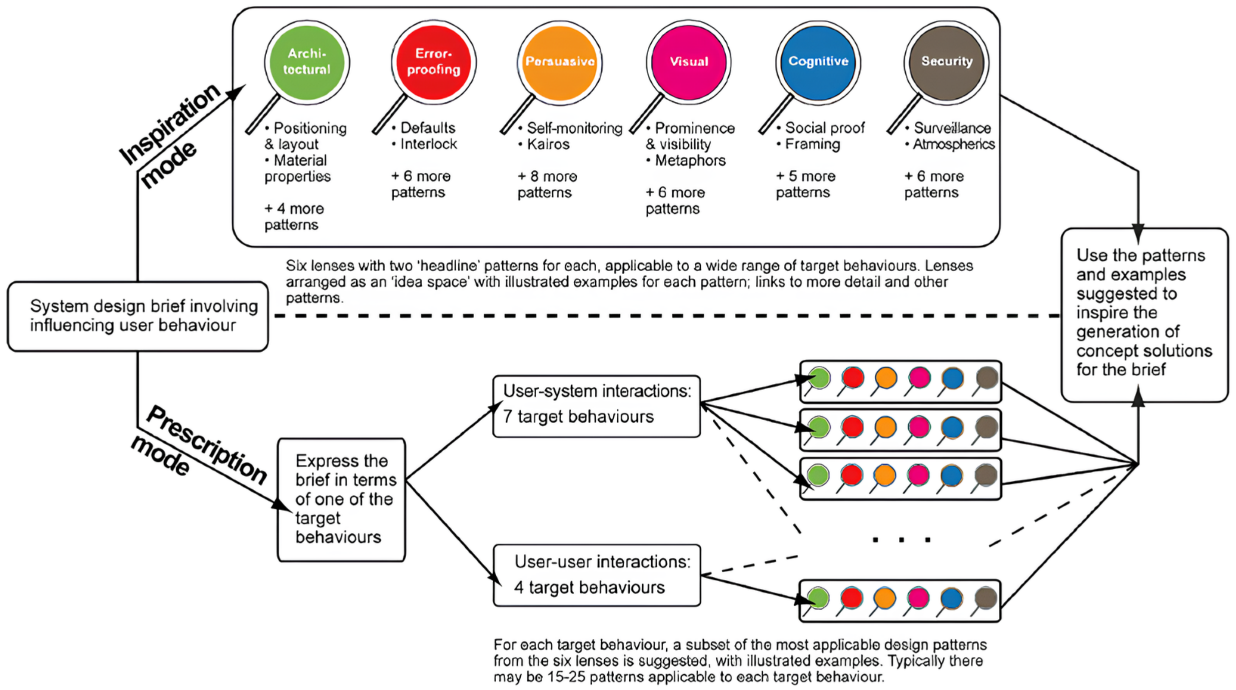


Figure 6 Design with Intent Tool

2.2.7.Questionnaire & user interview

Research questions:

- ***What are the key variables that negatively/ positively influence the fostering of return intentions?***

Participants

The age group and background information about return experience of the participants in this session are shown in Table 5.

Materials

- Return process variants differ based on six distinct variables.
- Questionnaires

Research setup

1. The process began with participants being introduced, the concept of mail-back, and smart collection methods.
2. Participants were then asked in the questionnaires about their previous return experiences. If they had any, they were asked a series of questions related to those experiences. If not, they were asked about the reasons why they had not initiated a return.
3. Next, participants were exposed to the existing pillbox return process and four alternative return processes that differed in six different aspects. These were compared in pairs to encourage participants to identify the factors they considered valuable in the return process.
4. Participants were then asked to select the top three factors out of ten that they considered most valuable in the return process.
5. Finally, the researchers offered participants the opportunity to participate in voluntary one-on-one interviews, which provided a deeper insight into their individual perspectives.

Number of participants	*Age group*			*Experience in return/recycling electronic devices*	
	18-24	25-34	35+	Yes	No
24	10	11	3	16	9

Table 5 Participants for questionnaires and interview.

2.2.8.Co-Creation Session

Research questions:

- ***How do users' perceptions of the difficulty of returning the smart pillbox at EoL vary across different return channels?***
- ***What information delivery strategies are most effective in improving user understanding and learning of the return process?***
- ***What are the preferred approaches to address the need for privacy and security?***
- ***What additional elements or methods could potentially enhance the promotion of the EoL return of the smart pillbox?***

Participants

Table 6 shows information about the participants in this co-creation session. Their background in design and as users of the smart pillbox was very helpful in this session.

Materials

- A smart pillbox
- A solution matrix includes six design ideas in two return channels (sketches)

Participants ID	*Specialty*
1	Smart pillbox user
2	Smart pillbox user / UX designer
3	Service designer
4	Service designer
5	UX designer
6	Product designer
7	Product Designer (Medical products)

Table 6 Participants for co-creation session.

Research setup

1. ***Free Exploration:*** Initially, participants were accorded the freedom to familiarize themselves with the product and its inherent features, fostering an understanding of the product in an unstructured environment.
2. ***Introduction:*** Following this, an overview of the product's context was articulated, alongside a detailed description of the scenario under investigation.
3. ***Preliminary Concepts:*** Participants were presented with six different initial concepts from the two design directions, each of which could correspond to both mail-back and collection point recall, and their feedback was actively sought. The aim of this interaction was to measure the different design elements, compare the two return methods and identify potential areas for improvement. Another aim was to inspire the participants and make them more open-minded about their needs.
4. ***Requirements Generation:*** Participants were divided into two groups, tasked with deliberating and outlining their prerequisites for the return process. This exercise aimed to generate a comprehensive set of user-defined requirements.
5. ***Brainstorming and Design:*** Each group embarked on a rapid brainstorming and design session, considering the requirements specified by the opposing group. This cross-referencing of requirements aimed to broaden the scope of idea generation and design.
6. ***Presentation:*** In the final stage, each group unveiled their ideas, providing and receiving feedback. This interactive segment fostered dialogue between participants, facilitating a deeper understanding of the presented ideas, and promoting a collective refining of the concepts.

2.2.9. Concept selection

Research questions

- ***Which design concept most effectively enhances user comprehension of its return process?***
- ***What specific design elements contribute to increased user engagement with its return process?***
- ***How does each design concept align with the needs and capabilities of different user groups?***

Participants

Two different groups were recruited for concept selection: a senior group (Table 7) and a junior group (Table 8). The senior group was selected using convenience sampling, prioritising individuals with long-term medication experience due to chronic conditions. Some also had expertise in related fields. The junior group was recruited mainly through voluntary participation. All participants were given detailed information about the study and signed an informed consent form before participating.

Materials

- Physical prototypes of 4 design concepts
- Questionnaires

Research setup

1. ***Introduction:*** This stage presented an overview of the project's context, elaborating on the functionality of the pillbox, its utilization in daily living, and the acquisition methods available to prospective users. The primary aim was to ground participants in the practical applications and real-world implications of the product.
2. ***Scenario Construction:*** Two distinct scenarios were formulated, each catering to a different age group. These scenarios were designed to reflect the varied needs and unique contexts of the respective age groups.
3. ***Design Exploration:*** In this phase, participants were encouraged to investigate four distinct design concepts. Following their individual exploration, an explanation of each design concept was provided. This allowed for a comparison of the participants' initial interpretations against the intended design concept.
4. ***Evaluation:*** Participants were prompted to evaluate each design concept using a rating scale of 1-7, based on their agreement with ten statements pertaining to product ability and potential usage difficulties. On this scale, 1 signified strong disagreement, whereas 7 indicated strong agreement. This evaluation aimed to capture their personal experiences and views towards the product.
5. ***Interview:*** Proceeding from the scores assigned to each statement, participants were asked to elaborate on the reasoning behind their ratings. They were queried about potential enhancements and asked how they might act if they found themselves in the proposed scenarios. This qualitative data aimed to add depth to the numerical evaluations and offer insights into participant thinking.
6. ***Value Proposition:*** In the final stage, participants were asked to prioritize eight values associated with ability requirements in the product return process. The objective was to ascertain what participants deemed crucial when deciding whether to follow return instructions. This value-ranking highlighted user priorities and shaped our understanding of their decision-making process.

Scenarios

Senior Group

You have been using this pillbox for several years to manage your medication, following your doctor's recommendation. This pillbox has served you well, providing reminders and helping you organize your medicines. However, as years passed, your needs have changed. A new medication management product has caught your eye, promising additional features that you find beneficial. You've decided to make the switch, leaving this pillbox redundant. Now, you are faced with the decision of what to do with your no-longer-needed device.

Junior Group

You're spending a weekend decluttering your house, and during this process, you stumble upon a smart pillbox. This electronic device isn't yours; it belonged to your parents or maybe your grandparents. They used it for years to help manage their medication schedules, but they've since moved on to a different system or maybe no longer require it. You don't know much about the pillbox itself or how it works. But now it's in your hands, and you're left with a decision to make. Now, you are faced with the decision of what to do with this idle device.

	Age	Gender	Long-term medication experience	Product return experience	Note
1	50-55	Female	No	Yes	
2	55-60	Female	Yes	Yes	
3	55-60	Female	Yes	No	*Physical Therapist*
4	55-60	Male	Yes	Yes	*Physical Therapist*
5	65-70	Male	Yes	No	*Retired*

Table 7 Participants for concept selection (Senior group)

	Age	Gender	Long-term medication experience	Product return experience
1	18-24	Female	No	Yes
2	18-24	Female	No	No
3	18-24	Male	No	Yes
4	18-24	Male	Yes	Yes
5	25-30	Male	No	Yes
6	25-30	Male	Yes	Yes

Table 8 Participants for concept selection (Junior group)

2.2.10.Concept Validation

Research questions

- ***How well does the design features in combination address each design challenge?***
- ***How do the proposed design features of this pillbox overall affect the user's perception of the difficulty of the return process in 2 different age groups?***

Participants

For the concept validation of the redesign features, two groups were again formed: a senior group (Table 9) and a junior group (Table 10), each consisting of 5 participants. The recruitment methodology mirrored the initial concept selection phase. The senior group was selected using convenience sampling, focusing on those with long-term medication experience and relevant expertise. The junior group relied primarily on voluntary participation. Notably, the majority of participants in the validation phase had also participated in the initial concept selection, ensuring consistency of feedback. All participants were fully informed of the objectives of the study and provided informed consent prior to participation.

Materials

- The current smart pillbox
- Functional prototype that integrates the proposed design features
- Questionnaires

Research setup

1. ***Introduction:*** Provide a detailed overview of the context of the project, highlighting the essential functions and unique features of the pillbox.
2. ***Understand design challenges:*** Introduce the participants to the four core aspects of the design challenge: returnability, user confidence, clarity of instructions and convenience in everyday life. Ensure that the participants understand these objectives as they will be an integral part of their evaluation.
3. ***Existing Experience Walkthrough:*** Present the current return experience to the participants and virtually walk them through the process. The procedure will vary depending on the participant's role as either a pillbox user or a returner.
4. ***Initial questionnaire:*** After the walkthrough, invite participants to complete a questionnaire that explores the four aspects of the design challenge.
5. ***Redesigned Experience Walkthrough:*** Present the proposed return experience of the redesigned pillbox. Conduct a virtual step-by-step walkthrough, which will vary depending on whether the participant is a pillbox user or a returner.
6. ***Follow-up questionnaire:*** Ask participants to complete a second questionnaire reflecting their experience with the redesigned pillbox. This feedback will be compared with their initial impressions to assess the effectiveness of the redesign.
7. ***Interviews:*** Using the scores assigned to each statement in the questionnaires, conduct in-depth interviews with participants to understand the rationale and insights behind their ratings.

	Age	Gender	Long-term medication experience	Affinity with the postal system
1	50-55	Female	No	High
2	55-60	Female	Yes	High
3	55-60	Male	Yes	Low
4	55-60	Male	Yes	Low
5	65-70	Male	Yes	High

Table 9 Participants for concept validation (Senior group)

	Age	Gender	Long-term medication experience (Family member)	Affinity with the postal system
1	18-24	Female	Yes	High
2	18-24	Male	Yes	High
3	25-30	Female	Yes	High
4	25-30	Male	Yes	High
5	25-30	Male	Yes	High

Table 10 Participants for concept validation (Junior group)

Chapter 3

Product Analysis

This chapter provides a comprehensive exploration of the smart pillbox. It dissects key aspects such as the user journey, hardware assembly, and software functionality to provide a holistic understanding of the product. It also describes the current product flow within the system, involving the manufacturer, the hospital, and the user. The intricacies of this exchange illuminate the real-world functioning of the smart pillbox.

In addition to the product specifics, this chapter also provides an overview of the user demographics, articulating exactly who interacts with the smart pillbox. Beyond the user, other stakeholders, and their roles within the smart pillbox return process are considered, highlighting the multiplicity of actors involved in this circular lifecycle. In essence, this chapter provides a thorough understanding of the smart pillbox, its users, and other stakeholders, which forms the basis for the subsequent design and analysis.

3.1. Product Details

3.1.1.Customer Journey Map

Based on the interviews with the professionals from the anonymous smart pillbox manufacturer, and the users of smart pillboxes, the user journey of a smart pillbox can be depicted in a customer journey map (Figure 7). Patients typically become aware of the pillbox through a doctor's recommendation to improve medication management and adherence. After receiving it, they learn how to use it, including creating an account, setting alarms, and managing medication records. Once set up, users will receive an alarm from the pillbox and a notification from the app at the scheduled medication time. During this time, upon opening the pillbox, the user will notice LED lights corresponding to the compartments containing the medication to be taken. The number of lit LEDs indicates the number of pills to be taken. After taking or skipping their medication, users can respond to the notification in the mobile app and log their medication intake. The app generates a weekly medication adherence report that can be accessed by the user's caregivers and physicians. Regular meetings can be scheduled with their doctors to review and discuss this medication adherence data.

As described by the participants in the exploratory research, some users may stop using the pillbox over time for a variety of reasons , including improved health, changing medication needs, switching to a new medication management solution, or even patient mortality. These users may begin to disregard its alarms, either turning them off or simply ignoring them until the battery runs out. When users realise that they no longer want to keep the pillbox, they will need guidance on what to do with the unused pillboxes, which may come from their doctor or directly from the manufacturer. Finally, albeit in limited cases, users return the pillbox to the manufacturer by post. This process happens in the stages of Obsolescence and Divestment, where this project focused on.

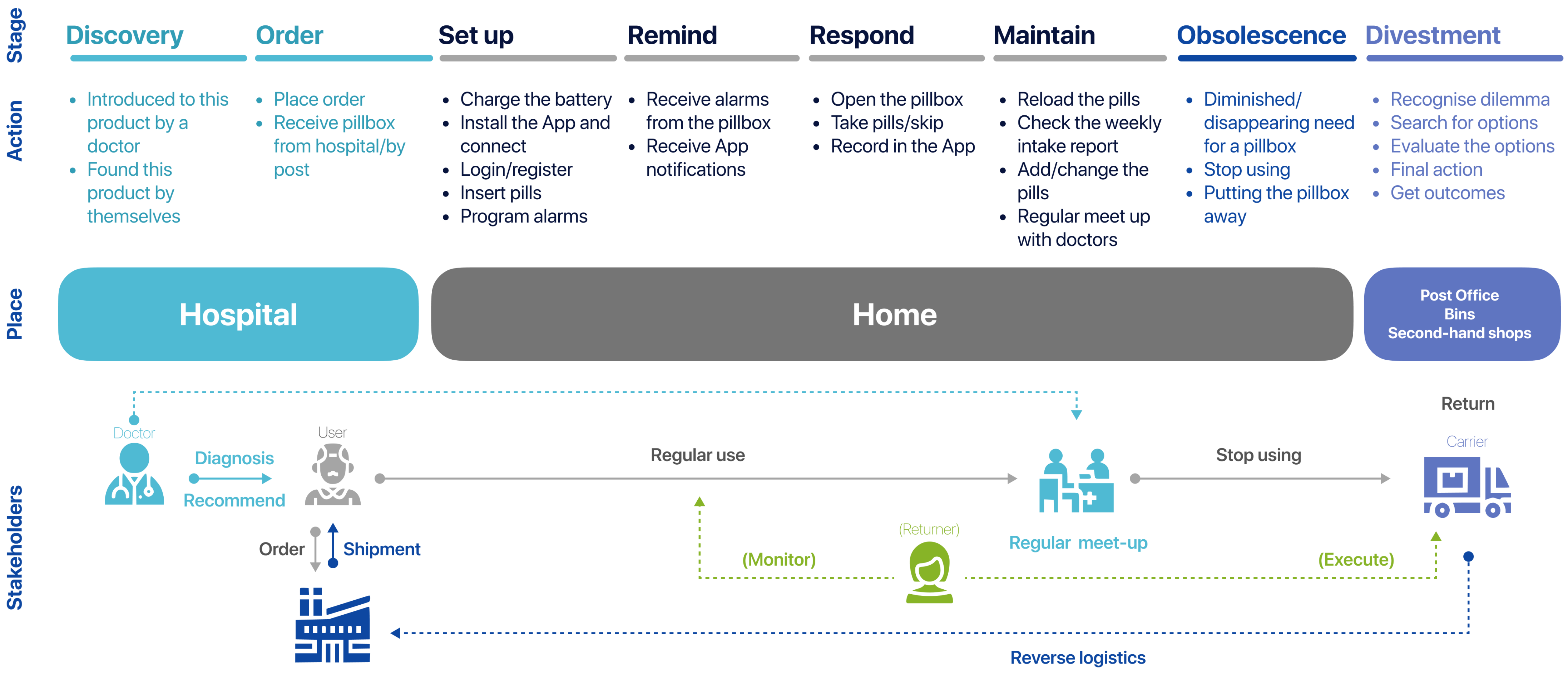


Figure 7 Current customer journey map of a smart pillbox.

3.1.2.Hardware

Throughout the lifecycle of a smart pillbox, different interventions can be applied to the hardware of the smart pillbox to extend its operational life or optimise its EoL impact. Each of these interventions varies in intensity and scope, targeting different components of the pillbox:

Repair

- ***Plastic housing:*** Minor cracks or damage to the housing are sealed or patched without replacing the entire structure.
- ***Core Components:*** Problems such as loose connections or minor faults in the circuit board are repaired. Faulty batteries may be reconnected or reset if not significantly degraded.

Refurbish

- ***Plastic housing:*** Thoroughly cleaned to remove any stains or residue. Scratches may be polished to restore the original appearance.
- ***Core Components:*** The battery will be checked for health and, if still functional, fully charged.

Remanufacturing

- ***Plastic housing:*** Depending on wear and tear, the housing can be completely replaced with a new or recycled plastic mould to ensure structural integrity.
- ***Core Components:*** Severely degraded batteries are replaced. The PCB can be comprehensively upgraded, replacing obsolete parts and updating software to the latest versions.

Recycling

- ***Plastic housings:*** The plastic is broken down into its basic material, which can be processed and reused to make new products or housings.
- ***Core Components:*** Batteries are dismantled, and reusable materials are extracted for new production. The PCB is dismantled and valuable metals such as gold, silver and copper are extracted for reuse.

The hardware of the pillbox can be divided into two main parts: the bottom tray and the top lid, which are connected by protruding latches and bearings on the tray and rail slots on the lid. Magnets in the two parts and a spring in the lid provide damping and limit positioning for the sliding opening and closing of the lid. The representation of a disassembly of a smart pillbox is shown in Figure 8.

The lid acts as a housing for the main functional components, which are divided into two sections and connected by snap fingers. Inside, the loudspeaker is connected to the PCB via contact points, while the lithium battery supplies power to the PCB via a connector. The PCB contains a series of LED lights, a touch sensor, a Hall sensor to detect opening and closing, a Bluetooth module and a Micro-USB charging port. These components provide the basic functionality of the smart pillbox, which includes sending alarms, displaying medication position and quantity, detecting the opening and closing of the pillbox to assess medication intake, and synchronising with the app.

The ease of assembly makes this pillbox suitable for repair, refurbishment, and remanufacturing . All electronic components, including the PCB, lithium battery and speaker, are housed in the lid. These components have relatively high remanufacturing values and environmental impacts, making the lid the primary target for collection and remanufacturing . Even if the plastic parts are damaged during reverse logistics, they can be recycled back into plastic material and used to make plastic components. Damage to the surface of these pillboxes will not have a significant impact on the remanufacturing value if the core components are not damaged. All electronics are secured to the case by the structure, with the PCB taped securely in place and flush with the top cover. This tape is easily removable and replaceable. Plastic components are joined together with snap-fit fasteners. This screwless assembly allows the pillbox to be disassembled quickly and easily without damage, greatly facilitating subsequent refurbishment or remanufacturing, and simplifying maintenance and repair.

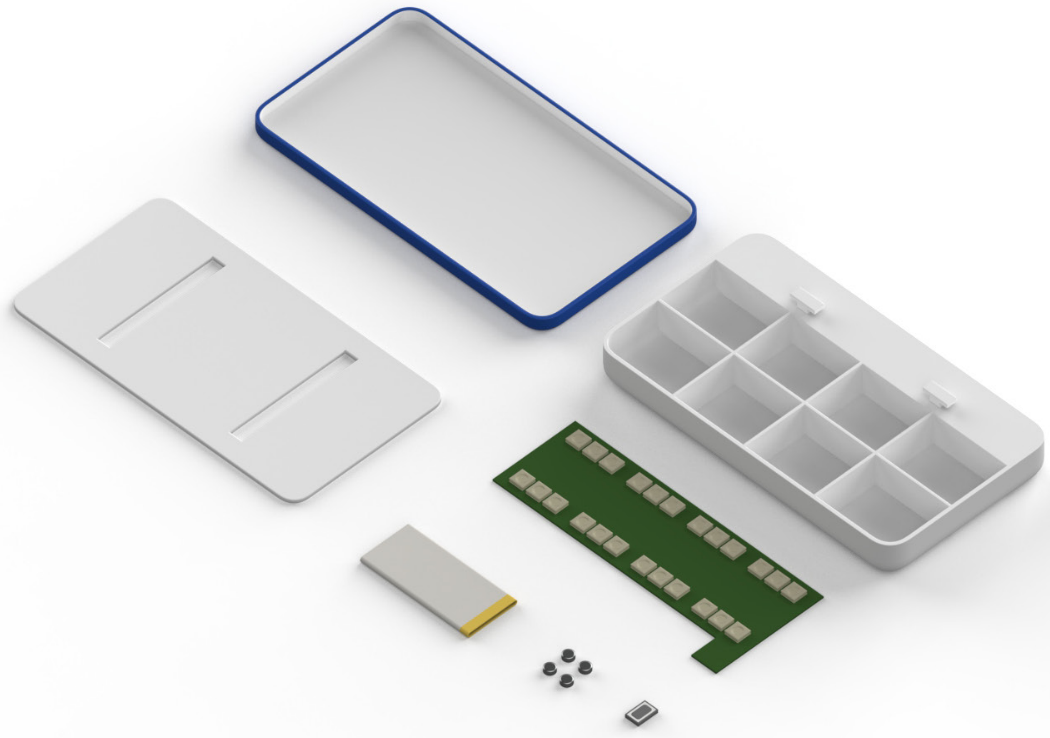


Figure 8 A representation of a disassembly of a smart pillbox

3.1.3.Software

The accompanying app serves as a critical element of the product ecosystem, providing a platform for programming alarms, logging medication intake and synchronising data with the pillbox to generate comprehensive medication statistics. This enables users, caregivers, and healthcare professionals to effectively monitor medication adherence. In addition, the application enables richer interaction and information sharing between the user and the pillbox, paving the way for advanced user engagement. The capabilities of the app also extend to the potential for implementing nudging strategies, providing a wealth of opportunities for effective communication of return information.

At the same time, however, some users stated that they no longer opened the app or their medication settings were complete. Th ignored the app's notifications and loggi feature while using it. In addition, some use apps failed to send notifications due to t user's system notification settings. The situations illustrate the risks and drawbacks relying on the app to communicate return a collection information.

3.2. Flow Model

Based on the information gathered from the expert interview with the professional from the anonymous pillbox manufacturer, the product flow between "hospital - patient - manufacturer" is modelled as Figure 9.

Under the current system, manufacturers work with hospitals to enable doctors to prescribe the smart pillbox to patients. Once prescribed, patients purchase the device online, which is then delivered by mail. To track patient adherence, manufacturers provide hospitals with back-end access to pillbox's system, including comprehensive data monitoring capabilities.

Conventionally, hospitals do not require the return of these pillboxes after use. However, some hospitals have implemented a deposit-based system that requires patients to return the pillboxes to reclaim their deposits. In such scenarios, patients are instructed by the hospitals to send the used pillboxes directly to the manufacturer's address to avoid duplicate shipping. After refurbishment, these pillboxes are either returned to the hospitals or donated to the patients who need them but cannot afford the cost of purchasing new ones.

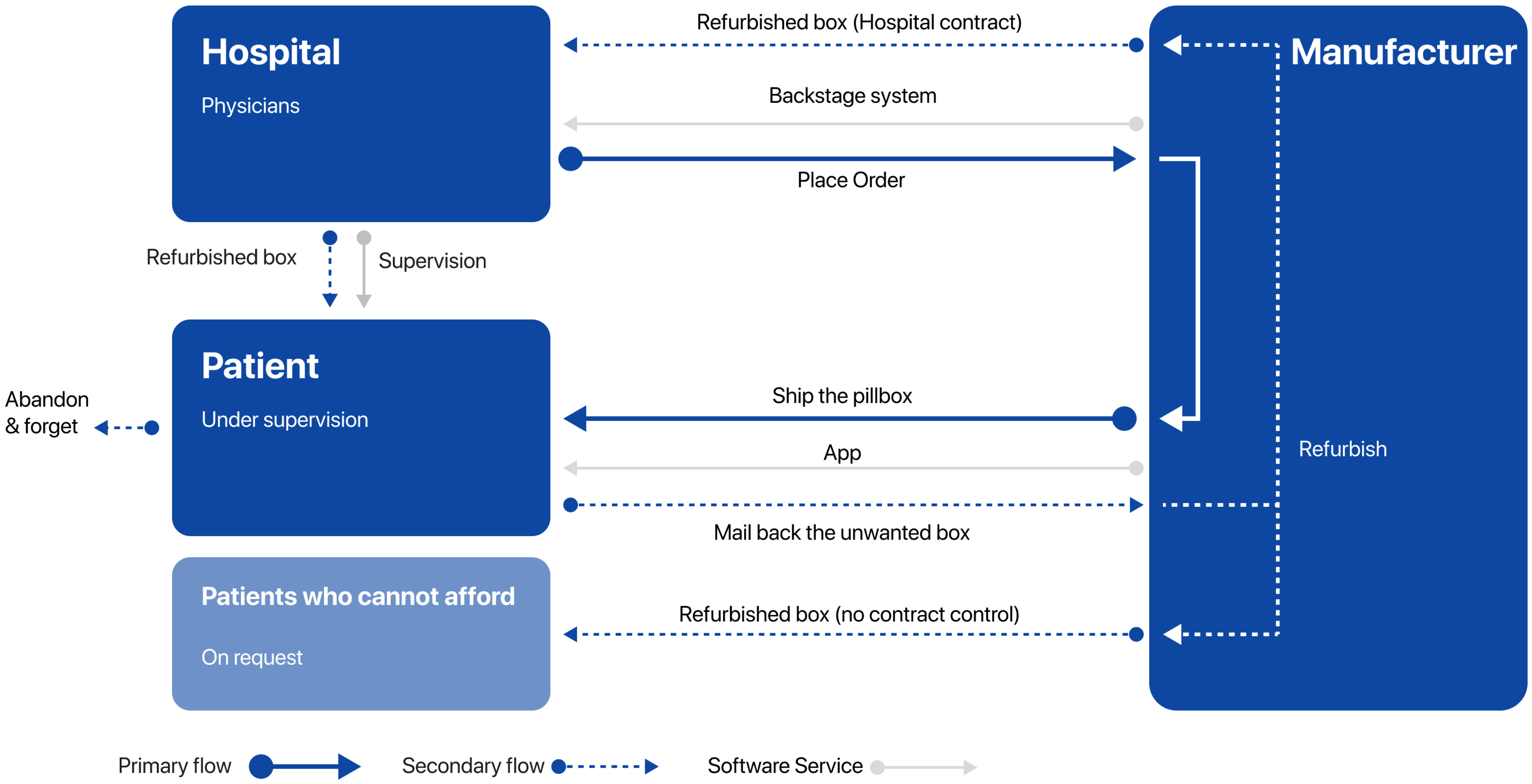


Figure 9 Current product flow of a smart pillbox

3.3. User Profile

3.3.1.Main User

The demographics of the users are based on information provided by the manufacturer through expert interview. The core demographic of users is between the ages of 50 and 70. These individuals primarily use this pillbox as a tool to manage long-term medication regimens, with most of users managing four or more medications through the system. Use of this smart pillbox covers a wide range of common chronic conditions, with users commonly managing medications such as levothyroxine for hypothyroidism, lisinopril for hypertension, metformin for type 2 diabetes and atorvastatin for hypercholesterolaemia and hyperlipidaemia. These conditions are chronic and typically incurable at the current state of medical technology, implying an ongoing need for medication management. This ongoing need for the pillbox presents an inherent challenge to the circular lifecycle model. Under normal circumstances, users are less likely to discontinue use, reducing the number of returns, in which case return scenarios may include the pillbox becoming obsolete for a particular user due to functionality issues, or extreme health deterioration, including the user's death. In these cases, where users may not be able to manage the return process, a designated returner becomes essential.

Interestingly, some pillboxes provide an option to subscribe premium services that allow family members or caregivers to monitor medication use. This feature not only reinforces medication adherence, but also represents a potential channel for implementing return and collection strategies by involving these additional facilitators in the process. For example, each user may register one family member or caregiver as a “emergency contact”, and they will get notified and reminded to help return the device when the user stops using it.

3.3.2.Returner

A 'Returner' in the context of the pillbox’s lifecycle refers to a person who is responsible for facilitating the return process when the user can no longer use or needs the device. The primary role of the returner is to facilitate the return of the device when it is no longer in use. This includes understanding the return process, packing the device appropriately and returning it to the manufacturer or designated collection point. This critical role helps to keep the pillboxes out of the general waste stream, contributing to its circular lifecycle.

Given the demographics of users and the circumstances surrounding the potential discontinuation of the pillbox, returners are often family members or caregivers, who were initially involved in the user's medication management process. The premium service in the App allows for third party monitoring, highlighting the likely involvement of these individuals as returners.

The ability of returners is largely determined by their proximity to and relationship with the user, as well as their understanding of the device and its lifecycle. It's important to note that while family members and carers are likely to be returners, healthcare professionals or even institutional settings such as nursing homes could also take on this role, especially if they are managing medication for a large number of patients using this smart pillbox.

Possible Returners

Family Members

Family members often have a personal relationship with the pillbox user and are privy to her health routines and the importance of the pillbox in her life. Their involvement in the return process can be crucial.

Goals:

- To protect the privacy of the user.
- Provide peace of mind regarding medication management.
- Minimise waste through proper return or disposal.
- Make a positive contribution to the healthcare ecosystem.

Ability:

- Intimate understanding of the user's medication routine and device operation.
- Long-term, frequent access to the user's home and pillbox.
- Potential to return pillboxes after extended periods of non-use.

Caregivers

Caregivers, including healthcare professionals and personal assistants, play an active role in managing the user's healthcare routines and related devices, including the smart pillbox.

Goals:

- Ensure seamless continuity of care.
- Protect patient privacy.
- Commit to a sustainable healthcare model.

Ability:

- Comprehensive understanding of the user's healthcare needs and the pillbox system.
- Ability to manage the return process efficiently.
- Quickly identify when the device is idle and initiate timely returns.
- Increased access and visibility to information and channels related to returns or collection due to their position in the healthcare sector.

3.3.3.Stakeholders

In addition to family members and caregivers, who are already identified as potential returners, there exist other significant stakeholders within the reverse logistics of the pillbox's return. These include retailers, hospitals, and logistic carriers, each possessing unique roles and capabilities that facilitate the product's return process, as is displayed in Figure 10.

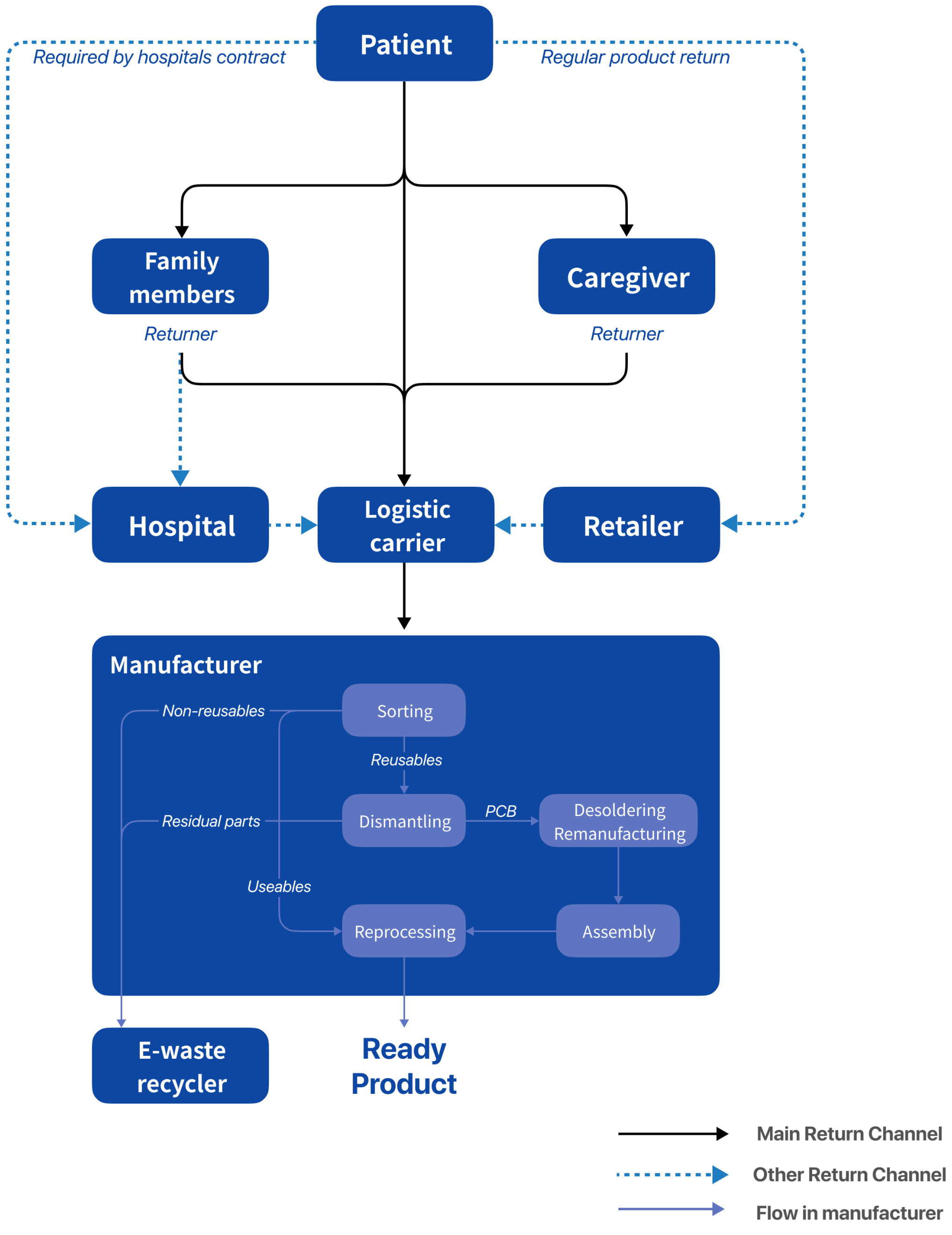


Figure 10 Stakeholder map of the potential reverse logistics for a pillbox.

Hospital

Hospitals are key touchpoints in patient care and play a central role in medication management. They are essential in guiding the patient's journey with the pillbox, especially as the lifecycle of the pillbox culminates.

Goals:
- Ensure a smooth transition for patients as they conclude their need for the pillbox.
- Maintain best medication management practices.
- Prioritize patient health and safety.
- Encourage patients to return the device post-use.

Ability:
- Direct, continuous contact with patients.
- Robust healthcare infrastructure.
- In-depth understanding of patient needs.
- Leverage high patient traffic for returns.
- Possess disinfection procedures suitable for returned devices.

Retailers

Retailers are the primary point of sale and return for many consumer goods. Their established infrastructure and customer-centric approach make them key players in the product return ecosystem.

Goals:
- Focus on ensuring customer satisfaction.
- Achieve commercial objectives.
- Support the return of end-of-life pillboxes, enhancing circular economy efforts.

Ability:
- Established infrastructure for product returns.
- Provide an accessible and familiar return avenue for consumers.

Logistics Carriers

Logistics companies play a key role in the transport of products. Their extensive infrastructure and expertise in handling goods make them an integral part of the take-back and refurbishment process.

Goals:
- Guarantee efficient, prompt, and sustainable transport of end-of-life devices.
- Facilitate transfers from collection points to appropriate refurbishment units.

Ability:
- Strong connections with various stakeholders.
- Comprehensive logistics infrastructure and material handling skills.
- Established information systems suited for reverse logistics.

E-waste recycler

E-waste recyclers specialize in the safe and efficient disposal or recycling of electronic waste, ensuring environmental safety and compliance with the set regulations.

Goals:
- Manage and process e-waste sustainably and economically.
- Prioritize environmentally friendly disposal or recycling methods for non-reusable pillboxes.

Ability:
- Expertise in waste management and recycling processes.
- Ensure reduced environmental impact and adherence to relevant legislation.

3.4. Conclusion

Following a thorough analysis of the smart pillbox and its associated systems, its potential for transitioning to a circular lifecycle becomes clear. The design enables easy and rapid disassembly, laying the foundation for streamlined refurbishment and remanufacturing processes. Additionally, the incorporation of a specialised app provides an effective means of communicating return information, suggesting a subtle communication strategy that may be under-utilised.

By collaborating with hospital physicians, consistent patient monitoring is ensured, aligning the product's lifecycle with the changing health conditions and needs of its users. Frequent consultations help maintain this alignment, ensuring the device is both relevant and beneficial throughout its usage period.

An interesting aspect to consider is the role of different individuals involved in the return and collection process. Apart from the direct users, the health-focused nature of this pillbox indicates that family members, partners, or caregivers, collectively referred to as 'returners', may often supervise the return process. These returners, in conjunction with other stakeholders, play a crucial role in maximizing the EoL return process.

However, there are still challenges despite these features. There is a mail-back system for unused pillboxes in place, but it is not adequately promoted as a primary return strategy. This inadequacy results in disappointingly low return rates. The lack of clearly defined guidance on product returns or trustworthy return channels, or both, could be the cause of low return rates. In the future, it could be pivotal to differentiate design scenarios to cater to both users and returners. It is crucial to address these concerns to enhance the return rate and ensure the successful transition of the smart pillbox into a truly circular lifecycle.

Chapter 4

Design Brief

This chapter delineates the challenges and objectives of this project, transitioning healthcare products, exemplified by the smart pillbox, towards a circular lifecycle model. The chapter sheds light on how primary users and returners interact with the product by presenting detailed scenarios that highlight their unique needs and challenges. Moreover, it outlines specific design objectives that aim to enhance user abilities and establish trusted return channels, all converging towards the overarching goal of improving the EoL return for this product.

4.1. Summary of Problem

While the healthcare industry provides invaluable services, it is also a considerable contributor to environmental pollution and waste generation. One potential way to mitigate this problem is to move towards a circular lifecycle model, where products are reused, redistributed, refurbished, remanufactured, and ultimately recycled, rather than simply discarded at the end of their lifecycle. However, for such a model to be effectively implemented, it first requires the collection or return of used products by consumers.

The case of a smart pillbox serves as an illustrative example of the challenges associated with implementing such a model. Although the company has established a return pathway allowing users to mail back those unused pillboxes, it is still not the primary strategy, and the return rate is relatively low.

A number of factors have contributed to this poor return rate. In particular, users show a reduced intention to return the pillboxes due to a lack of ability to participate in the collection process. This could be due to a lack of information or guidance on how to return products, or a lack of trusted return channels. In addition, the return behaviour required by the existing system does not fit in with their daily routines or planned routes, adding a layer of inconvenience.

4.1.1.Design Challenge

Based on the findings from background research and product analysis, the design challenge was concluded:

How to redesign the smart pillbox and the system around it in a way that increases its return rate, thus bridging the gap between the current state and the desired circular lifecycle?

This requires a thoughtful reconsideration of the product's design and return channels to better align with users' abilities, routines and levels of trust.

4.2. Return Scenarios

In addressing the complexity of the product return flow, two distinct return scenarios were developed: one for users and one for returners. This split was considered essential due to the unique interactions, needs and motivations of each group. While users interact with the product on a daily basis and have specific user experiences, returners come into play primarily at the end of the product's life. By developing two separate scenarios, the design process can address the specific needs and challenges of both groups, ensuring a more holistic and effective approach to increasing the product's return rate.

4.2.1.Scenario 1: Pillbox User

The main user in this scenario is a typical pillbox user from the core demographic, aged between 50 and 70, managing multiple long-term medications for common chronic conditions. The user initially discovered it through a doctor's recommendation and purchased the device online and received it in the post. This user has thoroughly integrated the pillbox and the service into his/her daily routine, relying on the smart alarm feature for medication reminders and logging medication intake for regular adherence reports.

However, due to a change in health status, a switch to a new medication management solution, or perhaps because the product has become obsolete, the user has stopped using the pillbox. Although aware of the pillbox's persistent alarms, the user increasingly ignores them until the battery runs out. The user, now convinced of the decision to stop using it, needs to understand the return process. To achieve this, the user must seek guidance, possibly from their doctor or directly from the manufacturer, and follow the return instructions to send the unused pillbox back to the manufacturer, thus contributing to the circular life cycle of the device.

4.2.2.Scenario 2: Returner

This scenario represents the case of a returner, often a family member or carer, who has the opportunity to get involved in the medication process of a pillbox user. In this situation, the user has reached a stage where they can no longer use or need the device. This could be due to improved health, a change in medication regimen, the pillbox becoming functionally obsolete, or extreme deterioration in health. It is at this critical juncture that the returner needs to be involved.

Having been close to the user and possibly involved in managing the user's medication, the returner understands the functionality and importance of the pillbox in the user's life. Using this knowledge, the returner steps in to facilitate the return process. This involves understanding the return process, packaging the device appropriately and returning it to the manufacturer or a designated collection point. In this way, the returns agent plays a vital role in maintaining its circular life cycle, ensuring its removal from the general waste stream and facilitating its return to the product cycle.

4.3. Design Aims

The primary objective of this project is to develop effective solutions that address the current challenges associated with product returns, thereby facilitating the transition to a circular lifecycle model, particularly in the healthcare industry. This objective will be pursued through several design objectives:

Improve user abilities:

Using nudging strategies, the project aims to provide users and re-users with clear, timely and actionable information. This is expected to improve their ability to participate effectively in the product development process.

Establishing trusted return channels:

The project aims to create an intuitive and reliable return system that gives users confidence in the return process.

Minimise the cost of participation:

The design will aim to minimise the costs associated with user participation in the recycling process - time, energy, and money - to reduce barriers to product collection.

The potential for broader application:

While the immediate focus is on the smart pillbox, the project also envisages the possibility of extending the strategies and solutions developed to a wider range of medical products by providing a comprehensive guideline based on the insights gained during the research and design process.

These specific objectives are in line with the broader aim of promoting environmentally responsible behaviour and practices, ultimately facilitating a shift towards a more sustainable, circular economic model.

Chapter 5
Design Development

This chapter provides a detailed exploration of the iterative design process that led to the final conceptual redesign of the smart pillbox. It illustrates the iterative journey of ideation and refinement that took place over several design sprints. Throughout the design and development phase, four distinct testing/co-creation rounds were systematically conducted to inform and steer the design direction. Conceptual ideas were regularly assessed, evaluated, and refined based on the results of these tests and subsequent feedback. Such insights not only drove the iterative refinement of the redesign of the pillbox, but also contributed to the creation of a comprehensive guideline that could potentially shape future design initiatives within this product category.

Exploration
Preliminary Ideas
Co-creation Session

Design Concepts
Concept Selection

Redesign Recommendation
Design Guidelines

5.1. Exploration

Having established the core design objectives of the project, an exploratory test was planned to explore potential directions for redesign. As demonstrated in Figure 11, the Obsolescence and Divestment stages of the customer journey map were zoomed in to the task level and certain factors that potentially influence return intent and perceived difficulty in the process were identified. These identified factors promoted a round of brainstorming to generate ideas that could positively influence users' willingness to participate in the return process.

Using inspiring design mapping, introduced in Chapter 2.2.6., about the return process, some initial brainstorm ideas were generated. The ideas were mapped into the existing return prose and categorised according to the aspect of the return process they addressed. In the end, six main variables encompassing the return process were identified and targeted as the key issues to be investigated in this testing phase, including Instruction, Size & shape, Routine, Appearance & presentation, Data privacy, and Transparency. Ideas corresponding to each variable were then refined and combined to form distinct process variants. These were used to stimulate the test participants and to facilitate comparisons of the different levels of importance they attached to each variable.

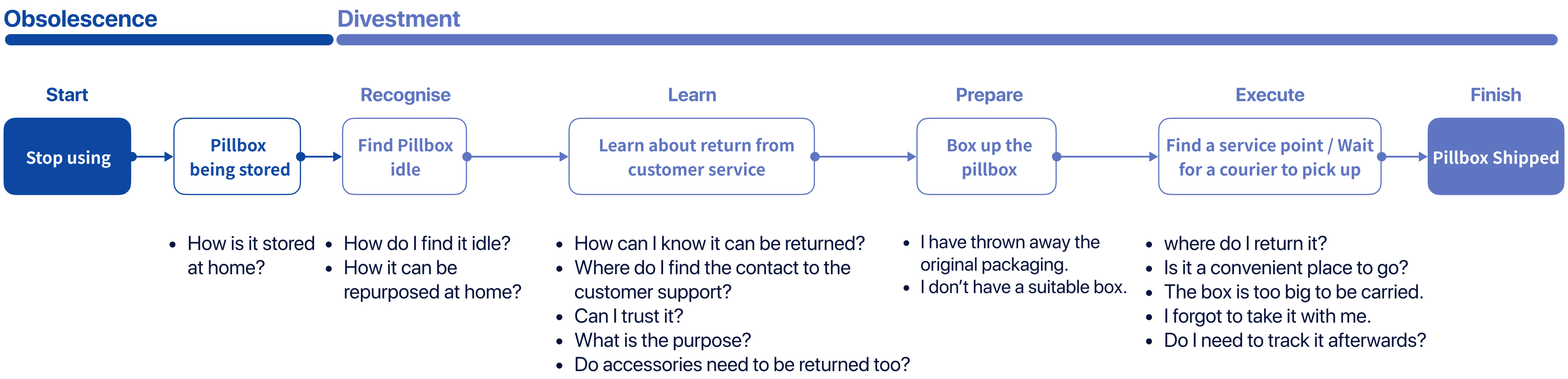


Figure 11 Possible influencing factors in the existing return process.

5.1.1.Exploratory user test

The objective of this research is to ascertain and analyse the main variables that exert a substantial and positive influence on fostering return intentions. As shown in Figure 12, the stimuli used in this test are 4 return process variants differ based on six distinct variables:

- *Instruction*
- *Size & shape*
- *Routine*
- *Appearance & presentation*
- *Data privacy*
- *Transparency*

This test consisted of two parts: questionnaires asking participants to reflect on and compare the different variables, and a subsequent conversational interview. Detailed information on the testing process can be found in Chapter 2.2.7. '***Questionnaire & user interview***'.

Results

Lack of relevant information:

The main barrier that prevented users from completing the return process, as revealed by the questionnaires and interviews, was a distinct lack of relevant information. Many participants, despite having a strong understanding of healthcare products and a genuine desire for sustainability, felt handicapped by the lack of essential guidance. This deficiency made it difficult for them to identify accurate return channels. Interestingly, even though they saw the return of the product as a social responsibility, their drive was stalled by this information gap. This is consistent with the importance attached to the instruction variable. There's also evidence that the perception of the product's identity can influence return decisions. When the pillbox was perceived as a health device, it was seen as more likely to be returned than when it was perceived as a daily necessity, highlighting the importance of clear product communication.

Concerns about privacy and trust:

Another significant barrier to returns was related to issues of privacy and trust. Given the sensitive nature of medical devices, participants demonstrated a higher need for security than with standard consumer electronics. This need for trust was underlined by their reluctance to use return channels that they perceived as untrustworthy. The underlying concern was about potential risks to subsequent users if the reliability of the return channel was uncertain. This sentiment is largely consistent with the importance of the 'transparency' variable, indicating an urgent need for transparency in the process.

Need for explicit & easy-to-follow instructions:

The feedback from the questionnaire showed that among the variables initiated by the return process, instructions were rarely mentioned. This may be due to the fact that the specific steps of the return process were made clear to the participants during the briefing, which may have reduced their perceived need for further instructions. Correspondingly, the relative importance of this is more strongly reflected in the interview results.

Return process not fitting into daily routines:

The questionnaires indicated that participants valued the integration of the return process into their routine. If a system does not fit effortlessly into a user's daily life, the likelihood of engagement is reduced. The interviewees expressed a clear preference for the location of the return pillboxes, with the preferred locations being those they frequented in their daily lives. This feedback illustrates the importance of making the returns process as seamless as possible for users so that it fits effortlessly into their daily activities.

Variant A

Size	20 x 10 x 3 cm
Instruction	***Printed on the back of the pillbox***
Presentation	*Example pillbox*
Privacy	***Reset button on the back together with instructions***
Routine	*Post Office/ Service points*
Transparency	*N/A*

Variant B

Size	***16 x 8 x 2.5 cm***
Instruction	*Contact customer support*
Presentation	*Example pillbox*
Privacy	*Reset button hidden on the side*
Routine	*Post Office/ Service points*
Transparency	***Visible future process, including how it will be refurbished and reused***

Variant C

Size	*20 x 10 x 3 cm*
Instruction	***Check the list of cooperative supermarkets/ pharmacies online***
Presentation	*Example pillbox*
Privacy	*Reset button hidden on the side*
Routine	***Collection points in supermarkets & pharmacies***
Transparency	*N/A*

Variant D

Size	*20 x 10 x 3 cm*
Instruction	*Contact customer support*
Presentation	***Stickers of CO2 footprint; Pattern indicating the direction of inserting it into collection box***
Privacy	*Reset button hidden on the side*
Routine	***Collection boxes with pillbox-shaped opening in Post Offices***
Transparency	*N/A*

Figure 12 Variants of the return process of a pillbox.

5.1.2.How Might We (HMW) questions

The results of the user tests highlight key areas for improvement to encourage returns. A closer look at the results reveals four HMW questions that need to be answered in order to promote a viable product return system. The HMW questions and their corresponding barrier and potential solutions are listed in Table 11.

Barrier	HMW Question	Potential Design Solution
Lack of relevant information	*How might we make users aware of the returnable property of the product?*	Provide clear communication about product's return potential.
Concerns about privacy and trust	*How might we build user trust in the returns process?*	Establish transparent and accountable return procedures.
Need for explicit and easy-to-follow instructions	*How might we provide intuitive instruction and aids to facilitate the return behaviour?*	Design a step-by-steWp guide or infographicW on the return process.
Return process not fitting into daily routine	*How might we make the return a convenient task that fits the users' everyday planning?*	Integrate return channels into daily life, like at local stores or post offices.

Table 11 HMW question and corresponding barriers

5.2. Preliminary ideas

In response to the HMW questions derived from the exploratory user test, several design directions were conceived. One direction is to embed information about the returns process into the natural interactions that users have with the pillbox. This approach aims to leverage touchpoints in the latter part of the product lifecycle where users are likely to engage with return information.

For example, return instructions can be strategically introduced when the user, no longer needing the pillbox, decides to clear out the pills or when they are considering disposing of the product. This just-in-time approach to providing information can help to facilitate seamless learning of the return process. It serves a dual purpose: not only does it educate users about the process, but it also demonstrates the product's identity as a circular, returnable healthcare product. This creates a subtle but persistent reminder of the pillbox's identity throughout the customer journey, encouraging users to make sustainable choices.

Another strategy is to embed cues within the product to stimulate curiosity and encourage users, especially returners, to discover the return information on their own. This approach can make users more proactive in learning about the return process and encourage them to follow the return instructions.

As an approach to address privacy concerns, a more accessible reset button or feature could be incorporated into the design to allow users to erase their data, thereby increasing their sense of privacy.

For integrating the return process into the user's daily routine, the creation of dense collection points was considered. These collection points, ideally located in common places such as supermarkets and pharmacies, could potentially meet users' needs for convenient access. As a result, smart collection machines could be a viable solution. From a logistics perspective, post offices and service points represent additional locations for returning pillboxes, where users could post the item back instead of using smart collection machines.

To summarize these design directions, six preliminary design ideas were generated from these directions. These ideas can be organised into a matrix based on how they disseminate return information (X-axis) and how they address privacy issues (Y-axis). Each idea could be adapted to either the smart collection strategy or the postal return method. The matrix and the explanation of the preliminary ideas are illustrated in Figure 13.

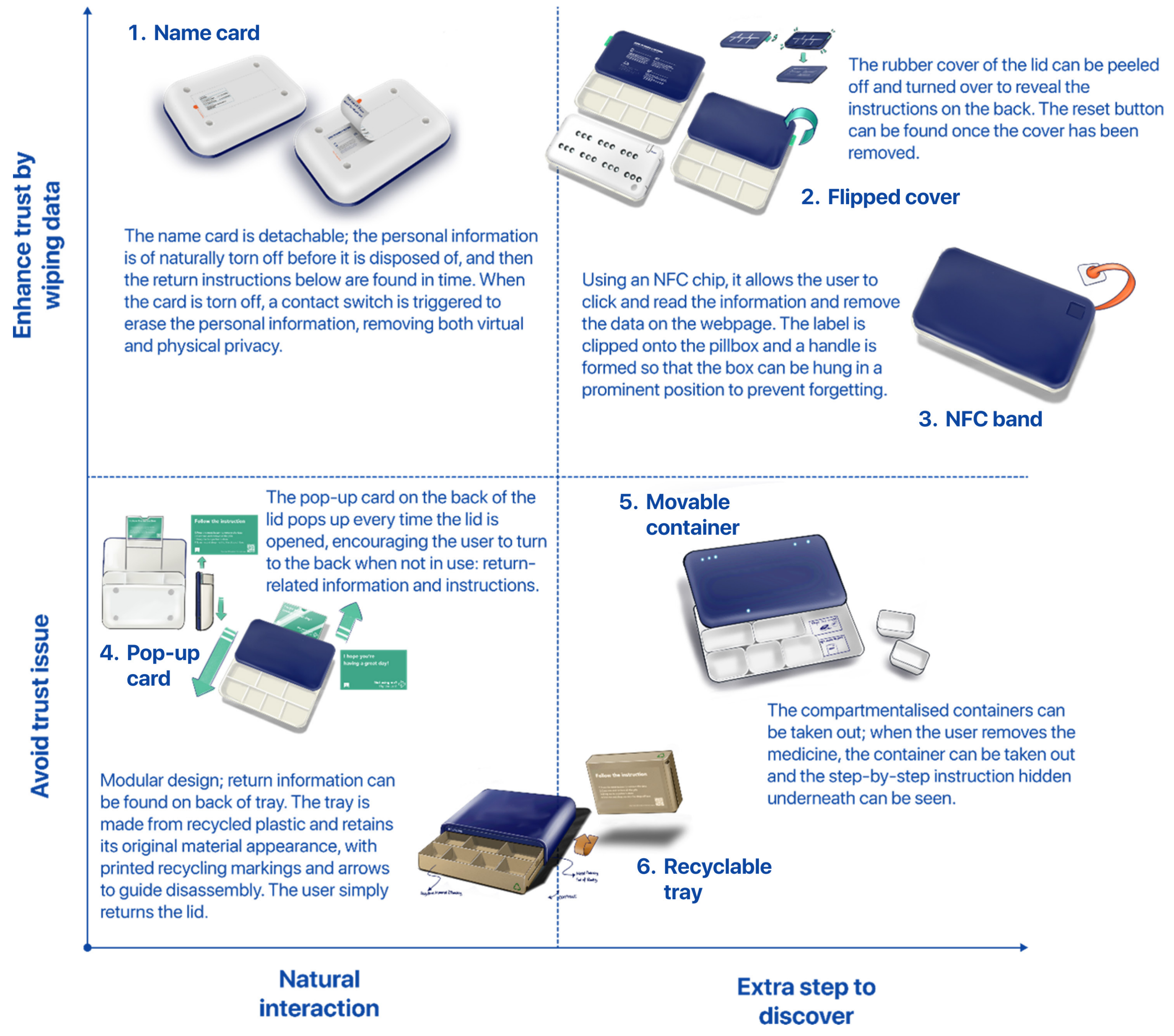


Figure 13 Solution matrix of preliminary ideas.

5.3. Co-creation Session

The primary objective of this session was to engage participants with a variety of preliminary design ideas with the specific aim of enhancing the return experience of the smart pillbox. Evaluations and propositions derived from user interactions, influenced by their individual capabilities and experiences, were employed to uncover user preferences and innovative ideas for the return process of the pillbox. Having involved its users, design experts, and experts with knowledge in healthcare industry, this session provides insights from their perspective and valuable feedback on the design.

The setup and the procedure of this co-creation session can be found in Chapter 2.2.8. "*Co-Creation Session*". The research questions to be answered in this session were:

1 *How do users' perceptions of the difficulty of returning the smart pillbox at EoL vary across different return channels?*

2 *What information communication strategies are most effective in improving user understanding and learning of the return process?*

3 *What are the preferred approaches to address the need for privacy and security?*

4 *What additional elements or methods could potentially enhance the promotion of the EoL return of the smart pillbox?*

5.3.1.Findings

How do users' perceptions of the difficulty of returning the smart pillbox at EoL vary across different return channels?

While the postal return approach is perceived as more laborious than smart collection points, it is easier for users to understand and accept. This can be attributed to its alignment with traditional perceptions of product returns. Despite the additional effort required, familiarity with the postal return process might make it seem less daunting.

In addition, integrating collection points into everyday locations such as supermarkets and pharmacies presents a unique challenge. While these locations offer convenience, it is difficult to guarantee that every potential location will be able to accommodate the return process. This uncertainty could undermine users' confidence in the success of their return efforts at such locations.

In comparison, postal service points offer a more reliable option. These points are usually easy to locate based on the user's location, making them accessible and trustworthy return locations. This convenience, combined with the trusted nature of postal services, can reduce the perceived difficulty, and encourage user participation in the product return process.

What information communication strategies are most effective in improving user understanding and learning of the return process?

The results showed that simplicity and straightforwardness were paramount in the communication of return information. Strategies such as incorporating cues into the product design were seen as intriguing and interesting. However, it was noted that such cues do not necessarily match the inherent nature of the product and could potentially be triggered or damaged during use. Whilst innovative strategies may stimulate user interest, they need to be balanced with the functionality of the product.

What are the preferred approaches to address the need for privacy and security?

In addressing privacy concerns, user perspectives may be context dependent. The study found that users may not perceive the data stored in the pillbox as significantly private or personal. They likened it to an alarm set in an alarm clock - a seemingly trivial piece of information.

Interestingly, when presented with an option or feature to delete data, users began to take data privacy more seriously and this influenced their intention to return. The presence of such a feature made them think about the potential privacy implications. This suggests a delicate balance in how design features can prompt reconsideration of privacy concerns, which may inadvertently cause users to overthink the issue.

What additional elements or methods could potentially enhance the promotion of the EoL return of the smart pillbox?

From the user insights, several methods and elements emerged that could potentially enhance the return promotion of the smart pillbox. One critical element identified is timely reminders, not only of the return process itself, but also of the existence of the pillbox. This will prevent the device from being neglected or forgotten at home once it has fulfilled its primary purpose.

In addition, participants suggested the use of compelling visuals or slogans to emphasise the benefits and value of the return process. By highlighting the positive environmental impact and the user's contribution to societal wellbeing, these communication strategies could promote greater awareness and contextual understanding of the return process.

5.3.2. Design insights

1. The design should primarily address the ***postal return scenario*** in the initial stages, as it's perceived to be easier for users to understand and more in line with their perception of product return. As the infrastructure for smart collection strategies develops and becomes more widespread, the design could then be adapted to accommodate these return methods.

2. The ***communication of return information*** needs to be simplified and naturally integrated into the user's interactions with the pillbox. This could include activities such as opening and closing the pillbox, removing pills, and resetting alarms. This simplification aims to make the return information less intrusive and more organically part of the user's experience.

3. The ***value proposition of returning*** the pillbox should be clearly communicated to users. This includes not only the practical aspects of the return process, but also the environmental and societal benefits. However, the focus should remain on the non-monetary value, as the monetary incentive may distort the user's decision-making process and make it more difficult to assess the ability aspect.

4. ***Constant reminders*** need to be integrated into the design to encourage the user to complete the return process and avoid forgetting. This should minimise the likelihood of the pillbox being left unused at home and encourage a seamless return once the user has decided to stop using it.

5.4. Design Concepts

Four preliminary design concept were developed to explore the design that has the potential to improve the return.

5.4.1.Concept A: Integrated return envelope

Figure 14 Prototype of concept A

Keywords: Return envelope; Return instruction manual.

Developed from: 4. Pop-up card; 5. Movable container

The design concept shown in Figure 14, derived from the idea of minimising the work involved in returning pills to the post office, incorporates a pre-paid envelope that is stored underneath the moveable transparent containers within the tray. When the small container is lifted to remove the pills, the user will find this envelope. Designed to resemble gift wrap, the envelope contains a prepaid stamp with a barcode that can be scanned by postal staff.

On the back of the envelope are step-by-step return instructions and a catchy slogan: "Gift the Planet-Return for a Circular Tomorrow". This communication prepares the user or returner for the context of the return and provides clear guidance on the steps involved. The user simply places the pillbox in the envelope, seals it and takes it to any service point of the cooperating postal carrier.

At the postal facility, the barcode on the envelope is scanned to register the shipment in the system. The prepaid nature of the envelope eliminates any return costs, further encouraging users to participate in this circular practice.

5.4.2.Concept B: Photo charm and folded return manual

Figure 15 Prototype of concept B

Keywords: Postal label with barcode; Return instruction manual.

Developed from: 1. Name card; 4. Pop-up card

The concept shown in Figure 15 aims to increase the user's understanding of the context of the return and to simplify the return process through the use of a pre-paid return label. Interestingly, the design uses a small detachable lid on the back of the pillbox to pique the user's curiosity and encourage further exploration. This lid, which resembles a photo pendant, contains a folded manual with comprehensive step-by-step instructions on the return process.

The manual clearly explains the reasons for returning the pillbox and how to do so, while reassuring the user of the privacy and security of their data. When the lid is removed, the user discovers the return label, which, when placed on the surface of the pillbox, serves as a constant reminder that the device should be returned at the end of its use. In addition to its functional role, the removable photo pendant adds a personal touch and serves as a souvenir for users, reminding them of their time with the pillbox. This design concept thus integrates informational and emotional elements that encourage users to return it.

5.4.3.Concept C: Direct instruction and text message

Figure 16 Prototype of concept C

Keywords: Instruction printed on pillbox; Text messages.

Developed from: 2. Flipped cover

This concept provides a simple solution by incorporating return instructions directly on the back of the pillbox, as illustrated in Figure 16. To trigger the return behaviour, its back-end system sends a message to the registered user's mobile number when it detects inactivity for more than a month. This message includes return instructions and an image of a pre-paid return label.

For returners whose phone number is not known to the system, they can simply scan the QR code on the back of the pillbox. This QR scan action triggers an automatic text message with a unique code to the system. As a result, the returner receives the return instructions and postal label, mirroring the process provided for the users. This approach simplifies the returns process and ensures that all relevant instructions and resources are readily available to both users and returners.

5.4.4.Concept D: A switch for return mode

Figure 17 Prototype of concept D

Keywords: Button/switch for return mode; QR code for instruction; Text messages.

Developed from: 3. NFC band

This concept is designed to allow users to proactively request information about the return process after they stop using the smart pillbox. As shown in Figure 17, a 'return mode' switch is built into the design which, when activated, disables alarms and notifications, and resets the pillbox. When the return mode is activated, users receive a message with return instructions and a return label to the phone number they originally registered with the system.

If the message does not arrive, users can scan the QR code to access a dedicated website where they can provide a phone number or email address to receive the return label. This platform also provides additional information about the return process and helps users locate a nearby service point. By allowing users to initiate the return process at their own discretion, this approach enhances user engagement and increases the likelihood of product return.

5.5. Concept Selection

The subsequent design evaluation and selection session was strategically designed to test the viability of the proposed concepts. This session involved both the target user group (senior group) and the returner group (junior group) and provided an opportunity to assess the suitability and effectiveness of the designs in addressing the design challenges raised.

The primary objective was to assess how these design concepts addressed the identified design challenges, thus facilitating the selection of the most promising concept and gathering critical feedback for future iterations. Through the analysis of the user feedback, this exercise aimed to identify the design elements that would effectively improve user ability in participating in the returns process and increase user engagement.

Different groups of participants were involved in this session, allowing the researcher to identify how the design of the return experience met the needs and expectations of both users and returners. It also sheds light on how the designs could bridge the knowledge gap between these two groups.

Detailed information on the research setup and participant demographics can be found in Chapter 2.2.9. "*Concept selection*".

5.5.1.Results

The concept selection session required participants to rate the four design concepts by assigning scores corresponding to their level of agreement with a series of statements. Each statement corresponded to a specific value to be measured and related to a specific design aspect that addressed a previously identified HMW question from the design process. A comprehensive listing of these statements and their respective values is provided in Table 12.

Aspect	*HMW Questions*	*Values*	*Evaluation Statements*
Returnability-awareness	*How might we make users aware of the returnable property of the product?*	Knowing what to do	I was attracted/led to learn about the return process and method.
		Confidence in system	I understand that the return of the pillbox will have ethical and sustainable results.
User trust	*How might we build user trust in the returns process?*	Feeling trust and privacy	I believe that this process is reliable and trustworthy.
		Avoid negative feelings	I was confused/upset/ sceptical when I learnt about the return and collection.
Clear instruction	*How might we provide intuitive instruction and aids to facilitate the return behaviour?*	Understanding the instruction	I feel confident to follow the return process outlined in this design
		Being reminded	I am very likely to forget to return this pill box
Convenience in daily life	*How might we make the return a convenient task that fits the users' everyday planning?*	Making little effort	I feel that returning this pillbox is cumbersome.
		Fitting everyday planning	I do not have the time or energy to participate in the return process.

Table 12 Tested statements and respective values, design aspects, and HMW questions.

In order to produce a more nuanced and accurate evaluation result that effectively addressed user needs, a weighted scoring system was used. The scores assigned to each value were weighted according to the perceived importance of that value as indicated by the participants. Participants were asked to prioritise eight values associated with ability requirements in the product return process, ranging from "nice to have" to "essential".

The calculation of total scores, influenced by these rankings, facilitated the derivation of an average weight for values across both groups of participants. The resulting distribution is shown in Figure 18.

By applying weighted scores to the values included in the design concepts, final cumulative scores, as well as scores for each design aspect, were determined for each group. These results, presented using a percentage-based scoring system, are illustrated in Figure 19.

Both the senior and junior user groups gave Concept D the highest overall score. Analysis of the senior group's results showed that Concept D outperformed the other designs, with virtually no weaknesses in the four key design aspects. The senior group participants attributed this superior performance to the interactive approach provided by Concept D's return mode switch. One participant likened the experience to a two-way 'I ask, it answers' dynamic. This feedback loop effectively counteracts user forgetfulness resulting from prolonged periods of inactivity and provides users with the necessary information on how to subsequently handle the product, as evidenced by the high returnability awareness score. Participants also described the text messages they received when activating the switch as hard to miss and worthy of their attention.

These attributes were also highlighted by the junior group, although the final scores for concepts C and D were quite close. Concept D's strength in communicating the message is due to its digital approach and web-based communication, which ensures clarity. However, it scored lower on the 'convenience in daily life' aspect. Participants suggested that the extra cognitive load required to scan the QR code may have contributed to Concept D's disadvantage over Concept C in this aspect. However, despite this minor setback and an overall score comparable to Concept C, Concept D's advantage in communication, coupled with a higher weighting for this aspect, makes it a more robust contender and a suitable concept for subsequent design iterations.

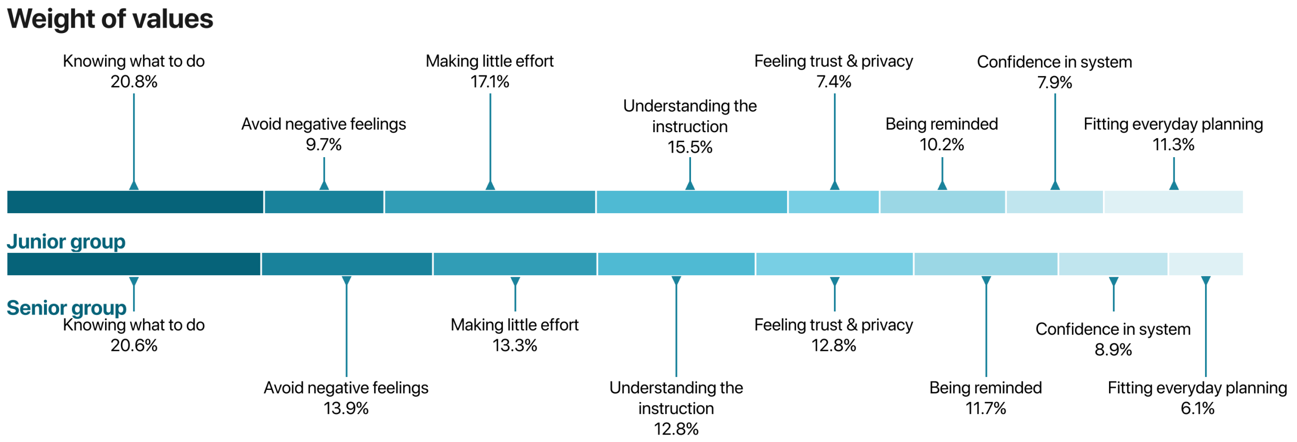


Figure 18 Weight of values in both participant groups.

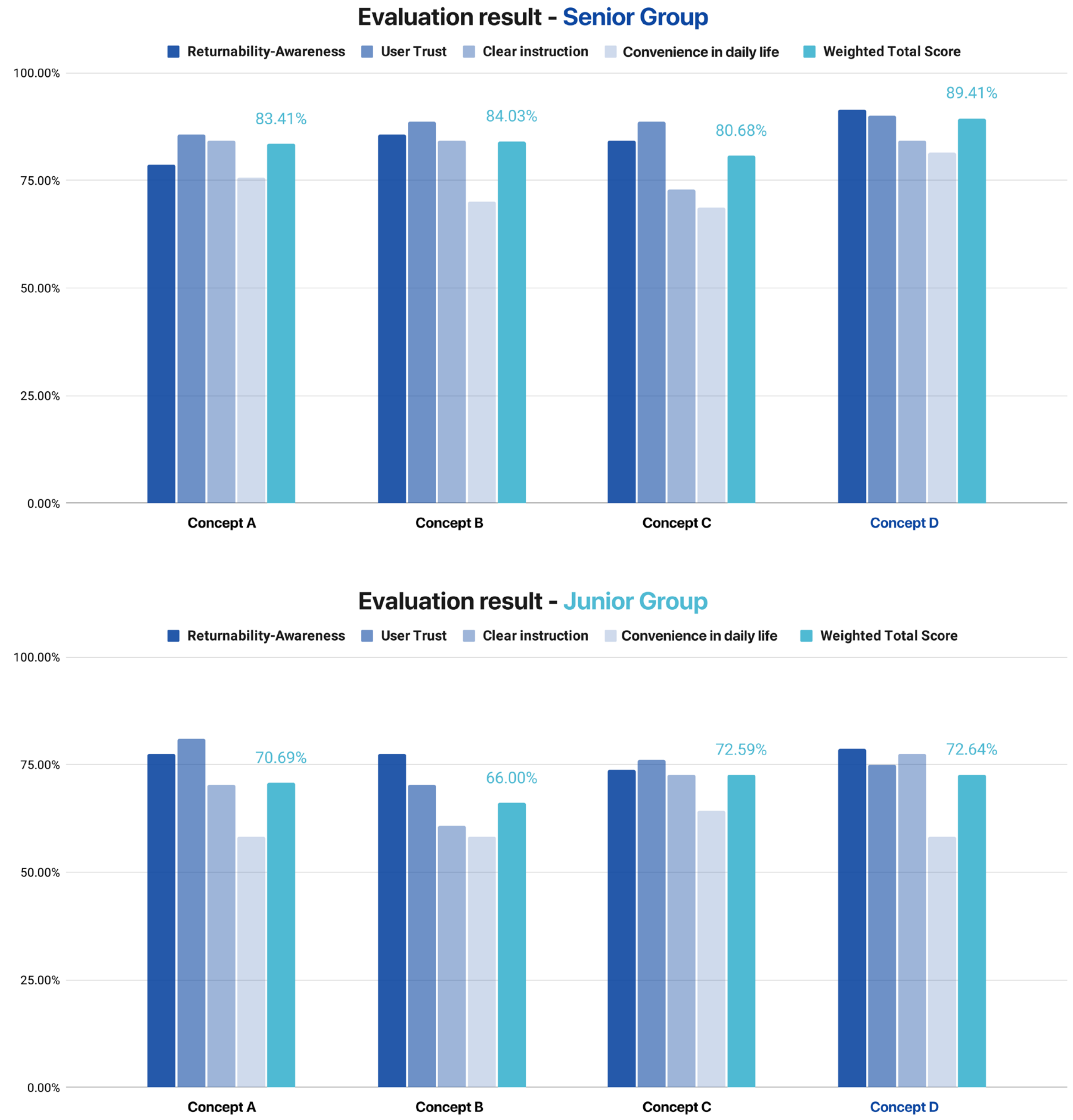


Figure 19 Evaluation results from both participant groups.

5.5.2.Findings about design elements

Constrained by the sample size, there were differences in the scores between the concepts, but overall, the final scores are still relatively close. This also means that while concept D was selected for further development, it is important to recognise that the other concepts also have valuable attributes that could enrich the final design. In order to identify these attributes, a comprehensive analysis of the participants' post-scoring interview responses was conducted. Grounded theory, a systematic methodology that involves the construction of theory through the analysis of data (Charmaz, 2014), was used for the coding process. The interview transcripts were meticulously coded using this approach, which allowed for the categorisation of responses based on design keywords from all concepts. This approach facilitated the identification of both positive and negative mentions of specific design elements. The results of this coding process, which include direct quotes from participants alongside their positive and negative remarks, are presented in Table 13.

Design Keywords

Positive Mentions	Negative Mentions
Return envelope	
45% positive mentions: • Process of discovery • Sense of mission/identity • Clear information and procedures • Fits the scenario of packing things *"I have it wrapped at home and a delivery parcel at home is not forgotten. I either open it or send it away."* *"I'll just wrap it up while I'm tidying up the house."*	**55%** negative mentions: • Extra steps to take • Lost during use • Not reliable for shipping • Easy to ignore *"These ubiquitous add-ons get in the way when you use them and might just be discarded."* *"I don't think I would use this type of envelope even if I returned it, it's easily broken and I don't think it's safe to send it away"*
Postal label with barcode	
62% positive mentions: • Simpleness in shipping • As a clue for return • Easy to conduct with everything physical *"Simple and straightforward, I can see the recycling label straight away. I don't need anything else, just take it and return it".*	**38%** negative mentions: • Hard to understand • Don't know where to go next *"First time I've encountered a barcode: not sure what it's supposed to be about, didn't connect it to return"*
Return instruction manual	
64%% positive mentions: • Help understand the context • Feel sincerity and privacy *"I was explained the purpose of this return and it was again specifically designed. It felt sincere and worthy of belief and acceptance, with a more positive impression and emotion."*	**73%** negative mentions: • Lost/throw away during use • Extra steps to take • Unwilling to read • Lack of a reminder *"I have no interest in opening a brochure to read when I'm tidying up."supposed to be about, didn't connect it to return"*
Instruction printed on pillbox	
64% positive mentions: • Constant reminding • Easy to understand the whole process • Feels like a default rule to follow *"The straightforward information is like basic information about the product itself, more like a default rule that everyone follows."*	**36%** negative mentions: • Forgotten with the pillbox • Easy to miss the information on the back • Lack of context • Easy to wear off *"You don't necessarily go to the back of the box, look at the front, open it up a bit and call it a day."*
Text messages	
56% positive mentions: • Feel supported by others • Effective if receive them as the right time • Being reminded and guided • Familiarity with text messages in medical-related matters *"There are also many SMS alerts for hospital visits and whatnot, which are familiar."*	**44%** negative mentions: • Miss it in a lot of mixed text messages • Slow acceptance of text information • Don't want to trouble others • Don't want to be reminded repeatedly *"If I haven't used it for a long time, I should have completely forgotten about it and may not read it even if I am given a text message."*
Button/switch for return mode	
71% positive mentions: • Easy to operate • Responsive to my input • Change in perception of the pillbox • Sense of mission from physical interaction *"I ask, it answers."* *"As soon as the switch was turned, the pill box went into a state of waiting to be returned, and it stayed upside down on the table, a constant reminder to me."*	**29%** negative mentions: • Extra steps to take • Worry about false button presses *"If I do it by mistake and clear the data and have to set it up again, it will be a hassle."*
QR code for instruction	
42% positive mentions: • Webpages are clear and rich in information • It can help me find the suitable place to return • Learn about one step at a time, easier to accept *"I wanted to understand step by step, telling me everything straight away would have put me off and made me feel less motivated."*	**58%** negative mentions: • Distrust of unfamiliar QR codes • Higher cognitive load • Complex as it involves physical, digital, offline locations *"High probability of process problems due to the number and complexity of the links"*

Table 13 Participants' responses to different design keywords.

Return envelope

Feedback from participants indicated that there were concerns about the durability and retention of the return envelope. They expressed concern that the envelope could be lost by being removed at an early stage of the product interaction, which could cause problems, particularly for the 'returner' group who first encounter the pillbox at the key moment of the product journey. In addition, participants expressed doubts about the envelope's ability to effectively protect the pillbox during the return process, which could potentially influence their decision to initiate a return.

However, this feedback also provided some critical insights to refine the final design concept. Participants noted that the discovery of the envelope was an intuitive process during their exploration of the pillbox. Interestingly, the presence of the envelope changed the user's perception of the product, transforming it into a package to be returned. This subtle shift had a considerable impact, helping users to complete the return process rather than overlook it.

Postal label with barcode

Participants described the postal return label as a valuable tool that could simplify the return process. The ease of taking the product to a service point where the postal worker can scan the label was seen as a positive feature. However, if this element is included in future designs, it's important to ensure that detailed explanations accompany the label. Without proper contextual understanding, users may find it difficult to grasp its purpose and therefore miss its intended benefit.

Return instruction manual

The inclusion of a manual, similar to the envelope solution, faces a potential risk of losing if removed early in the product interaction. This is compounded by the common user habit of neglecting to read such manuals, especially when users believe they understand how the product works. Despite these drawbacks, participants valued understanding the context and purpose of the return when making their decision. Therefore, an integrated approach, where information and instructions are incorporated directly into the pillbox, may offer a more effective solution.

Instruction printed on pillbox

The instructions printed directly on the pillbox provide users with immediate and intuitive access to relevant information. In addition, as participants noted, these instructions can serve as a constant reminder to return it, pointing to the embedded rule of returning the unused pillbox as a default behaviour. This could act as an effective nudge in users' subconscious decision-making processes.

However, there are challenges to this strategy. For example, the printed information, especially if positioned on the back of the pillbox, could easily wear off over time. It also runs the risk of being overlooked, much like the pillbox itself when not in use. Therefore, to optimise its effectiveness, it may be beneficial to combine this strategy with additional nudging designs.

Text messages

Text messaging was found to be more readily accepted by users than initially expected. According to the participants, they are familiar with text messages in the context of health care, such as notifications of doctor's appointments, regular meetings and the like. Text messages can therefore be an effective tool for both reminding and guiding users and returners through the return process.

However, an important consideration is the likelihood that users, particularly the elderly, will miss the message from the pillbox manufacturer in the midst of a large volume of incoming text messages. Therefore, the timing of the text message is crucial; if multiple text messages can be sent at the appropriate times and, for example when the user is interacting with the pillbox, they are less likely to be missed.

Button/switch for return mode

Participants generally praised the inclusion of an interactive button or switch, particularly when combined with SMS, for its ability to create a conversational experience as they gathered information about return procedures. It also introduced a ceremonial aspect to the return process. Participants noted that activating the return mode changed their perception of the pillbox, transforming it into a task to be completed. In this mode, they were more likely to place the pillbox upside down at home as a reminder.

However, despite these benefits, users were immediately concerned about the consequences of misuse. Accidental activation would require a complete reset of the pillbox. Therefore, if this feature is to be included in the final design, the functionality of the button or switch will need to be refined to better meet user expectations.

QR code for instruction

Participants expressed different preferences for scanning QR codes and reading online instructions. On the one hand, a number of users, particularly within the younger demographic, found the act of scanning a QR code to access information to be an unnecessary cognitive burden. This perception may be due to their daily inundation with QR codes, leading to a form of 'scan fatigue'. Conversely, a subset of users demonstrated a preference for consuming detailed information via interactive, step-by-step web pages.

It is therefore important to strike a balance between the convenience of QR codes in conjunction with web-based information and over-reliance on this technology. Minimising the cognitive load associated with QR codes while exploiting their ability to direct users to detailed, interactive information is a key consideration in the final design approach.

5.5.3. Design insights

1. Materials such as envelopes and instructions that are detached from the pillbox are easily lost during use. It is therefore advisable to ***integrate key information*** directly into the pillbox itself to ensure that it remains accessible throughout use.

2. It is better to ***integrate information into the user's interaction*** with the pillbox by providing cues during the steps where the user naturally interacts with the device, including the lid and inside of the tray, etc., which will be visible when the pillbox is picked up or opened.

3. The inclusion of an interactive button or switch for return mode is a preferable feature. It provides a ***conversational experience*** for users and ***changes their perception*** of the pillbox. However, its functionality should be refined to avoid misuse and the associated need to reset the pillbox.

4. ***Visual cues*** should be prominently placed so that users will easily notice them during regular use. This could include important instructions or symbols printed on the pillbox to act as a constant reminder to return it.

5. While ***QR codes*** can provide quick access to web-based instructions, there should also be an option for users to ***read the information directly*** on the pillbox.

5.6. Redesign Recommendation

The resulting redesign recommendations summarised the insights gained throughout the design and development process, including the exploration, co-creation and concept selection phases. It proposed features that would effectively address the identified design challenges. User journey maps were used to illustrate how these features could play a role in the return experience for both users and returners. Based on the proposed design features, some examples of possible design applications were presented to explain the design features more clearly and visually.

5.6.1.Features for improving return

Switch for state

A switch controlling the activation status of the pillbox allows the user to perform an active action when the pillbox is no longer in use. The operation of this toggle switch serves as an important starting point for delivering a return message to the user. Through a hint and the appearance of the switch, the user can be encouraged to activate the switch when they no longer wish to receive an alarm and thus receive a return message through an appropriate channel.

Status switches have the potential to play an important role in increasing the awareness of the user to return the cartridge when they intend to stop using it. This feature improves timeliness and prevents users from storing the pillbox and then forgetting about it. And this change in mode, brought about by the switch, is intended to also trigger a change in the user's perception of the product - from a medication management tool to a to-do task in a sustainable initiative.

Printed instruction

The printed instructions on the pillbox should start with an attention-grabbing slogan. Based on previous interviews, participants consistently showed an understanding of the objectives of returning the pillbox. They largely associated this action with altruistic motives, such as helping others and promoting sustainability. Conversely, the majority of participants expressed that awareness of a deposit would significantly increase their motivation to return the pillbox. Therefore, the slogan should address at least one of these two motivations: either the altruistic and sustainable benefits of returning the product, or the tangible incentive provided by the deposit system.

Following this, users will quickly see a concise set of instructions accompanied by relevant icons. The aim is to facilitate a quick understanding of the whole process. As previous research and exploration has shown, when users have a clear expectation of what will happen next, they have more confidence in their ability to complete the return and are therefore more likely to engage in the return process.

During a return attempt or process, users can quickly refer to these printed instructions. At the same time, these details act as a constant reminder of the tasks that users need to complete. As a result, the guide is not only a guide, but also acts as a nudge, encouraging users to complete the returns process.

Deactivate/reset button

The final deactivation and reset of the pillbox can be achieved by interacting with the buttons. A good layout will allow the user to see and interact with the reset button after flipping the switch from OFF mode. This should allow the synchronised application to open a page/popup and re-confirm with the user whether they wish to clear the data and remove the set alarm. This approach has the potential to reduce users' concerns about private data and thus increase their trust in the entire collection process. At the same time, the final confirmation in the app can act as a good safeguard against false positives, preventing the user from unknowingly deleting all alarms and medication data.

SMS reminder

When a user signs up for a smart pillbox, the app can ask them to add an emergency contact, which could be a family member, fellow resident or carer. If the back-end system detects abnormal box activity or a prolonged period of inactivity (e.g., a month), an SMS notification is sent to both the box user and the emergency contact, reminding them to check the status of their medication. As this may also be triggered by the user's plans to stop using the smart pillbox, they will also be reminded that the pillbox in their possession can be returned to help more patients and contribute to the circular economy. The SMS will include a link to a page where the return instructions can be accessed. This feature is designed to provide a window of information and remind users in a timely manner that the pillbox can be returned, while providing oversight to minimise risk.

Web/App based return instruction

Recognising the differences in ability between users and between users and returners, users will be able to access the detailed return instructions page through a variety of channels. This may include clicking on a link in an incoming reminder text message, responding to an app push notification, scanning a QR code, etc. Here the user can view detailed instructions and guidelines for the return process and download a specially generated return label. If the user does not have packaging that can be used for shipping, they can tick the "I need an additional shipping box" box to attach a paper box purchased from the courier, which is included in the postage cost, to the generated label. The courier can scan the barcode on the label to deliver the box, eliminating the need for the user to enter the recipient's details or address, and eliminating the cost of shipping.

This feature ensures that whether or not the returner is the actual user of the box, they have enough information to obtain a return label. This increases the likelihood of more boxes entering the system for refurbishment and remanufacturing, even if the user is deceased or unable to return the box in person.

5.6.2.Example of application

Derived from Concept D from previous concepts and combined with design elements from other concepts, below is an example of possible application for the recommended design features mentioned above.

In this example, the top of the lid is fitted with a slide switch and colour differentiation, giving the impression of a large switch. As demonstrated in Figure 20, this switch allows the user to switch the pillbox between active mode and OFF mode. Once activated, the OFF mode turns it into a dormant pillbox, revealing previously hidden information or elements under the slide switch. These include a message to pique the user's interest in returning the product, an abbreviated guide to the return process represented by an icon and short text, a touch button to request a return label, and a QR code that directs the user to a website with detailed step-by-step instructions that also provides an alternative channel of obtaining the return label. Another possible channel is through the SMS reminder shown in Figure 21, which will be sent to both user and their registered emergency contact when the pillbox stays inactive for a month.

Deposits have not been included in this integration of design features due to their strong influence on motivation rather than ability, although previous research has shown that they display information content that is of great interest to users. This is also due to the fact that this example will be used for concept validation, and the inclusion of an object that has a strong influence on motivation is not conducive to the assessment and analysis of ability to participate.

Upon discovering these elements, users can initiate the return process. If the pillbox is synchronised with the paired app, users will receive a notification on their smartphone with both the recycling instructions and an image of the return label. The wireframe of this process is demonstrated in Figure 22. If the app is not connected, users or returners can scan the QR code to access a website where they can register their device to receive the return label. The abbreviated instructions printed on the box works as a reminder of the return process.

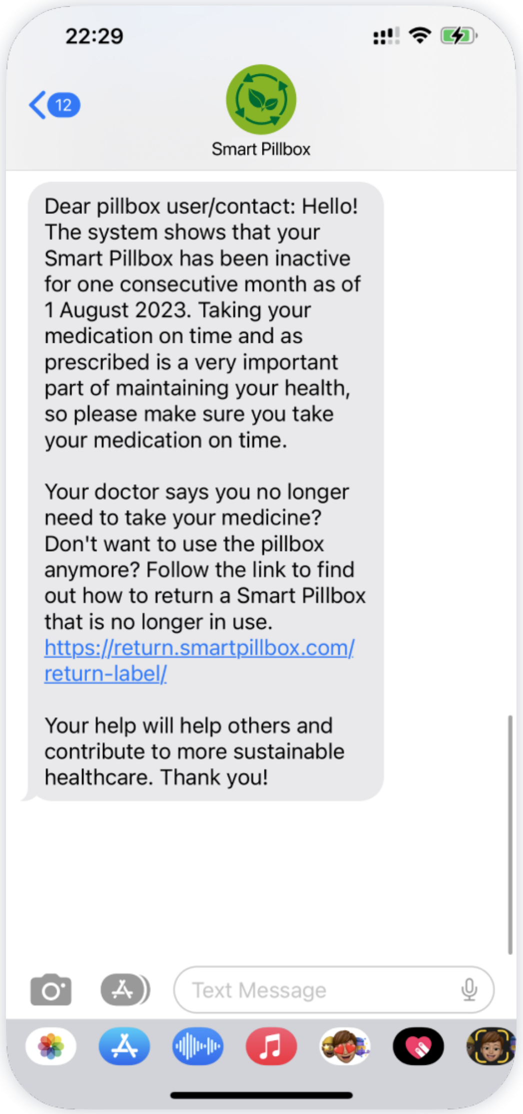


Figure 21 Text message after a period of inactive

Figure 20 Example of application of design features

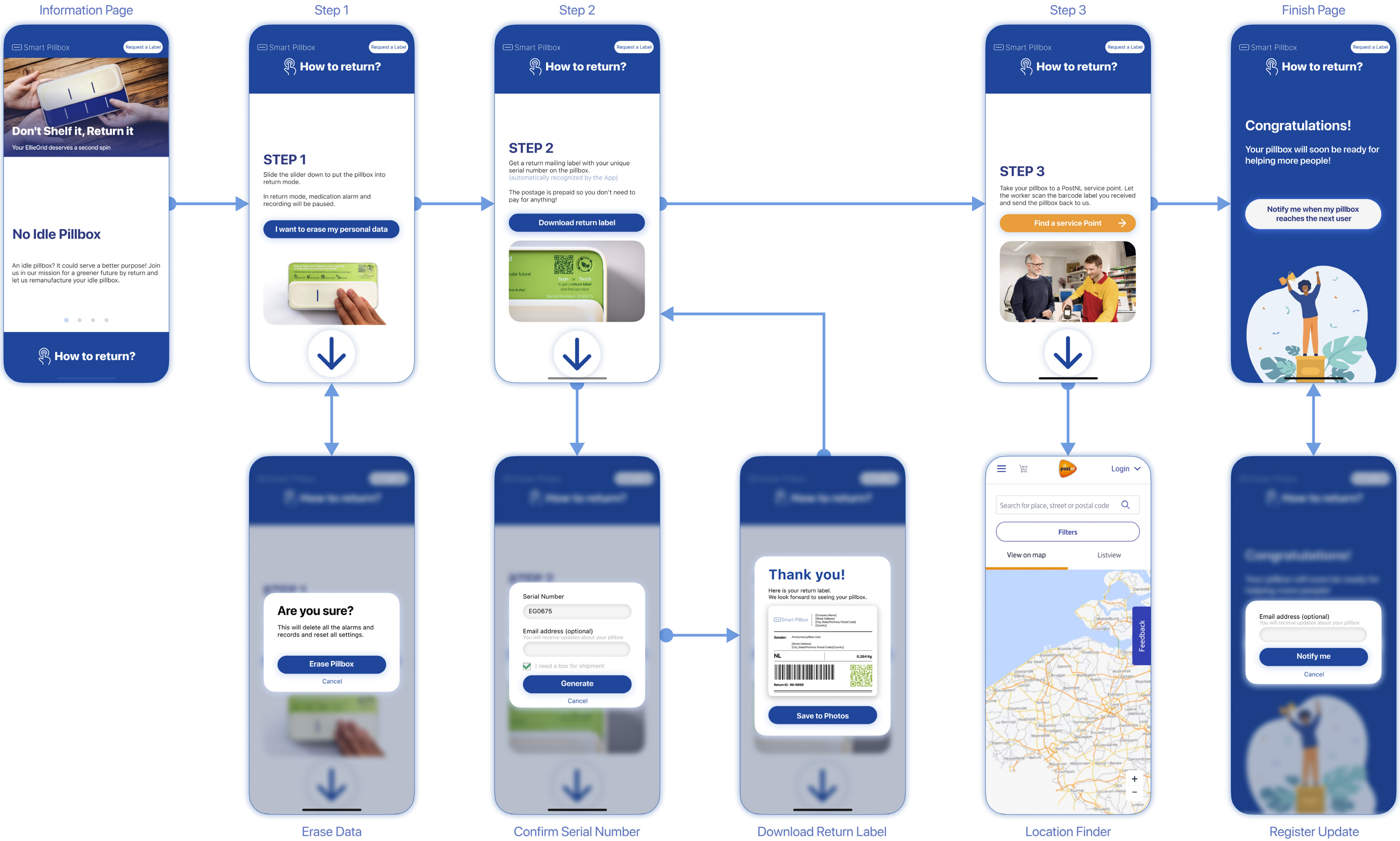
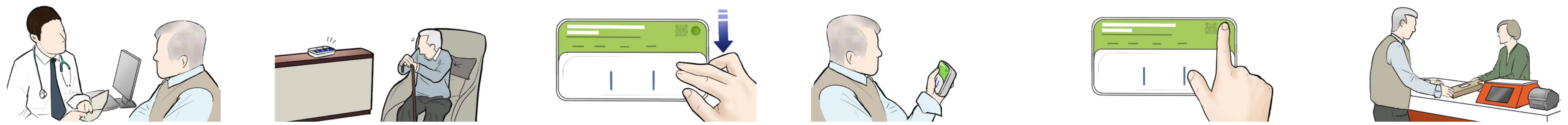


Figure 22 Framework of return page.

5.6.3.Return Journey Proposal

Figures 23 and 24 show the potential return journey of the proposed application example. These user experience journeys show the task or action to be performed by the user/returner, the response of the system and how they interact.

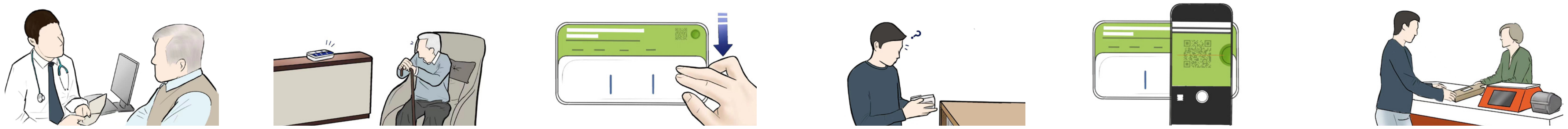
Return Journey - User



Customer Experience Proposed user story of the activities related to return	Decide to stop using the pillbox	Find the pillbox still working	Turn off the pillbox	Discover the return information	Request a label	Bring it to a service point	Return the pillbox
User							
User Action Actions, decisions, or tasks that user performs during the product experience	• Get suggestions from the doctor. • Stop following the alarms from the pillbox	• Hear the alarm from the pillbox • Receive notifications from App	• Notice the switch on the pillbox • Toggle the switch to put the pillbox in "OFF Mode".	• Read the printed instruction of return • Notice the portals for web/ app based instruction	• Receive an notification from App on user's phone • Read the web/app based instruction • Save the image of return label from this page	• Notice the pillbox in "OFF Mode" at home • (Optional) Find a service point nearby through the page in the App • Take it to a service point of a post carrier.	• Let postal worker in the service point scan the barcode on the label • Get the pillbox shipped
Line of interaction							
Frontstage Actions Actions, decisions, or tasks performed by the system that directly interact with the user	• *Doctor gives suggestion on stop taking the medication*	• *Pillbox sends out alarms as usual*			• *A notification for an app page appears on the phone*		• *Postal worker scans the barcode and receive the pillbox*
Line of visibility							
Backstage Actions Actions, decisions, or tasks performed by the system that the user doesn't see or feel directly		• Pillbox work as usual	• Sensor detects the switch being toggled • Alarms in the pillbox are paused • Via Bluetooth module, the pillbox synchronises with App • Notification for medication from the app are paused		• Via Bluetooth module, the pillbox synchronises with App • App read the signal and open a page • System read the serial number of the connected pillbox • System generates a barcode for return label		• System receive the information synchronised with postal carrier • Return information logged in the system

Figure 23 Customer Journey-User

Return Journey - Returner



	Decide to stop using the pillbox	Find the pillbox still working	Turn off the pillbox	Discover the pillbox	Request a label	Bring it to a service point	Return the pillbox
Customer Experience Proposed user story of the activities related to return	User			Returner			
User Action Actions, decisions, or tasks that user performs during the product experience	• Get suggestions from the doctor. • Stop following the alarms from the pillbox	• Hear the alarm from the pillbox • Receive notifications from App	• Notice the switch on the pillbox • Toggle the switch to put the pillbox in "OFF Mode".	• Read the printed instruction of return • Notice the portals for web/ app based instruction	• Scan the QR code • Read the web/app based instruction • Save the image of return label from this page	• Notice the pillbox in "OFF Mode" at home • (Optional) Find a service point nearby through the page in the App • Take it to a service point of a post carrier.	• Let postal worker in the service point scan the barcode on the label • Get the pillbox shipped
Line of interaction							
Frontstage Actions Actions, decisions, or tasks performed by the system that directly interact with the user	• *Doctor gives suggestion on stop taking the medication*	• *Pillbox sends out alarms as usual*			• *Red LED flashes* • *A webpage is opened upon scanning* • *A message sent to the contact info of returner*		• *Postal worker scans the barcode and receive the pillbox*
Line of visibility							
Backstage Actions Actions, decisions, or tasks performed by the system that the user doesn't see or feel directly		• Pillbox work as usual	• Sensor detects the slider being slide down • Alarms in the pillbox are paused • Via Bluetooth module, the pillbox synchronises with App • Notification for medication from the app are paused		• The pillbox **FAILED** to synchronise with App • System receives serial number via webpage • System generates a barcode for return label • System show a label to returner and let it be saved		• System receive the information synchronised with postal carrier • Return information logged in the system

Figure 24 Customer Journey-Returner

5.6.4.Prototype

A functional prototype (Figure 25) of this example of application was made to validate the effectiveness of the combination of design features. Basic features such as Bluetooth synchronisation, alarm notifications and LED indicators are operational. However, there are a few features of the redesigned model that have not yet been implemented in this prototype: the slide switch's ability to turn off the pillbox and the touch sensor's ability to trigger an app notification. These functions can be added by updating the board's firmware. Despite these limitations, these features can be easily demonstrated manually, making this prototype sufficiently robust for concept validation. Images of the prototype are shown in the figure below.

Figure 25 Prototype of the final redesign

5.7. Design Guidelines

Based on the extensive research, testing, and real-world application of the redesign, this project serves not only as an innovative solution for a product, but also as a case study. This chapter builds on the findings and insights from research on redesigning smart pillboxes. It serves as a guideline to provide actionable recommendations on promoting circularity in the design of similar healthcare-related smart devices. The fundamental aim of these guidelines is to encourage designers and manufacturers to rethink their approach to the EoL phase of their devices, to facilitate their return and collection. The detailed guidelines are listed in Table 14.

Categories	Keywords	Explanation
User Interaction	*Design for 'Returner'*	Emphasize the device's identity as a returnable healthcare product. Address potential 'returners' who might not have in-depth knowledge about the product to promote product circularity and EoL return success.
	Key Moments of Nudging	Identify pivotal moments for nudging users or returners about the return process. Intervening during these crucial times may be more effective. Examples from this project include when users first learn about the product, decide to stop using it, interact with it after discontinuation, and when returners first encounter the device.
	Seamless Return Reminders	Integrate return and collection reminders seamlessly into the natural interaction process between the user and the device. This constant reinforcement ensures the return concept isn't easily forgotten or overlooked.
	Change of Perception	Utilize nudging design elements that alter the user's perception of the device or its return process. Leverage the psychological impact and ambiguous categorization of borderline medical devices to foster lifecycle friendly EoL decisions.

Table 14 Comprehensive guidelines

Categories	Keywords	Explanation
Communication	*Lifecycle Communication*	Ensure that from the onset, users are aware of the product's intended lifecycle, including any EoL services, refurbishment opportunities, or the potential for reuse. This can be facilitated through in-product notifications, packaging, or user manuals.
	Prominent 'Return' Markings	Clearly mark the device with identifiers that highlight its returnable nature. This aids users and returners in quickly recognizing its returnable trait, preventing inappropriate disposal.
	Avoid Solely Paper-Based Cues	Refrain from solely using independent paper materials like flyers or envelopes as prompts. They have a high likelihood of being lost or discarded during user interaction, hindering returner's access to return information.
	Increase Return-Related Elements in Hardware	Elevate the proportion of hardware elements related to returns and collections. A higher ratio might enhance user trust in product collection and returns and their assessment of the company's circular economy initiatives, motivating participation.
	SMS Notifications	Utilize the intelligence of the device to discern user activity. Based on this, employ SMS to send targeted reminders to users or returners at various stages, ensuring proper device use and prompt returns during inactivity. SMS is an effective communication mode accepted by users of such products.
Trust & privacy	*Transparency in Remanufacturing Journey*	Offer insights to users about the post-collection story of the device. Showcasing how the returned device is cleaned, processed, and remanufactured can foster trust and incentivize user participation.
	Provide Data Erasure Methods	Depending on the device's functionality and category, offer accessible, and visibly simple methods to erase data. This ensures user data security, increasing their trust and sense of security.

Table 14 Comprehensive guidelines

Categories	Keywords	Explanation
System	*Digital Integration*	Utilize integrated apps or web platforms to notify and guide users about the return process. This digital approach can also offer interactive FAQs, tutorials, and direct customer support channels.
	Postal Returns as Primary	Initially prioritize accessible postal return processes, offering a familiar procedure for users and returners. As infrastructure improves, expand return channels by collaborating with local entities.
	Monetary Incentives	Consider the use of deposits or other monetary incentives and ensure they are visibly marked on the product. Users view deposits as a powerful motivator for returns. If a deposit system is implemented, ensure users and returners are constantly reminded of its presence to avoid forgetfulness or unawareness.

Table 14 Comprehensive guidelines

These guidelines aim to provide a comprehensive reference that identifies and addresses user needs and potential opportunities during the return and collection process. The intention is to support the design of devices that are inherently designed to be returned, ensuring ease of return, and understanding for both the end-user and the returner. This will increase the return rates of these devices, thereby promoting both environmental sustainability and resource efficiency in the healthcare sector.

5.8. Conclusion

The results of this iterative design process include a deliberate selection of design features with the goal of improving the end-of-life return of the smart pillbox. Furthermore, an exemplary application of these features was described, along with a comprehensive guideline destined for wider application. The next step in this process should be concept validation to evaluate how well it meets the design requirements and addresses any design difficulties. This will ensure that design elements not only fulfil the theoretical expectations but also align with practical requirements.

Chapter 6
Evaluation

This chapter evaluates the project and explores the impact and effectiveness of the proposed design features on the difficulty of EoL returns and the facilitation of return decisions in the context of circular economy and edge medical device design. It also critically reflects on the limitations encountered during the research and design process and provides an understanding of areas for future improvement.

6.1. Concept Validation

The concept validation was carried out to assess the interoperability and combined impact of various design features, specifically: the switch for state, the printed instruction, the deactivate/reset button and the web/app-based return instruction, as described in the previous chapter. The primary objective was to determine the collective effectiveness of these design elements in addressing the design challenges previously outlined.

Feedback for this validation was gathered from a mixed group of five senior users, the target demographic for the smart pillbox, and five junior participants who could potentially act as returners. Data was collected through structured questionnaires and brief interviews to ensure a comprehensive understanding of user perspectives.

Central to this validation was understanding changes in users' perceptions of the complexity of the return task and their confidence in completing it. Key desired outcomes of this validation included:

1. *Quantify improvements in users' perceptions of difficulty and their self-assessed ability.*
2. *Measure the percentage increase in users' willingness to participate in the return process.*
3. *Evaluating how the newly integrated features improved the original design, focusing on four key aspects: Raising awareness of returnability, increasing user confidence, providing clear instructions and ensuring convenience in daily routines.*

A more detailed breakdown of the research design and methodology can be found in Chapter 2.2: ***Methods - Concept Validation.***

6.1.1.Results

In the questionnaire, participants assigned scores corresponding to their level of agreement with a series of statements. The aspects of the current pillbox and proposed design can be reflected from the statements shown in the table 15 and 16.

Aspect	*HMW Questions*	*Evaluation Statements*
Returnability-awareness	*How might we make users aware of the returnable property of the product?*	Without asking for help, I understand that this pillbox should be collected.
		I consider the return of unused pillboxes to be a rule to be followed by default.
		I understand what this pillbox will be collected for.
User trust	*How might we build user trust in the returns process?*	I believe that this pillbox will be collected correctly.
		I think this system is safe, reliable and trustworthy.
		It makes me feel good to be part of this return process.
Clear instruction	*How might we provide intuitive instruction and aids to facilitate the return behaviour?*	I have received enough guidance to complete the return.
		I am confident that I will be able to complete the return.
		This pill box will ensure that I don't forget to return it.
Convenience in daily life	*How might we make the return a convenient task that fits the users' everyday planning?*	The process of returning the pillbox had few steps and was easy
		Returning the pillbox fit in with my lifestyle.
		Learning how to return the box was natural and intuitive.

Table 15 Statements and their corresponding aspects

Aspect	*Evaluation Statements*
Perceived difficulty	Overall, the return of the pillbox was easy.
Self-assessed ability	I now feel able to complete the return process on my own.
Willingness	I will be proactive in returning and collecting the pillbox.

Table 16 Statements related to the comprehensive evaluation of difficulty, ability and willingness.

Overall, the combination of design features reached a good result in addressing the design challenges as expected. As illustrated in figure 26, it improved the current situation especially in the aspects of providing information for awareness and instruction. The detailed feedbacks for these four aspects are shown below.

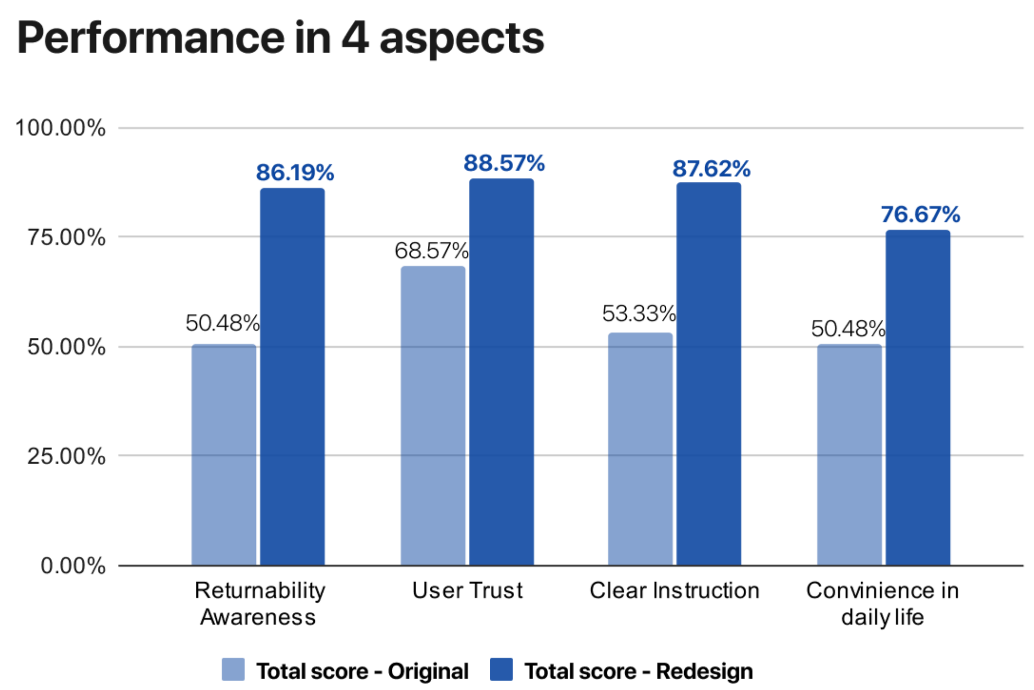


Figure 26 Performance in 4 aspects

Returnability-awareness

Feedback from participants on awareness was generally positive. Over half of the participants agreed that the redesigned pillbox with slogans and instructions increased their awareness of the 'return' channel. This was a significant change from the original pillbox design and prompted consideration of potential return options. In addition, the extensive information provided via the app/ web interface further clarified the details of the return process, including its underlying rationale. In particular, three participants highlighted that the pronounced colour disparity (green) resulting from the state switch was instrumental in drawing attention to the 'return' information. While the influence of specific colours on users' return perceptions was beyond the scope of this validation study, it warrants attention in future research efforts.

User Trust

In terms of fostering trust, the redesigned features produced the expected results. Overall, participants expressed a high level of trust in the return mechanism. A majority (seven participants) felt a sense of value in the return and collection by the manufacturer, as evidenced by the significant design real estate allocated to the return and collection process. This specialised hardware adaptation, perceived as an investment, reinforced the trust that the company's commitment to the collection of pillboxes was a long-term commitment. Consequently, this perception significantly boosted trust. Moreover, one participant expressed an interest in understanding the post-collection journey of the boxes. While this didn't diminish his trust quotient, a more in-depth exploration of the company's circular economy strategies could boost the overall trust metrics. The potential influence of this aspect on user participation requires further research.

Clear Instructions

Overall, the new design features provided participants with sufficient instructions to facilitate the return process. The front-facing return instructions were appreciated for their assistive and reminder functions. However, one participant commented that despite the clear instructions on the box, he resorted to scanning the QR code for the essential return label, suggesting a potential barrier to return. Such feedback is consistent with previous concept selection findings and highlights the need for ongoing experimentation to identify an optimal alternative to the QR code as the primary access point for the return label for the returners. Interestingly, after reading the sequential return instructions, several participants internalised them as a personal responsibility, evoking a sense of mission. This insight may inform strategies to increase user engagement in collection efforts. The effectiveness of such an approach and its underlying mechanisms will require more detailed design analysis.

Convenience in daily life

While participants praised the streamlined nature of the process, the design changes showed less improvement in the 'convenience' aspect compared to the other three aspects. This may be due to the inherent limitations of the underlying postal system, which blocks attempts to refine certain physical interactions. The increased convenience was largely a result of users and returners being more intuitive about the details required, a sentiment supported by the 'awareness' and 'instruction' feedback. In addition, observational data from prototype interactions revealed that some participants initially overlooked the slider's role in modulating the device's state, possibly due to reduced marker visibility. Their focus may have been monopolized by salient elements such as instructions or slogans. However, once the slider's function was recognised, a unanimous preference emerged to position the slider in the 'return' section during the interval preceding formal returns, as a reminder for return.

Perceived difficulty and willingness

According to the results of the questionnaire, shown in Figure 27, there was a notable improvement of 14.29% in participants' perceived ability - measured by their confidence in completing the return process - compared to the existing smart pillbox. When broken down, the junior group experienced an increase of 11.43%, while the senior group's confidence increased by 17.14%. Similarly, participants experienced a reduction in perceived difficulty, as evidenced by their assessment of the simplicity of the process, with an overall reduction of 15.71%. In particular, seniors experienced a more pronounced decrease of 22.86%, while juniors experienced a more modest decrease of 8.57%. Crucially, the overall propensity to participate in the return process increased by around 40%. Broken down further, juniors showed a significant increase of 48.57%, while seniors showed an increase of 31.43%.

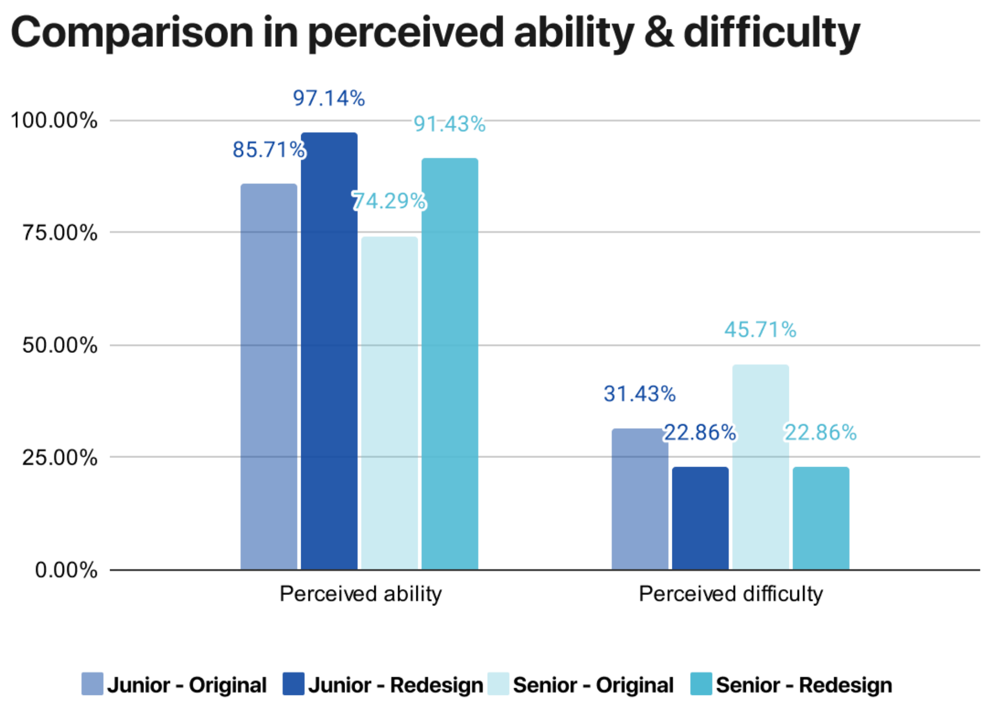


Figure 26 Performance in 4 aspects

6.1.2.Conclusion

The concept validation has highlighted the potential of the modified design features to effectively address the challenges identified in the initial design process. Across both the senior and junior groups, there is clear evidence of improved awareness, confidence, instructional clarity and convenience of the smart pillbox return process. In particular, the senior group showed increased confidence and reduced perceived difficulty, suggesting the adaptability of the new design to meet the needs of older users. Meanwhile, the junior group's significant increase in willingness to participate, driven by an increase in trust, exemplifies the design's ability to effectively engage a younger demographic.

Despite these advances, the validation also highlighted areas for further refinement. For example, the use of QR codes as a gateway to return labels and the design of on/off markers warrant deeper investigation and optimisation. In addition, certain aspects of convenience in the return process, influenced by external factors such as the postal system, pose inherent challenges.

In summary, the revised concept represents a promising step forward in promoting a proactive return, with the lessons learned from validation paving the way for more nuanced iterations in the future. Importantly, the test results reveal potential avenues for future design exploration and research, setting the stage for ongoing innovation and refinement.

6.2. Impact on material and lifecycle

On average, consumer electronics and small appliances have a lifespan of less than five years, often plateauing at around three years. This statistic, supported by data from manufacturers and research by Cox et al. (2013), contrasts sharply with the longevity of some of their core components. For example, the PCB and polycarbonate housing of these devices are designed to last between 10 and 20 years.

Constraints on the lifetime of a device often come from specific components such as rechargeable batteries which, as noted by Keiski & Pongrácz (2022), have a lifetime of no more than five years due to the degradation of battery performance over charging cycles. This sets the stage for a remanufacturing process in which components such as the PCB and housing are retained, while consumables such as batteries and rubber pads are replaced. In addition, when these devices are returned to the manufacturer, there is a structured recycling and disposal process for the components, ensuring that they are diverted from the general waste stream. This strategic approach reinforces the circularity of the product lifecycle.

Based on the results of the concept validation, the application of the new design features had a double positive impact. Firstly, the 15.7% reduction in user perceived difficulty increases the efficiency and accessibility of the return process. Secondly, a staggering 40% increase in participants' willingness to return means that core components such as the PCB are more likely to be remanufactured. This has a direct impact on reducing e-waste and conserving vital raw materials such as gold, silver, copper, aluminium and various rare earths, as highlighted by Pokhrel et al. (2020).

However, there's a trade-off to consider. Implementing these design features requires additional material consumption, especially for the housing. To illustrate, while the standard smart pillbox requires 228.4g of polycarbonate for its casing, the new features push this up to 247.7g. But the silver lining is the recycling potential. If a returned pillbox is in good condition, its lifecycle can essentially be doubled, halving the amount of plastic used per lifecycle. Therefore, if we were to recover just 15.6% of these redesigned pillboxes, the additional plastic generated by the new design would be effectively neutralised, even without taking into account the material loss during reprocessing.

In summary, while the introduction of new design features may have an initial environmental cost, the long-term benefits in terms of material conservation and waste reduction can outweigh this cost, provided that effective collection mechanisms are in place. This alignment between design innovation and sustainable practices not only extends the product lifecycle, but also paves the way for more resource-efficient manufacturing in the future.

6.3. Limitations

While this project has shed light on important aspects of product return design in the context of smart pillboxes, it has also had several limitations. This chapter aims to discuss and reflect on these limitations in order to provide a more holistic understanding of the findings and potential directions for future research.

6.3.1. Limitations in design features

While the recommended features address the identified design challenges and has the potential to improve the ability of users to participate in the return and collection processes, there also exist certain limitations.

There are scenarios where the pillbox may be dormant and inactive for extended periods of time. In such cases, the return button could be ineffective, depriving users of the seamless app-based return feature. In such cases, users would have to resort to web-based methods for their return requests. In addition, the portability of the pillbox poses a challenge in terms of inadvertent off-switching resulting in missed medication reminders. Furthermore, the potential need to provide address details for some return methods could raise privacy concerns, leading to hesitation or even abandonment of the return process.

These limitations present challenges for future implementations and transitions within its lifecycle and highlight the need for further improvements and optimisations through a comprehensive service solution.

6.3.2. Limitations in design process

1. Influence of participant motivation

Central to this project was the aim of exploring designs that enhanced the user's ability to encourage product returns. However, an inherent limitation arose from the challenge of separating genuine design influences from participant motivation in both the design and testing phases. While the project aimed to identify the impact of the design, the motivations of the participants, may have influenced their behaviour, thereby clouding the pure impact of the design elements.

2. Sample size and accessibility:

The validity of any design research is often related to the breadth and diversity of its participant pool. In the concept selection and validation phases, this project ideally required a larger sample size to generate more robust and universally applicable insights. The unique challenge here was the target user group for the Smart Pillbox - the elderly. Given their limited accessibility, particularly in the context of this study, it was challenging to gather a large and diverse group of older participants, potentially limiting the breadth of feedback received.

3. Lack of life cycle analysis:

In comparing the new design with existing product configurations, this project was time constrained and couldn't undertake an LCA. As a result, the impact of the new design features on the environmental footprint of the product remains an estimate. Future studies should prioritise a detailed LCA to quantitatively assess the nuanced environmental impacts of the product, particularly in relation to increased recycling rates.

4. Validation and wider application:

The comprehensive guidelines represent preliminary findings due to the time and situational constraints of the project. Their validation, particularly in terms of wider application, remains an unexplored avenue. The current study couldn't determine the potential extrapolation of these design guidelines to other smart or borderline medical devices. This points to a significant research opportunity where these guidelines could be tested, refined and potentially made more universally applicable.

The limitations identified in this study highlight crucial areas for improvement and refinement in both the design features and the process. These challenges not only highlight the iterative nature of design, but also point to specific avenues for future research and development. It's imperative that future endeavours use these findings to drive more holistic and effective solutions in this area.

Chapter 7
Conclusion

This chapter provides a summary of the project's primary goals, outlining methods for promoting the voluntary return of products through design nudges. It illuminates the challenges and opportunities related to the transition of healthcare products to a circular economy. The chapter outlines the main findings, implications arising from design explorations, and future recommendations, grounded in insights gleaned from the study's exploration of smart pillboxes and their potential for wider application in the healthcare sector.

7.1. Project summary

The primary objective of this project was to strengthen the user's ability to voluntarily return the product by implementing nudging strategies. At the same time, it aimed to provide design guidelines for future digital healthcare-related products, ensuring that they adhere to a circular lifecycle. Over the course of the project, this overarching goal was distilled into four precise design objectives:

1. *Improve user abilities.*
2. *Establishing trusted return channels.*
3. *Minimise the cost of participation.*
4. *The potential for broader application.*

Various analyses, coupled with rigorous user research and design exploration, were undertaken. The iterative nature of this process culminated in well-defined design recommendations for a smart pillbox to increase return rates. Using the user feedback and design insights gathered during the journey, a comprehensive set of guidelines (Table 14) was summarised, which holds promise for broader applications in the field of smart health-related products.

7.2. Challenges & Opportunities

In the healthcare sector, the generation of waste and the consumption of energy and materials are of serious concern. The transition to a circular economy for such products is crucial for sustainability. A critical step in achieving a product's circular lifecycle is its collection, ensuring that returnable products serve as the basis for subsequent reuse, refurbishment, remanufacturing and recycling. In reality, however, many of these products are not returned. In the context of this project, this is often due to a lack of user awareness of returnability, a lack of trust, a lack of clear instructions and a lack of convenience.

This project's research and design exploration revealed that a user's willingness to participate in collection and return can be influenced by both the product's design and the communication strategy of information. Therefore, a pressing challenge in driving CE transformation is to increase user engagement in collection and return. This can be achieved by addressing the gaps identified above through thoughtful product design, effective communication and systematic construction.

Using the smart pillbox as a case study, and through rigorous product analysis and user research, this project postulated four key questions:

1. *How might we make users aware of the returnable property of the product?*
2. *How might we build user trust in the returns process?*
3. *How might we provide intuitive instruction and aids to facilitate the return behaviour?*
4. *How might we make the return a convenient task that fits the users' everyday planning?*

By addressing these questions, there is an opportunity to conceive designs that encourage users to return.

In addition, this study introduced the concept of 'returners' - potential actors in return and collection scenarios beyond the end user. This perspective adds a new dimension to design considerations and introduces new scenarios for EoL returns. This brings new challenges, particularly in understanding and meeting the needs of the returners and integrating them into the collection process. Conversely, it offers the opportunity to increase return rates by shaping future designs that cultivate broader, more inclusive return pathways, thereby encouraging the participation of a wider demographic beyond primary users.

7.3. Implications

This project began with design explorations rooted in HMW questions, culminating in a refined design proposal for an smart pillbox. Central to this design are innovative features such as Switch for state, printed instruction, Deactivate/reset button, SMS reminder, and Web/App based return instruction. These features have been tested and received positive feedback from users. This positive response indicates a tangible potential for these features to be incorporated into the smart pillbox design, thereby increasing users' willingness to participate in the EoL return of the product.

A comprehensive set of guidelines has been proposed based on the user feedback and insights gathered throughout the project. While originating in the context of the smart pillbox, the potential applicability of these guidelines spans a broader spectrum, encompassing other smart health-related products. These guidelines provide actionable recommendations for the return and collection design of such products, touching on crucial facets such as user interaction, communication, trust and privacy, and system infrastructure. A detailed presentation of these guidelines is provided in Table 14. Moving forward, it's imperative that further research and validation be conducted to strengthen the robustness of the recommendations and to determine their broader applicability.

7.4. Recommendations

While this project has provided pragmatic recommendations for the design of the smart pillbox and formulated comprehensive guidelines with potential for wider application, certain areas require further research and development. This will ensure that implementations truly increase voluntary return rates and have the intended positive impact.

7.4.1.Product design

After preliminary validation, the proposed design features have demonstrated their effectiveness. However, given the limited sample size of this study, it's imperative to delve deeper into how these features influence user ability and intent. In addition, understanding their interaction is crucial. Recognising the facets they influence and their synergies with other features will enable a more systematic application of design features and nudging strategies.

7.4.2.Returner

The concept of 'returners' emerged as a key component of the return and repatriation scenarios within this project. Future research should deepen the understanding of returners by rigorously analysing and validating their roles. This includes identifying their specific identities, mechanisms of engagement, particular needs and motivational triggers. Through nuanced analysis and comprehensive profiling of returners, end-of-life (EoL) return designs can be more effectively tailored.

7.4.3.Comprehensive Guidelines

The guideline outlined in this project are an outcome of design explorations centred on the return process of the smart pillbox. Further research and rigorous validation are essential to determine their wider applicability to other similar products. Such validation could include working with larger participant groups and extending the design parameters to other smart health-related devices beyond the smart pillbox. This expanded scope may reveal complementary design strategies that enhance user capabilities and motivations, thereby complementing and refining the established guidelines.

7.4.4.Motivation

While the scope and duration of this project focused primarily on improving users' ability to promote voluntary participation in product returns, motivation remains an integral factor in achieving this goal. A recurring observation throughout the project was the emphasis participants and users placed on motivation. As a result, future research should explore in more depth strategies to increase the motivation of both users and returners to participate in the return and collection processes. This exploration could include avenues such as product design refinements, communication methods and systemic design improvements.

FIN.

References

Agyemang, M., Kusi-Sarpong, S., Khan, S. A., Mani, V., Rehman, S. T., & Kusi-Sarpong, H. (2019). Drivers and barriers to circular economy implementation. *Management Decision*, *57*(4), 971–994. https://doi.org/10.1108/md-11-2018-1178

Aloini, D., Dulmin, R., Mininno, V., Stefanini, A., & Zerbino, P. (2020). Driving the transition to a circular economic model: A systematic review on drivers and critical success factors in circular economy. *Sustainability*, *12*(24), 10672. https://doi.org/10.3390/su122410672

Alkahtani, M., Ziout, A., Salah, B., Alatefi, M., Abd Elgawad, A. E., Badwelan, A., & Syarif, U. (2021). An insight into reverse logistics with a focus on collection systems. *Sustainability*, *13*(2), 548. https://doi.org/10.3390/su13020548

Bocken, N. M., de Pauw, I., Bakker, C., & van der Grinten, B. (2016). Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering*, *33*(5), 308–320. https://doi.org/10.1080/21681015.2016.1172124

Charmaz, K. (2014). Constructing grounded theory. sage.

Ciliberto, C., Szopik-Depczyńska, K., Tarczyńska-Łuniewska, M., Ruggieri, A., & Ioppolo, G. (2021). Enabling the circular economy transition: A sustainable lean manufacturing recipe for Industry 4.0. *Business Strategy and the Environment*, *30*(7), 3255–3272. https://doi.org/10.1002/bse.2801

Delve, Ho, L., & Limpaecher, A. (2021). *The Practical Guide to Grounded Theory*. Practical Guide to Grounded Theory Research. https://delvetool.com/groundedtheory

Diabat, A., & Govindan, K. (2011). An analysis of the drivers affecting the implementation of green supply chain management. *Resources, Conservation and Recycling*, *55*(6), 659-667. https://doi.org/10.1016/j.resconrec.2010.12.002

Digital Health in the Circular Economy. (2023, April 20). https://circulardigitalhealth.eu/

Dijkstra, H., van Beukering, P., & Brouwer, R. (2020). Business models and sustainable plastic management: A systematic review of the literature. *Journal of Cleaner Production*, *258*, 120967. https://doi.org/10.1016/j.jclepro.2020.120967

European Commission. (2014). *Circular economy action plan*. Environment. Retrieved January 30, 2023, from https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en

Fogg, B. J. (2009). A behavior model for persuasive design. In Proceedings of the 4th international Conference on Persuasive Technology (pp. 1-7). Govindan, K., & Hasanagic, M. (2018). A systematic review on drivers, barriers, and practices towards Circular Economy: A Supply Chain Perspective. *International Journal of Production Research*, *56*(1-2), 278–311. https://doi.org/10.1080/00207543.2017.1402141

Forti V., Baldé C.P., Kuehr R., Bel G. (2020). The Global E-waste Monitor 2020: Quantities, flows and the circular economy potential. United Nations University (UNU)/United Nations Institute for Training and Research (UNITAR) – co-hosted SCYCLE Programme, International Telecommunication Union (ITU) & International Solid Waste Association (ISWA), Bonn/Geneva/Rotterdam.

Govindan, K., Kaliyan, M., Kannan, D., & Haq, A. (2014). Barriers analysis for green supply chain management implementation in Indian industries using analytic hierarchy process. *International Journal of Production Economics*, *147*, 555-568. https://doi.org/10.1016/j.ijpe.2013.08.018

Gumley, W. (2014). An analysis of regulatory strategies for recycling and re-use of metals in Australia. *Resources*, *3*(2), 395–415. https://doi.org/10.3390/resources3020395

Guzzo, D., Carvalho, M., Balkenende, R., & Mascarenhas, J. (2020). Circular business models in the medical device industry: Paths towards sustainable healthcare. *Resources, Conservation and Recycling*, *160*, 104904. https://doi.org/10.1016/j.resconrec.2020.104904

Kalmykova, Y., Sadagopan, M., & Rosado, L. (2018). Circular economy – From review of theories and practices to development of implementation tools. *Resources, Conservation and Recycling*, *135*, 190-201. https://doi.org/10.1016/j.resconrec.2017.10.034

Kandasamy, J., Kinare, Y. P., Pawar, M. T., Majumdar, A., K.E.K., V., & Agrawal, R. (2022). Circular economy adoption challenges in medical waste management for Sustainable Development: An empirical study. *Sustainable Development, 30*(5), 958–975. https://doi.org/10.1002/sd.2293

Kane, G., Bakker, C., & Balkenende, A. (2018). Towards design strategies for circular medical products. *Resources, Conservation and Recycling*, *135*, 38-47. https://doi.org/10.1016/j.resconrec.2017.07.030

Keiski, R. L., & Pongrácz, E. (2022). End-of-Use vs. End-of-Life: When Do Consumer Electronics Become Waste? *Resources*, *11*(2), 18. https://doi.org/10.3390/resources11020018

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, *127*, 221-232. https://doi.org/10.1016/j.resconrec.2017.09.005

Lockton, D., Harrison, D., & Stanton, N. A. (2010). The Design with Intent Method: A design tool for influencing user behaviour. *Applied Ergonomics*, *41*(3), 382-392. https://doi.org/10.1016/j.apergo.2009.09.001

MacArthur, E. (2014). Towards the circular economy: Accelerating the scale-up across global supply chains. In *World Economic Forum*.

Mathews, J. A., & Tan, H. (2011). Progress toward a circular economy in China. *Journal of Industrial Ecology*, *15*(3), 435–457. https://doi.org/10.1111/j.1530-9290.2011.00332.x

Medicines & Healthcare products Regulatory Agency. (2021, January 6). *Borderline products: How to tell if your product is a medical device and which risk class applies*. GOV.UK. Retrieved November 28, 2022, from https://www.gov.uk/guidance/borderline-products-how-to-tell-if-your-product-is-a-medical-device#types-of-borderline-products

Moultrie, J., Sutcliffe, L., & Maier, A. (2015). Exploratory study of the state of environmentally conscious design in the medical device industry. *Journal of Cleaner Production*, *108*, 363-376. https://doi.

org/10.1016/j.jclepro.2015.06.014

Pamminger, R., Glaser, S., & Wimmer, W. (2021). Modelling of different circular end-of-use scenarios for smartphones. *The International Journal of Life Cycle Assessment*, *26*(3), 470–482. https://doi.org/10.1007/s11367-021-01869-2

Pokhrel, P., Lin, S., & Tsai, C. (2020). Environmental and economic performance analysis of recycling waste printed circuit boards using life cycle assessment. *Journal of Environmental Management*, *276*, 111276. https://doi.org/10.1016/j.jenvman.2020.111276

Prieto-Sandoval, V., Jaca, C., & Ormazabal, M. (2018). Towards a consensus on the circular economy. *Journal of Cleaner Production*, *179*, 605-615. https://doi.org/10.1016/j.jclepro.2017.12.224

Publications Office. (2017). *REGULATION (EU) 2017/745 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL - of 5 April 2017 - on medical devices, amending Directive 2001/ 83/ EC, Regulation (EC) No 178/ 2002 and Regulation (EC) No 1223/ 2009 and repealing Council Directives 90/ 385/ EEC and 93/ 42/ EEC*. Official Journal of the European Union.

Rizos, V., Behrens, A., van der Gaast, W., Hofman, E., Ioannou, A., Kafyeke, T., Flamos, A., Rinaldi, R., Papadelis, S., Hirschnitz-Garbers, M., & Topi, C. (2016). Implementation of circular economy business models by small and medium-sized enterprises (SMEs): Barriers and enablers. *Sustainability*, *8*(11), 1212. https://doi.org/10.3390/su8111212

Singhal, D., Tripathy, S., & Jena, S. K. (2020). Remanufacturing for the circular economy: Study and evaluation of critical factors. *Resources, Conservation and Recycling*, *156*, 104681. https://doi.org/10.1016/j.resconrec.2020.104681

Sunstein, Cass R., Nudging: A Very Short Guide (September 22, 2014). 37 J. Consumer Pol'y 583 (2014), Available at SSRN: https://ssrn.com/abstract=2499658 or http://dx.doi.org/10.2139/ssrn.2499658

Thaler, R. H., & Sunstein, C. R. (2009). Nudge: Improving decisions about health, wealth, and happiness. Penguin.

Tura, N., Hanski, J., Ahola, T., Ståhle, M., Piiparinen, S., & Valkokari, P. (2019). Unlocking circular business: A framework of barriers and drivers. *Journal of Cleaner Production*, *212*, 90-98. https://doi.org/10.1016/j.jclepro.2018.11.202

Wang, Y., Huscroft, J. R., Hazen, B. T., & Zhang, M. (2018). Green information, green certification and consumer perceptions of remanufctured automobile parts. *Resources, Conservation and Recycling*, *128*, 187-196. https://doi.org/10.1016/j.resconrec.2016.07.015

Wee, S.-C., Choong, W.-W., & Low, S.-T. (2021). Can "nudging" play a role to promote pro-environmental behaviour? *Environmental Challenges*, *5*, 100364. https://doi.org/10.1016/j.envc.2021.100364 0

Weßel, G., Altendorf, E., Schwalm, M., Canpolat, Y., Burghardt, C., & Flemisch, F. (2019). Self-determined nudging: A system concept for Human-Machine Interaction. *Cognition, Technology & Work*, *21*(4), 621–630. https://doi.org/10.1007/s10111-019-00556-5

Woiceshyn, J. (2011). A model for ethical decision making in business: Reasoning, intuition, and rational moral principles. *Journal of Business Ethics*, *104*(3), 311–323. https://doi.org/10.1007/s10551-011-0910-1

Appendices

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