Insights into the Circular (re)Design of Medical Wearable Sensors

Insights into the Circular (re)Design of Medical Wearable Sensors

MSc Graduation Thesis

Integrated Product Design
Delft University of Technology
Faculty of Industrial Design Engineering

Author
Matthijs Bult
4446151

Supervisory Team
Chair: Ruud van Heur
Mentor: Tamara Hoveling

I • Preface

Hi! You're about to read my master's thesis which I used to graduate within Integrated Product Design at the TU Delft.

In my search for a thesis, I knew I wanted sustainability to play a central role. Throughout my studies, I had encounters with circular design, but I never got a chance to delve into it. This thesis provided me with the opportunity to explore circular product design and understand how we, as designers, can reduce our environmental impact by embracing the principles of the circular economy.

I hold the belief that our field inherently contributes to polluting. After all, the products we create require manufacturing, materials, and eventually, end up as some form of waste. I also firmly believe that as product designers, we have a moral responsibility to design for a better world. This involves not only creating products that enrich people's lives but also products that contribute positively to the environment, to our environment.

With this thesis, I hope to inspire you to apply circular design to your project. Let's work together towards a sustainable future!

II • Acknowledgemetns

I want to thank my supervisors, Ruud and Tamara, for their continuous support throughout the thesis. I could always count on your honest feedback and your support when I needed it at the right times.

I want to thank Hans and everyone at Philips for sharing their knowledge, perspectives and insights on the Healthdot and how it can be improved. Special thanks to Suzanne and the people at Games for Health for their valuable input on my concepts.

A massive shoutout to my parents for putting me on this earth, feeding me and supporting me, for all the hours spent proofreading my work mere hours before the deadline is due.

Finally, a big hug to all my friends from IO. Thank you for supporting me from day one, all the way up to this final moment. You lifted me when I was down, and pulled me out when I was stuck. I could not have gotten to this point without any of you.

III • Glossary

Circular Economy	A system wherein the value of materials and resources is maintained indefinitely, further explained in Chapter 3.
Circular Flows or **Circular Loops**	Describes how a product cycles through a circular system
Circularity	A way of describing how good something fits in the circular economy.
Cleaning	Act of removing dirt and debris from inanimate object, but not disinfecting or sterilising.
Criticality	How critical it is that a device is, clean, disinfect or sterilised.
Disinfection	The process of reducing microorganisms from inanimate objects to safe levels
E-waste	Electronic products that have become obsolete and are viewed as a waste
Impact	Environmental impact of a product, often measured in Kg/CO2
Life Cycle Analysis (LCA)	Assessment method to analyse the impact of a product
Medical wearable sensor (MWS)	Small medical product that wirelessly measures biosignals, also referred to as 'sensor'
Original Equipment Manufacturer (OEM)	An organisation that makes devices for other organisations.
Sterilisation	The process of killing all microorganisms from inanimate objects
Sustainability	Environmental sustainability, further defined in Section 3.1.

IV • Digital Health in Circular Economy

This thesis is executed within the context of the DiCE project: Digital health in Circular Economy (European Commission, n.d.). The European-funded project "aims to address the issue of increasing digital health waste" (WEEE Forum, 2023) and involves 20 different organisations, including the TU Delft and Philips. The project aims to guide the medical sector towards a more sustainable future.

V • Executive Summary

This thesis presents recommendations based on a case study focused on the circular redesign of the Philips Healthdot. The study addresses a knowledge gap by offering insights into the circular design for products like the Healthdot. The proposed redesign of the Healthdot's system led to a substantial reduction of CO2 emissions, with potential for further improvements.

Philips Healthdot

The Philips Healthdot (Figure I) is a medical wearable sensor designed to wirelessly capture bio measurements and transmit them to hospitals. Once used, the sensor becomes inactive and is discarded as waste. While similar reusable sensors exist, only two were identified during research.

Research

Literature research was conducted concerning the circular economy, its design strategies and business models. A comprehensive analysis of the Healthdot's product journey was performed, complemented by a fast-track Life Cycle Analysis (LCA). The LCA revealed the high CO2 impact of its electronics, highlighting the importance of extending their usage. Based on the outcomes of these analyses, requirements and criteria were defined, which formed the foundations of the proposed solution.

SecondSense

The proposed solution, SecondSense, consists of two components: SenseFlow and SenseCab (Figure II & III). SenseFlow describes the sensor lifecycle within the system, while SenseCab enables easy reprocessing. In the SenseFlow system, used sensors are collected, cleaned, and placed in the SenseCab for data removal, disinfection and charging.

Life Cycle Analysis

A comparison between SecondSense and the original Healthdot was conducted using an LCA (see Figure IV). SecondSense shows reductions in CO2 emissions after only three uses, with 45% and 60% reductions

Figure I: Philips Healthdot (Philips, n.d.-d)

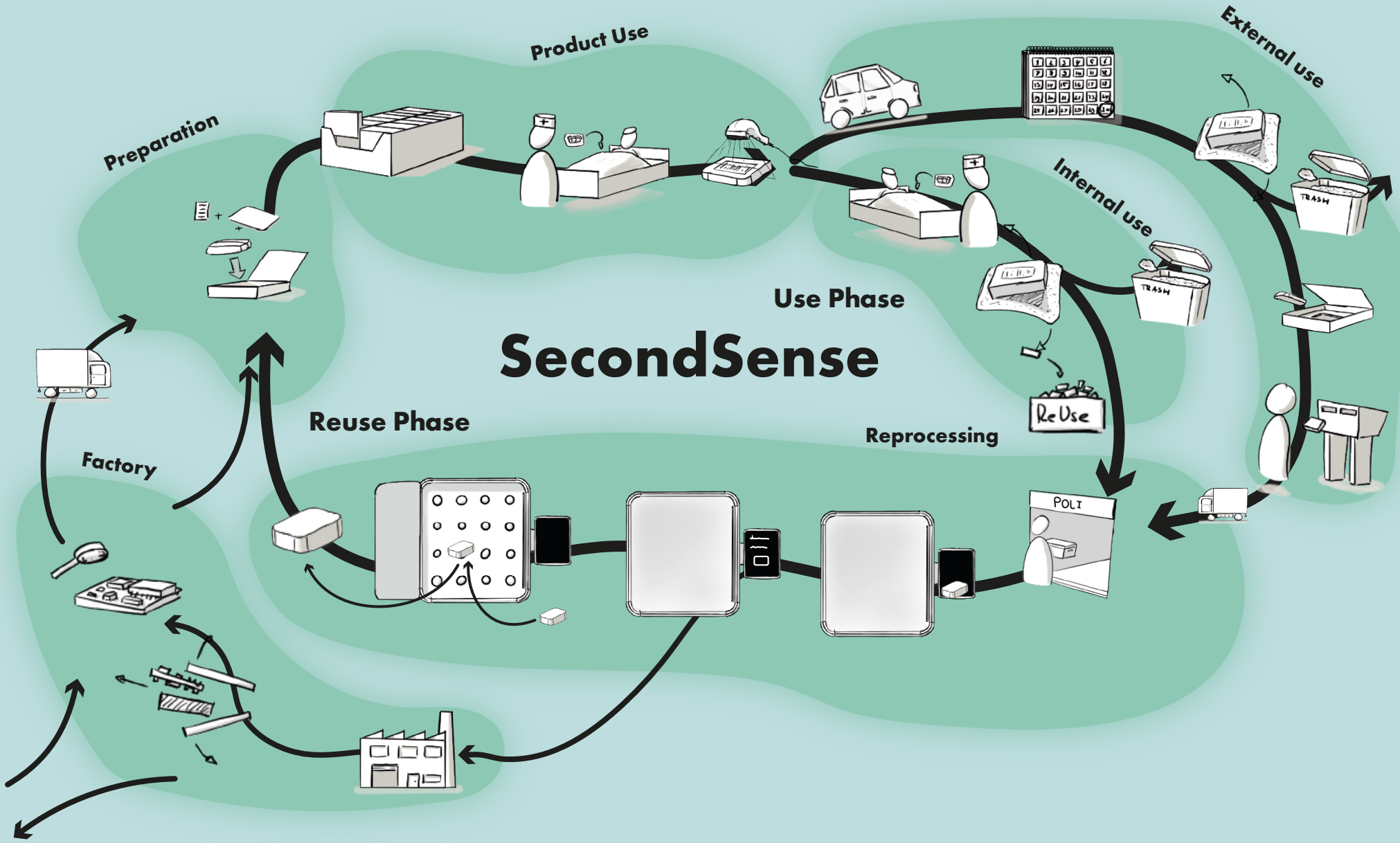


Figure II: SeconSense System

Figure III: Front view of SenseCab with dummy sensors

after five and ten uses. The analysis considered worst-case scenario, with a best-case scenario showing CO2 reductions upwards of 80% after 10 uses.

Recommendations

The case study outcomes led to the following recommendations, intended as a starting point for designers and engineers developing circular solutions for medical wearable sensors:

R1. Gain a solid understanding of the basic principles of the circular economy
R2. Research circular design strategies and business models for the design challenge
R3. Determine what defines circular economy
R4. First, determine how the system is going to be circular, then design the product so that it enables this system.
  R4.1 Take additional care when determining boundaries
  R4.2 Determine a detailed system outline
  R4.3 Analyse the system to formulate requirements
  R4.4 Integrate the classic design process into the circular system
R5. Use fast-track LCAs for conceptual insights
R6. Involve stakeholders in the design project.

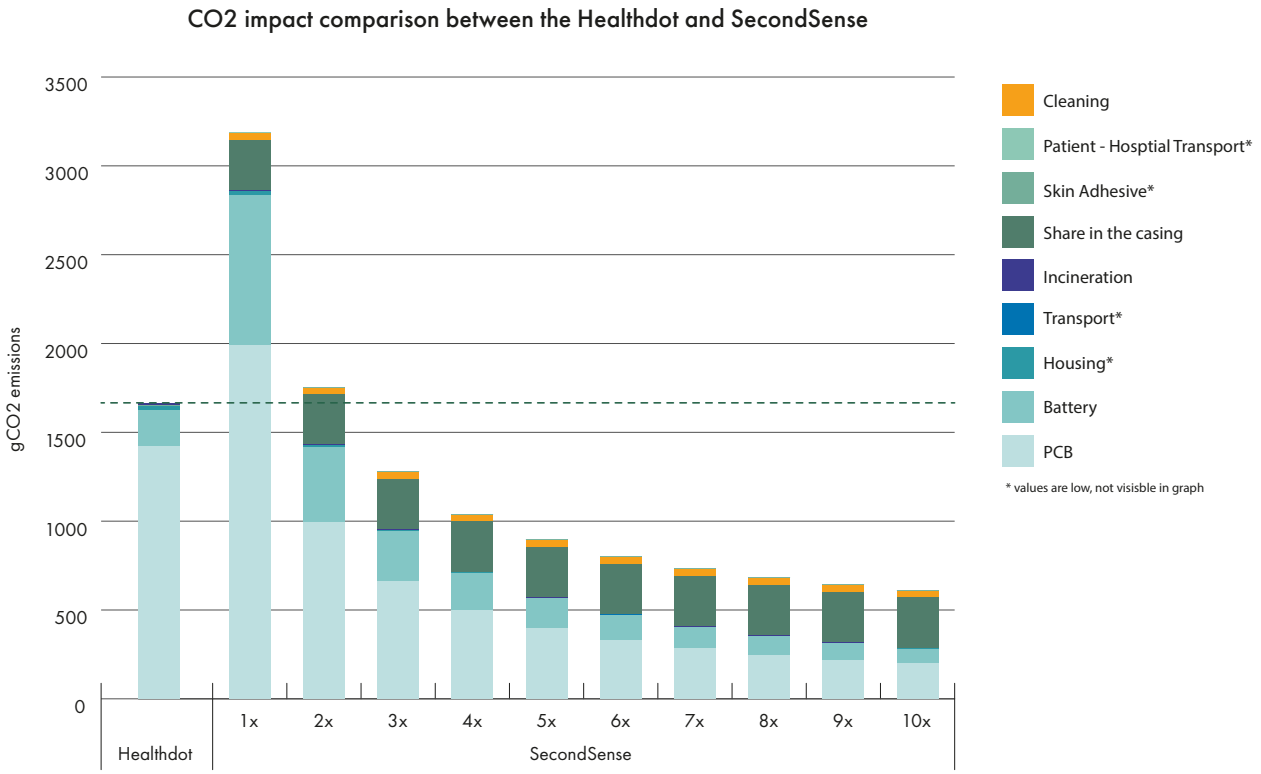


Figure IV: CO2 impact comparion between the Healthdot and SecondSense

VI • Content

Part one

introduction

1 • Problem Definition

2 • Aim and Approach

1 • Problem Definition

Healthcare is an important part of our daily lives; from small inconveniences to life-saving procedures, we all have been in touch with the healthcare system at some point. Healthcare is here to protect us from harm and to heal us, but in doing so it creates an enormous amount of waste that is hurting us and our planet in the long run.

Healthcare sector has, in fact, a large impact on our ecosystem. To illustrate, 4,4% of all global emissions come from the healthcare sector (Health Care Without Harm, 2019), and in the Netherlands, this number rises to 7% (Gupta Strategists, 2019). When it comes to waste, the average European hospital generates 2,4kg of waste per patient per day (Singh et al., 2022). While these numbers are high, the sector is actively trying to become more circular, with initiatives such as "Samen naar een circulair ziekenhuis" [To a circular hospital together] (de Zorgambassade, 2022).

With the healthcare industry becoming smarter and more digitized, you can also expect the amount of electronic waste to rise. According to the European Parliament, e-waste is one of the fastest-growing waste streams while less than 40% of this waste is recycled (European Parliament, 2020). The global average is even lower, with only 17% being collected and recycled properly (Forti et al., n.d.). General e-waste products often end up stockpiled at home and too often end up at the incinerator (Miliute-Plepiene, 2021).

E-waste is a dangerous waste stream as it contains toxic and harmful materials that are detrimental to both humans and the environment (Lin et al., 2022; Ogunseitan, 2022; Wirtu & Tucho, 2022). Although medical products serve to make us better, unfortunately, they are no exception to this waste stream (Lefebvre et al., 2011; Ogunseitan, 2022).

Healthdot

In 2021, Philips introduced the Healthdot (Figure 1.1): a small Medical Wearable Sensor (MWS) that measures the patient's heart rate and uploads this to the hospital, so that patients can be monitored remotely from their own home (Philips, n.d.-d). With the introduction of the Healthdot, Philips aims to improve healthcare by allowing transitional care, as it frees up bed space

Figure 1.1: Philips Healthdot being applied (Philips, n.d.-b)

which could reduce hospital emissions. However, after its use the Healthdot's battery is empty and the device has to be disposed of. So this improvement in care comes at the cost of another disposable electronic device.

While Philips already has made improvements to this with a circular successor, which contains reusable electronics, I believe that we can do this more sustainably. With this thesis, I aim to inspire designers, engineers and anyone else involved in the development of medical products to create more circular solutions, to reduce the impact we have on our world.

1.1 Medical wearable sensors

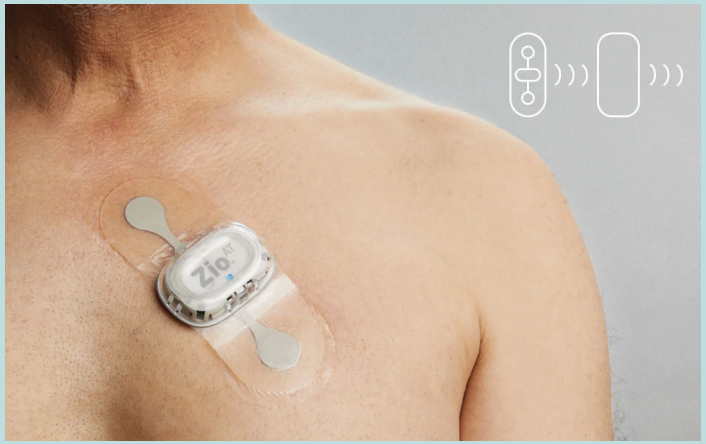
The Healthdot can be categorised as a medical wearable sensor (MWS), but what defines a medical wearable sensor? This is a group of products that sense bio measurements from patients, such as heart rate or ECG signals, wirelessly. They are commonly attached to the patient using an adhesive patch and monitor the patient without the use of external devices for an extended amount of time. Some have data connectivity to allow continuous monitoring by hospital staff, and other record data to be read and analysed later.

Wells et.al (2022) define a category of 'wearable sensors' as follows: "a device worn on the external body surface, unencumbered by wires, for the continuous and non-invasive detection of biosignals

(such as movement, heart rate, respiratory rate, and oxygen saturation).". This definition is used by Wells to define the Healthdot but also includes products such as smartwatches, which he also compares in his paper. While this definition captures the sensing side of the Healthdot, it also allows non-medical products to enter the category. For this reason, the term 'medical' was added to this definition, creating the following working definition for this thesis:"A medical device worn on the external body surface, unencumbered by wires, for the continuous and non-invasive detection of biosignals (such as movement, heart rate, respiratory rate, and oxygen saturation)."

1.1.1 The current state of the medical wearable sensor market

There are several MWS on the market, see Figure 1.2, however, most seem to operate in the US market. Little information was found on the adoption of these devices in the European healthcare sector. Most devices are single-use devices, but Vivalink and Philips' BioTelemetry were two companies that I found that create reusable sensors. Interestingly enough, most of these ECG sensors appear to market themselves more towards a 'medical consumer', rather than directly on hospital use. This likely indicates that there is no medical reusable sensor on the market that is focused on reuse after hospital use. However, please not that this is a high-level scan, and further market research should be done to conclude on this.



Zio XT - iRhythm
Single-Use Device
ECG
(iRhythm, n.d.)

Vitalpatch - Vitalconnect
Single-Use Device
ECG
(Vitalconnect, n.d.)

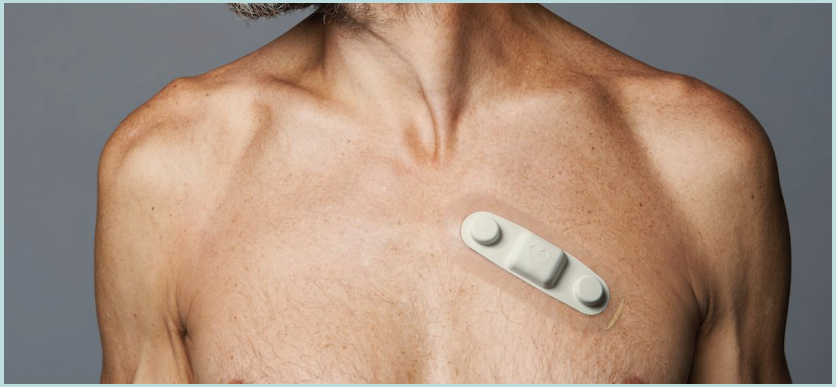
Figure 1.2: Medical Wearable Sensors from different manufacturers

AT Patch - ATSens
Single-Use Device
ECG
(ATsens, n.d.

Centroid - Masimo
Single-Use Device
Vitals
(Masimo, n.d.)

Healthdot - Philips
Single-Use Device
Vitals
Philips, n.d.-d)

ePatch - BioTelemetry
Reusable Device
ECG
(BioTelemetry, n.d.)



Wearable ECG monitor - Vivalink
Reusable Device
ECG
(Vivalink, n.d.)

2 • Aim and Approach

This chapter outlines the purpose and approach of this thesis. It begins by defining the thesis's objective, followed by an explanation of its structure. The research questions are presented, and a detailed description of the case study is provided. Lastly, the process of generating insights is illustrated.

With my thesis, I aim to present insights for designers that can be used in the design process to improve the circularity of MWS. I will do this by first analysing an existing medical wearable sensor, the Philips Healthdot, after which a proposal for a circular redesign is made. The final insights are presented in the form of recommendations and can be found in Section 12.4.

I aim to address the knowledge gap that exists when it comes to designing circular MWS. At the time of writing no previous work was found that specifically focuses on the design of circular and small medical electronics like the Healthdot. One master thesis was found that focused on the Healthdot, which focused on engaging patients in a circular Healthdot (van Hamersveld, 2019).

The main deliverables of the thesis were recommendations for designers regarding the circular design of MWS and a concept that shows how a circular Healthdot and its system could look like. Some core activities include the analysis of the current Healthdot and the creation of a circular system. Out of scope were activities such as embodiment and patient interactions, as these were found to not add significant value to this thesis in particular or are already covered in the DiCE project elsewhere. In Appendix A the full scope can be seen.

It is important to emphasize, that the concept presented in Chapter 9 is developed to create recommendations for designers, based on a case study where the Healthdot is used as a reference design. It serves as an inspiration and a vision of what a circular system could look like and does not offer a closing design.

2.1 Thesis Structure

To bring structure to my thesis I used the Reflective Transformative Design Process (RTDP) (Hummels & Frens, 2009), with some elements from Integrated Creative Problem Solving (iCPS) (Buijs & van der Meer, 2013). RTDP differentiates between five phases, as seen in Figure 2.1, between which you move flexibly

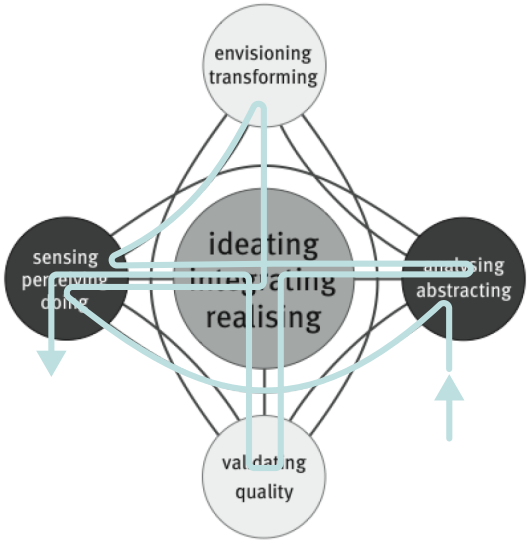


Figure 2.1: RTDP and the process flow between phases

using reflections. The method focuses on information and information flows, which suits the research through design approach of this thesis. iCPS has a clearer division between phases, which I found did not work for me in this project; the flexibility of RTDP had my preference. However, I did use the project management and overview steps from iCPS as an addition to the

The aim of this thesis is to

“..present insights for designers that can be used in the design process to improve the circularity of MWS”

RTDP method. For a more detailed comparison, see Appendix B.

2.2 Research Questions

This thesis is guided by the following research question: What should designers keep in mind when designing circular MWS? With the following sub-questions to support the process:

RQ1. What is the circular economy?
- RQ1.1 What defines the circular economy
- RQ1.2 How do you design for the circular economy

RQ2. What is the current status of the Healthdot?
- RQ2.1 What is the environmental impact of the Healthdot?
- RQ2.2 Who are the stakeholders in the system?
- RQ2.3 What are the barriers and opportunities to a circular system?

RQ3. What could a circular MWS look like?
- RQ3.1 What could a circular system look like?
- RQ3.2 What could a circular Healthdot look like?

2.3 Knowledge Acquisition

To gather literature I performed an explorative search on databases such as Google Scholar, PubMed and ScienceDirect for a variety of keywords. Selected papers were scanned for their relevance and read if found relevant. Some unpublished or confidential background knowledge was used, however, all data presented in this thesis are acquired from public sources. Furthermore, I had (informal) conversations with people at Philips (n=3), Games for Health (n=3), the Erasmus MC (n=2) and the LUMC (n=1) to gain information not found in papers and to validate findings. Data was collected by taking notes and in some cases, audio recordings (n=3).

2.4 Research Through Design: a Case Study Approach

To generate insights on how MWS can become circular, I selected a case study approach as my method. In this case study I went through the design process, from problem analysis to concept selection, and reflected upon my process to generate these insights. I have looked at different recovery flows, how they affect circularity and how to choose between these options.

The Healthdot currently on the market is a single-use device, meaning that after its use it is disposed of. For reasons stated earlier, this needs to change. The new Healthdot 5.0 is already an improvement, featuring a reusable printed circuit board (PCB), but I think we can go further; I think that the Healthdot has great potential for reuse. Other medical electronics already have shown that it is possible to reuse complete devices (see Section 1.1), so why shouldn't the Healthdot be reusable too? For these reasons, I believe that the Healthdot makes a good fit as the subject of this thesis.

But how can it be made circular? Does it even make sense to make it circular? Is reuse even the best option? This leads to the following design challenge: "... to improve the circularity of the Philips Healthdot"

2.4.1 Design process

For the design process, I used the double diamond method as a guideline. The process had an iterative nature, when needed choices were made earlier, later or revisited. The four phases were used in conjunction with the RTDP described earlier. This process can be seen in Figure 2.2, with references to relevant sections.

2.5 Insight Generation

To come to insights, I reflected on my project and discussed this with peers, as well as perspectives. In these reflective moments I focussed on the activities that I had done and what stood out to me, and especially focussed on why I did it. I focussed on finding tensions between activities, and I translated the results of these reflections into insights. I used perspectives to take on different mindsets of different readers, for example, a 'business' perspective or a 'materials-engineer' perspective, to try and find insights that I otherwise would have missed. Insights are presented in the form of take-aways at the end of their relevant chapters. An overview can be found in Appendix C.

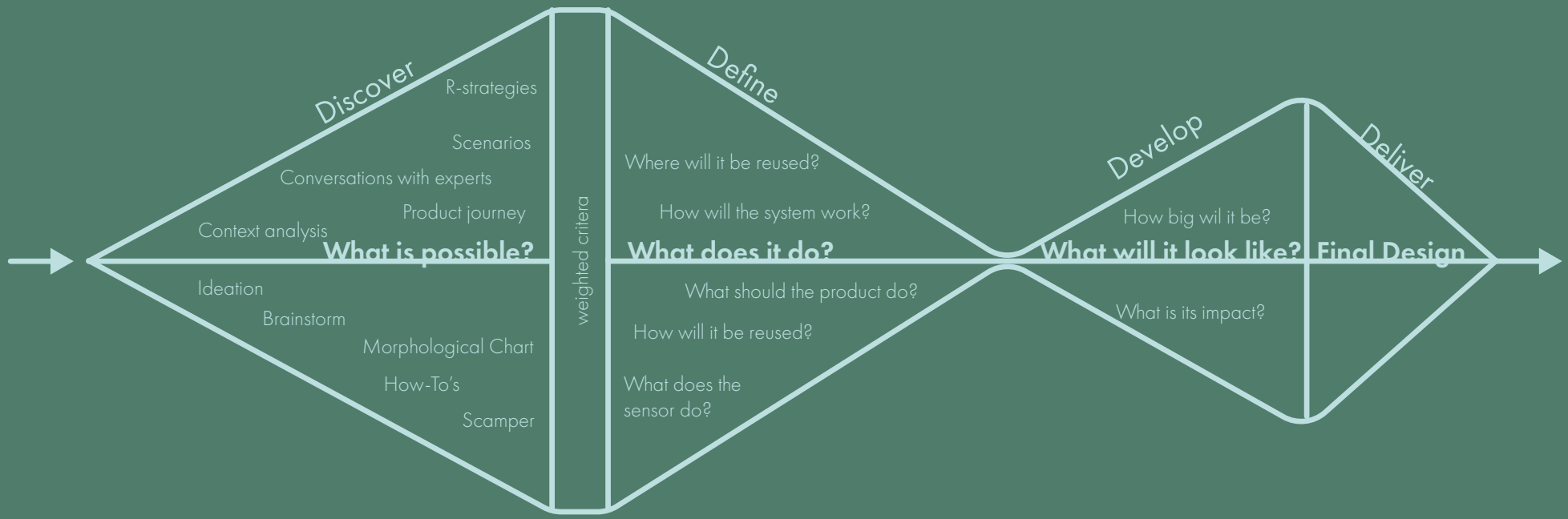


Figure 2.2: General design process followed in this thesis

Part two:

the circular economy

3 • What is the Circular Economy

In this chapter, we will look into what the circular economy is, and how you can design for it. First, an introduction to the circular economy will be given, then the working definition for this thesis is discussed and research on circular design is described.

The circular economy refers to a system that is restorative by intention (Ellen MacArthur Foundation, 2013a). Unlike the linear 'take-make-waste' model, the circular economy intentionally designs processes, products and systems which ensure that resources are kept in use as long as possible.

A commonly used framework for visualising the principles of the circular economy is the adapted value hill (Corbin et al., 2021), seen in Figure 3.1. This framework combines the value hill (Achterberg et al., 2016) and the 9R framework (Potting et al., 2017) (see Figure 3.2). It depicts how value is built up and destroyed in relation to these strategies. It shows that the shorter you keep your circular loop (e.g. reuse), the more value you keep and the less you destroy, which should lead to a more sustainable product. However, it is important to highlight that this is a general guideline (Potting et al., 2017). Certain circumstances may arise where the actions required to reuse a product have so much impact, that recycling could be a better option than reuse.

3.1 Circular or Sustainable?

The terms sustainability and circular economy are often mixed up and used interchangeably in the context of environmental impact. However, they do not mean the same. Sustainable means '[something] that can continue or be continued for a long time' (Oxford Learner's Dictionaries, n.d.), and is usually combined with economic, social and environmental factors. However, in recent years the definition became associated with being environmentally conscious, allowing for the meaning 'involving the use of natural products and energy in a way that does not harm the environment' (Oxford Learner's Dictionaries, n.d.) to be common as well.

On the same note, circular economy does not perse mean environmentally sustainable behaviour, it is about keeping resources in use for longer. Circular use of material could be more polluting compared to more linear use (Blum et al., 2020); that is if the actions needed to reprocess the material for reuse would have more impact than if the material was repurposed. In this thesis, any references towards circularity or sustainability are made within the context of environmental impact, unless stated otherwise.

3.2 Defining 'Circular Economy'

Even in the context of environmental impact, many definitions try to describe the circular economy; in one instance 114 different definitions were found in different papers (Kirchherr et al., 2017). In an attempt to come to a universal definition, multiple papers have tried to create descriptions for the circular economy (Ellen MacArthur Foundation, 2013b, 2013a; Geisendorf & Pietrulla, 2018; Kirchherr et al., 2017, 2023).

For this thesis, I choose the following working definition: "the value of products and materials is maintained, waste is avoided, and resources are kept within the economy when a product has reached the end of its life and is restorative in nature.". This is based heavily on Geisendorf & Pietrulla's (2018) definition, to which I've added the term 'restorative'.

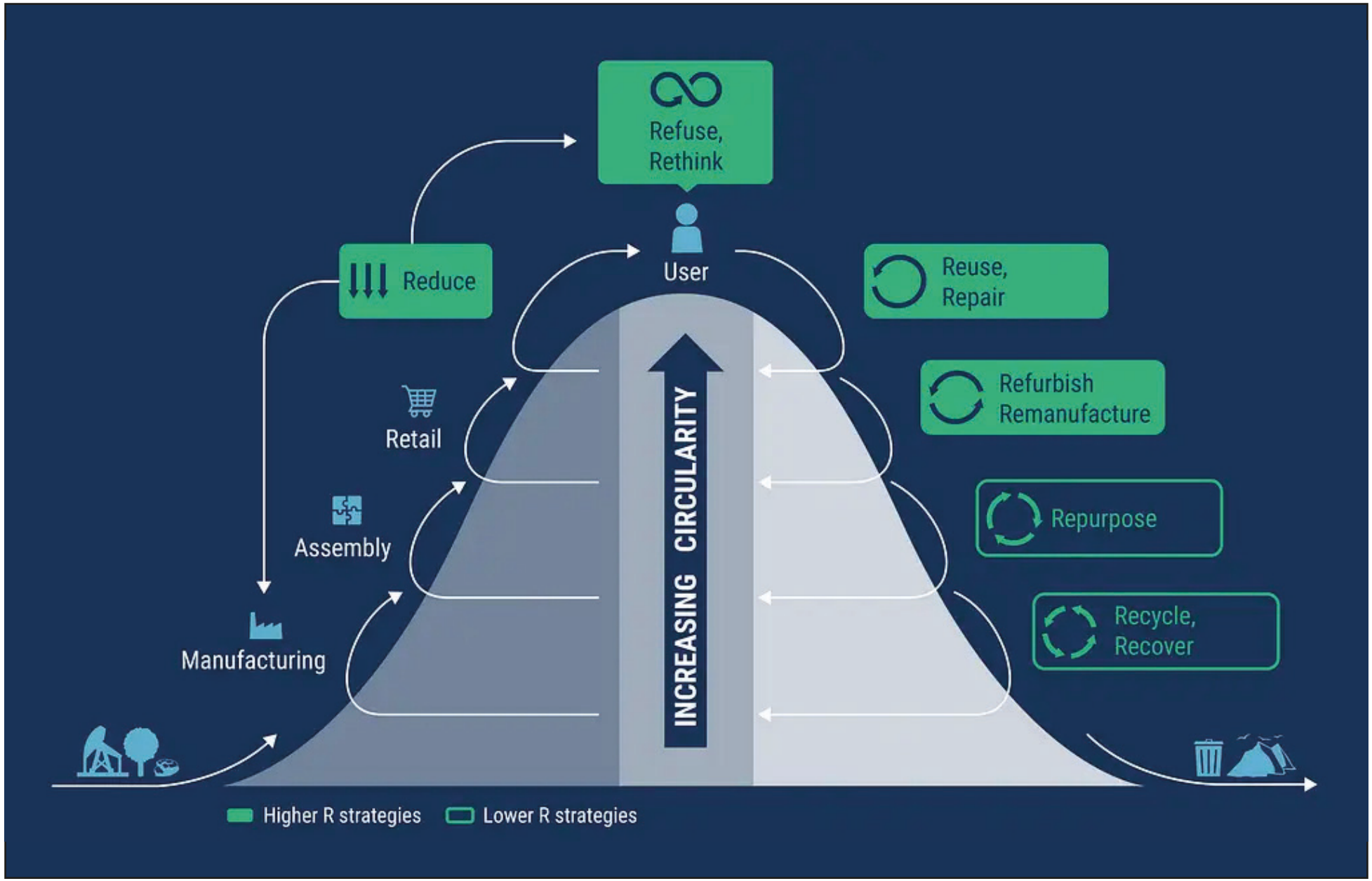


Figure 3.1: Adapted Value Hill (Metabolic Institute, 2021)

Smarter product use and manufacture	**Refuse**	Make product redundant by abandoning its function or by offering the same function with a radically different product
	Rethink	Make product use more intensive (e.g. through sharing products, or by putting multi-functional products on the market)
	Reduce	Increase efficiency in product manufacture or use by consuming fewer natural resources and materials
Extend lifespan of product and its parts	**Reuse**	Reuse by another consumer of discarded product which is still in good condition and fulfils its original function
	Repair	Repair and maintenance of defective product so it can be used with its original function
	Refurbish	Restore an old product and bring it up to date
	Remanufacture	Use parts of discarded product in a new product with the same function
	Repurpose	Use discarded product or its parts in a new product with a different function
Usefull application of materials	**Recycle**	Process materials to obtain the same (high grade) or lower (low grade) quality
	Recover	Incineration of materials with energy recovery

Figure 3.2: The 9R framework (Adapted from Potting et al., 2017)

My reasoning to use description is that it is conclusive in what circular economy is, and at the same time simple enough to work with. For example, Kirchherr's (2017) definition – "A circular economy describes an economic system that is based on business models which replace the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes, thus operating at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations." – I found to be overly complex, and difficult to understand. My reasoning for including the term 'restorative' in my working definition is because the original definition – which did not include restorative – does not imply any action with the environment. It is a more economical perspective, where it is all about 'maintaining value'. However, I believe that in order to be sustainable we need to be restorative in our actions. Simply reducing waste is not enough.

The topic of definition deserves more attention than is in the scope of this thesis. For further reading, the following articles are suggested as a starting point:

- Blum et.al., 2020 – Why "Circular" doesn't always mean "Sustainable"
- Corvellec et.al., 2022 – Critiques of the circular economy
- Geisendorf & Pietrulla, 2018 – The circular economy and circular economic concepts: a literature analysis and redefinition
- Kirchherr et.al, 2017 – Conceptualizing the circular economy: An analysis of 114 definitions
- Kirchherr et.al, 2023 – Conceptualizing the Circular Economy (Revisited): An Analysis of 221 Definitions

3.3 The Current State of Medical Circularity

As mentioned in Chapter 1, the medical sector generates quite some waste. Part of this waste is generated by the use of single-use devices. One reason why the medical sector is still heavily using single-use devices is that there is convenience in them (MacNeill et al., 2020); after use, you simply dispose of them. Another reason given by MacNeill is that there are concerns regarding safety and infections.

Research towards how the medical sector can become more circular has been done as well. For example, multiple road maps and visions for a green future have been created (de Zorgambassade, 2022; Gupta Strategists, 2019; MacNeill et al., 2020) and hospitals such as the Erasmus MC have initiatives such as 'De Groene IC' [The Green IC] (Erasmus MC Foundation, n.d.-b).

In some areas, the medical sector already adopted circular practices. For instance, when it comes to larger, more expensive equipment like X-rays or MRIs, repair and refurbishment are often done due to their substantial initial investment. However, repair costs are often quite high, because the medical field is high-risk (Kane et al., 2018).

3.4 Take Aways

I1: There are many interpretations of what the circular economy means. Deciding on a definition that fits the vision of you and your team can help you in making decisions, however, keep the discussion open as you will likely run into situations where your definition is not closing.

I2: Models such as the 9R model and the adapted value hill offer a good but simple starting point for designing for the Circular Economy.

I3: Circularity can sometimes be counter intuitive. Validate your ideas with tools such as the Life-Cycle Analysis (LCA), further described in Section 5.2.

4 • Designing for the Circular Economy

Now that we have established a baseline for the circular economy, how would you design for this? In this chapter, a brief look into circular design strategies and business models is given.

4.1 Circular Desing Strategies

Research has been done towards circular design strategies (Bocken et al., 2016; Kane et al., 2018; Moreno et al., 2016). Bocken et.al. (2016) lists numerous strategies categorised on their 'circular flows'. Circular flows are ways that the circular economy allows the flow of resources to happen. Bocken mentions three resource cycles or loops: narrowing, slowing and closing (see Figure 4.2). Narrowing loops will not be further looked into, because it does not address the cycling of materials or anything that is restorative – it mostly focuses on (material) efficiency. It is not considered a circular strategy (Bocken et al., 2016) and thus is not taken into consideration in this thesis.

4.2 Circular Business Models

Designing a circular system requires you to rethink your business model. Research has been done towards which business models apply to the circular economy, specific to the medical sector. In one study, business models are linked to certain medical products based on their (monetary) value and medical criticality (Guzzo et al., 2020), see Figure 4.1. Based on conversations with Philips and comparisons with examples given in the paper, it is assumed that the Healthdot is located on the border of low-medium value and non-critical.

In Appendix D an overview of design strategies and business models can be found related to the resource loops. This overview was used as a start for my ideation, which is further described in Chapters 10 & 11.

4.3 Take-Aways

I4: A lot of research is done on how to design for the circular economy which offers a great starting point. Try to find examples of your product – or something similar – that already feature circular economy actions.

I5: The circular economy requires you to design the system and context of your product, more than you might be used to from a classic product design process.

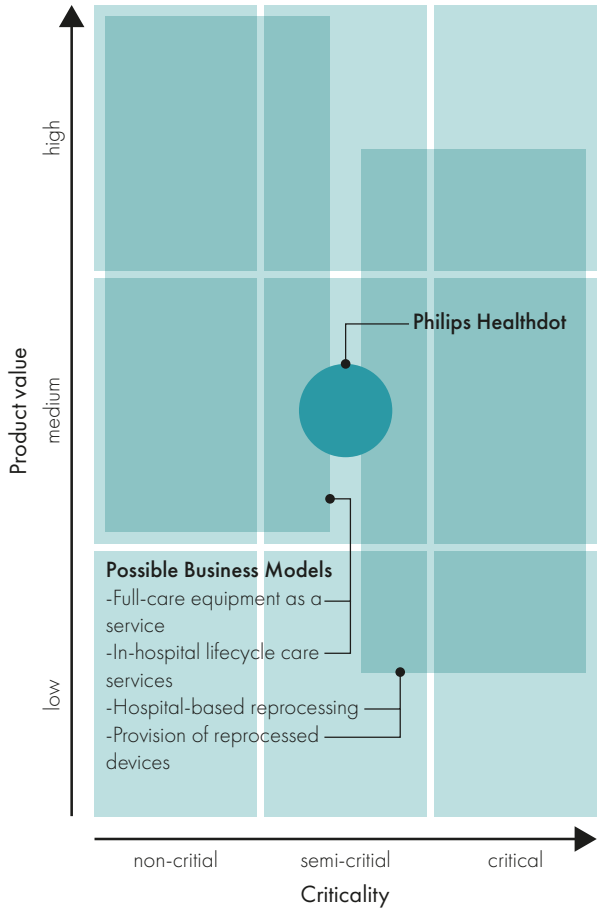


Figure 4.1: Business models for the medical sector, adapted from Guzzo et.al (2020)

Narrowing Loops

Narrowing loops focusses on reducing the required resources, meaning you focus on minimizing resource use. This is a way to be more sustainable, but not circular. It focusses on consuming less materials, but it does not imply any form of any cycling or change in cycling speed. While it could be used as a tool to boost sustainability, on its own it is not a circular strategy and will not be looked into in this thesis.

Slowing Loops

Slowing loops focusses on making the resource loops take more time through product-life extension and the design of life-long goods. This allows resources to stay in the loop longer, in theory reducing the amount of resources required and getting more value out of these resources. However, the end result of slowing loops is still left open, as it is not (per se) a closed system.

Closing Loops

Closing loops is focussed on creating a circular flow of resources between post-use and production. This allows resources to stay in the flow to be reused and recycled. It means that at the End of Life (EoL) of a product, the product somehow stays in the material flow.

The distinction is made between a 'technological' cycle and a 'biological' cycle. Materials that are not suitable to a biological system should be recycled, while dissipative losses should be compatible with biological systems.

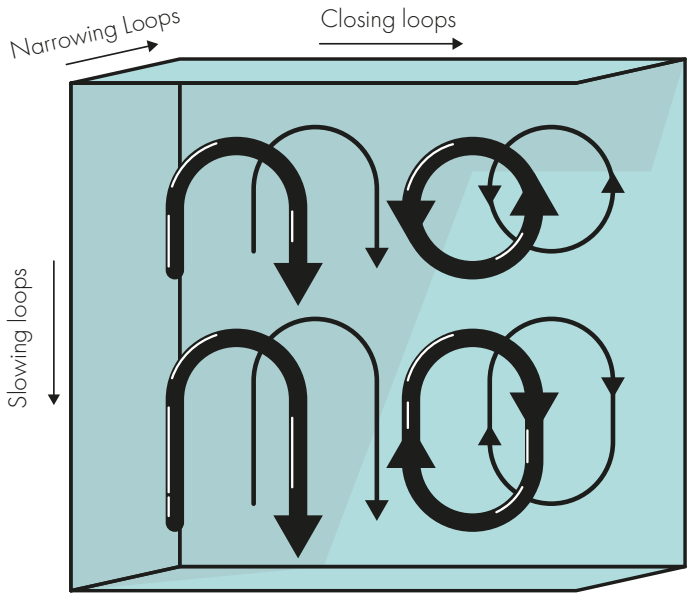


Figure 4.2: Resource loops and their descriptions. The illustration shows how they result in certain flows. Adapted from Bocken et.al. (2016)

Part three

context analysis

5 • The Philips Healthdot

In this chapter, the Healthdot is looked at in more detail. First, a detailed look at the product is given, after which its product journey is analysed. Finally, a fast-track life-cycle analysis is performed to assess its environmental impact.

The Philips Healthdot is currently deployed by Philips and used in hospitals in the Netherlands. The sensor is currently on version 3.1 and is a medical device classified as a Class IIa product (European Commission, 2023). It measures heart rate, respiratory rate and patient activity, which is then uploaded to the hospital (Philips, n.d.-c), however, this also means that personal data is stored on the device. It is a single-use device and can be used for up to 14 days.

Currently, Philips is developing a new, circular version called the Healthdot 5.0. This version features a larger battery which can be used for up to 30 days, but what is more significant, is that after its use the PCB can be removed and reused (personal communication, 14-03-2023). Within the context of DiCE, version 5.0 is the subject of research towards collection, reverse logistics and remanufacturing. However, due to confidentiality constraints, this thesis focuses on a redesign of the Healthdot 3.1; any reference to the 'Healthdot' in this thesis refers to this version (3.1) unless stated otherwise.

The Healthdot consist of five major parts – a PCB, a battery, an upper and lower casing, and a skin-adhesive patch – and some smaller components, which can be seen in Figure 5.1-5.3. It weighs 12 grams, has an IP55 rating and LoRa connectivity (Philips, n.d.-c). It is glued together, making recycling very difficult. It comes packaged in a blister, together with a simple instruction manual, and is shipped out in boxes containing 30 units.

5.1 Product Journey

To gain insight into how the Healthdot is used and its system works, a product journey was created.

In a conversation with Philips, four possible scenarios were described that the Healthdot might go through, see Figure 5.4. They can be categorised into pre-operative use (scenarios 1 and 2) and post-operative use (scenarios A and B). While the Healthdot can be used for other treatments as well (Philips, n.d.-d), it was decided to focus on a surgery context due to the scope of this thesis.

Scenario 2 describes a situation where the Healthdot is used for trending; collecting data before treatment to establish a baseline. Currently, scenario 1 is predominantly used, which is why scenario 2 was left out of scope. Scenarios 1A and 1B were further developed into a product journey, which can be seen in Figure 5.5. It is assumed the Healthdot is used 50% in scenario 1A and 50% in scenario 1B. In Appendix E a detailed product journey can be found.

Figure 5.1: The Philips Healthdot. (Philips, n.d.-d)

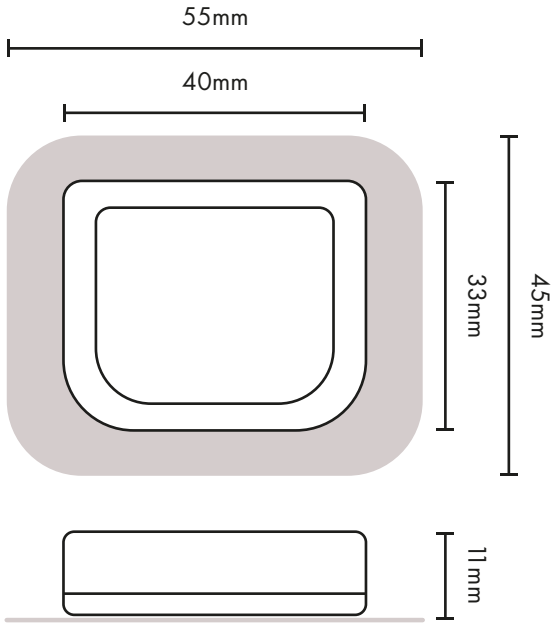


Figure 5.2: Dimension of the Healthdot, on a 1:1 scale.

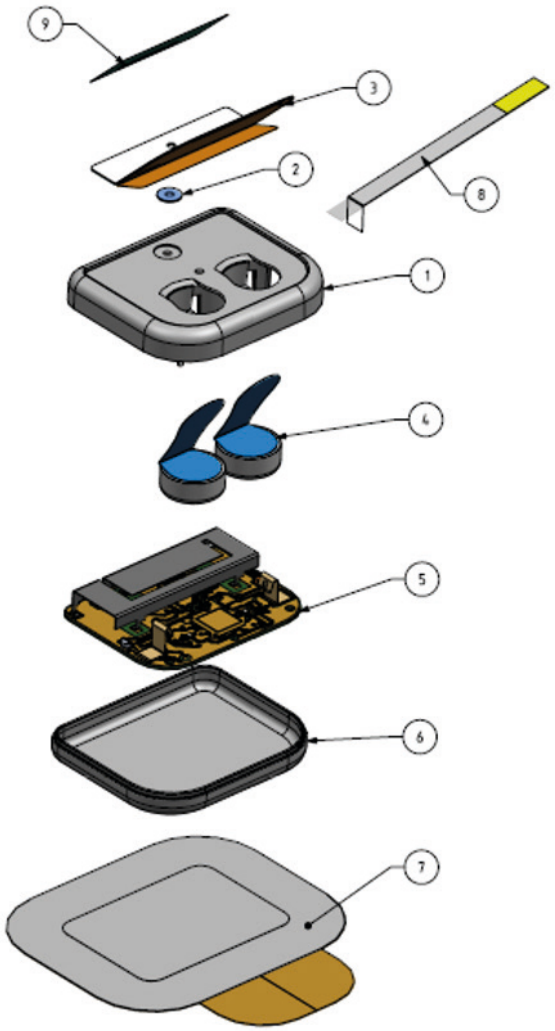
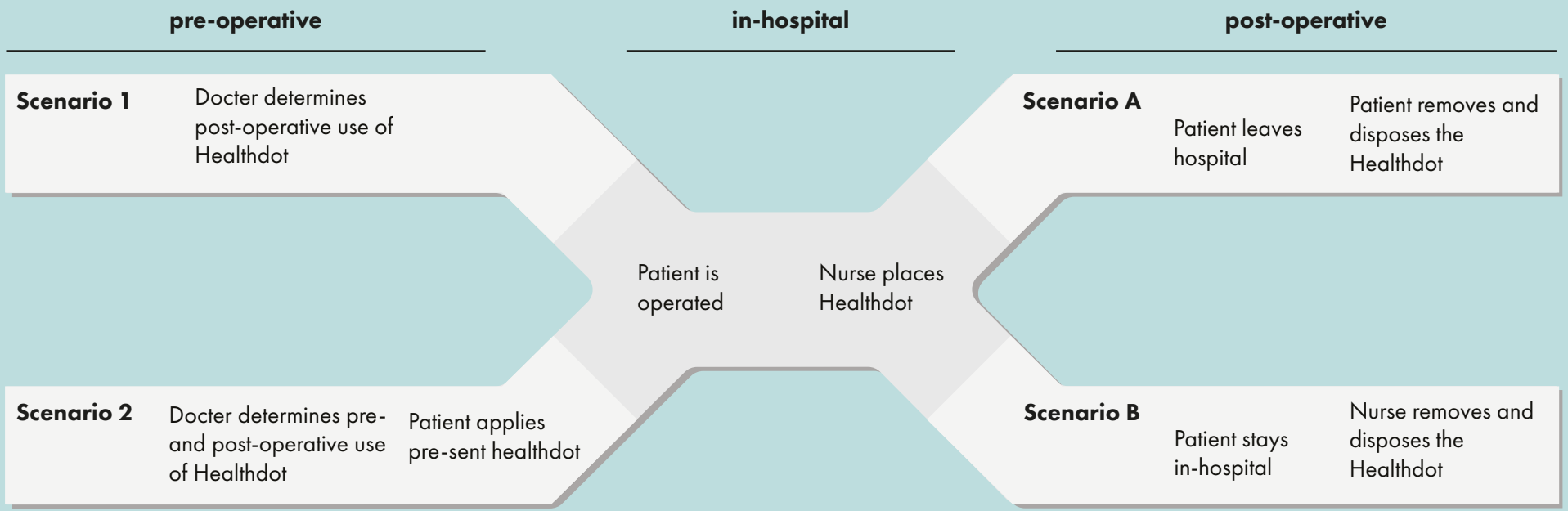


Figure 5.3: Exploded view of the Healthdot. Image courtesy of Philips (Personal communication, 08-08-2023)

Part ID	Name	Mass (grams)
1	Casing, Top	~ 2
2	Membrane filter	<<1
3	Seal Tape (including the release liner)	<<1
4	Batteries	2*1.68 = 3.36
5	PCB	~ 3
6	Casing, Bottom	~ 2
7	Skin Adhesive Assembly	~1
8	Circuit Breaker Tab	<<1
9	Product Label	<<1
10	Glue (0.04 mL)	<<1
	Total	12

Table 5.1: Components and weights of the Philips Healthdot. Data courtesy of Philips (personal communication, 08-08-2023)



Scenario 1

In this scenario the Healthdot is only used for post-operative monitoring. This means that before going to the hospital for surgery, the doctors determine that a Healthdot is used after surgery but the patient has no interaction with the product. After the surgery, the product is placed on the patient.

Scenario 2

In this scenario the Healthdot is used for pre-operative trending and post-operative monitoring. The doctors determine that establishing a baseline or finding trends in heart- and respiratory rates is necessary, and send the patient a Healthdot. The patient then has to place and activate the Healthdot themselves. In the hospital, the Healthdot is removed from the patient pre-surgery, and after surgery a new one is placed.

Scenario A

In this scenario, the patient is capable of going home immediately (<24h) after surgery. The Healthdot is placed on the patient, which allows the hospital to monitor the patient remotely.

This scenario is very patient depended. Philips noted that some patients have to wear it for only 2-4 days, while other patients are required to wear it for up to 14 days.

Scenario B

In this scenario, the patient is required to stay in the hospital for monitoring. The Healthdot is applied here to allow the patient to move freely through the hospital, and not to be hindered by wires. Before leaving the hospital, the Healthdot is removed from the patient.

Figure 5.4: Possible use scenarios for the Healthdot

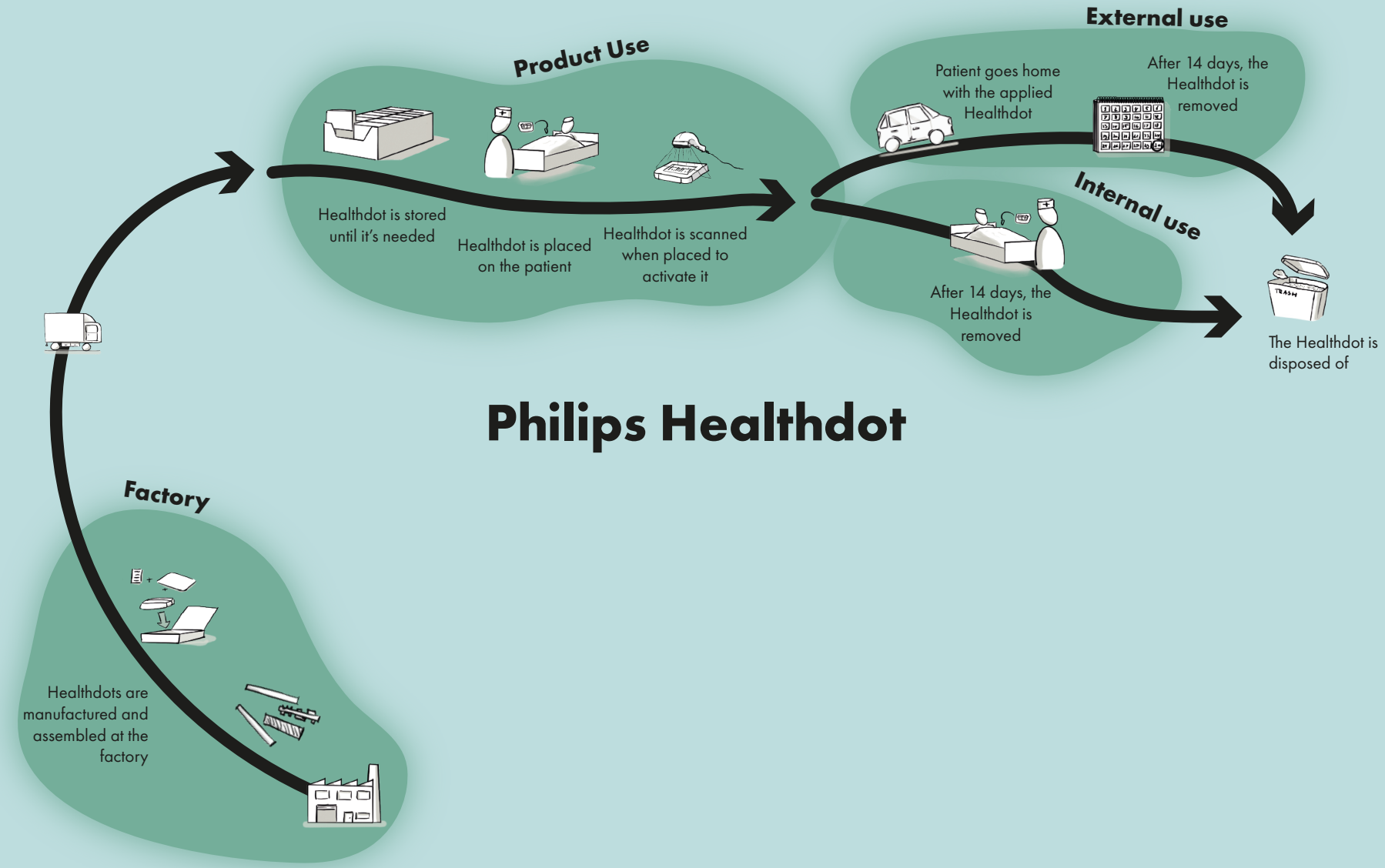


Figure 5.5: The Healthdot's product journey

Reflection

At first, I decided to focus solely on scenario 1A, as this is the most common-use scenario for the Healthdot. However, in a later conversation with Philips where concepts were discussed, it became apparent that changing the scenario you design for will subsequently change the circular system you design. In this case, adding scenario 1B to the scope changes where the Healthdot ends after its life, changing the options for your collection system. For this reason, both scenarios 1A and 1B were included in the final product journey.

5.2 Life Cycle Analysis

Although the Healthdot is a relatively straightforward product, it is still valuable to analyse its environmental impacts. To get an overview of the impact of the different components, I performed a fast-track Life Cycle Analysis (LCA) using the 2023 Idemat database (Stichting Sustainability Impact Metrics, n.d.-a). This method is used to quickly get a rough evaluation of the eco-burdens of a product throughout its life cycle (Stichting Sustainability Impact Metrics, n.d.-b). However, it's important to note that due to the nature of this fast-track LCA, several assumptions had to be made. As a result, no specific amounts for CO2 are mentioned, but approximations are offered instead.

In this LCA, only the Healthdot's primary parts mentioned previously are taken into account, the weight of which is given in Table 5.1. Not enough detail is known on the weights of the other parts, and it is assumed they're too small to have a significant impact. The casing of the Healthdot is made from an ABS + PA blend, which due to lack of data is simplified to ABS.

In this analysis one life cycle of the Healthdot is tracked, according to the product journey from Figure 5.3. It is assumed that it is produced at Philips in Eindhoven and transported to the Erasmus MC in Rotterdam. As previously described in Section 5.1, it is assumed that 50% of the use cases are outside the hospital. It is assumed the patient travels 5 km (CBS, 2023) from the hospital to their home by car. For its end-of-life, a worst-case scenario of incineration is assumed, in part due to a lack of data on the eco-impacts of the recycling of PCBs. Packaging was not taken into account as no detailed information was available. The results of the LCA can be seen in Figure 5.6, and a detailed calculation can be found in Appendix F.

As expected, the PCB has by far the biggest impact on the sustainability impact of the Healthdot. Electronics are challenging to recycle, and with their high production impact – over 150 times that of ABS, according to the Idemat database – it makes sense to keep them cycling for as long as possible, which will be done with the new Healthdot 5.0. Because the Healthdot is so light and small, the transport movements barely show up on the graph. It is assumed that transport from the factory to the hospital will have more impact if the packaging is counted.

5.3 Take-Aways

16: It is important to choose the right scenario and context, as small changes here can drastically influence the outcome of your design.

17: LCA's are a valuable tool to understand where the impact lies in your product, or why your product isn't circular. If you could only save one component, which one would it be and why? For example, the PCB has the biggest impact on the Healthdot, so it makes sense to make this part last as long as possible.

18: LCA's can be tricky, as minor changes in your assumptions can drastically change its outcomes. Test different assumptions in your LCA to see how these affect the impact of your product.

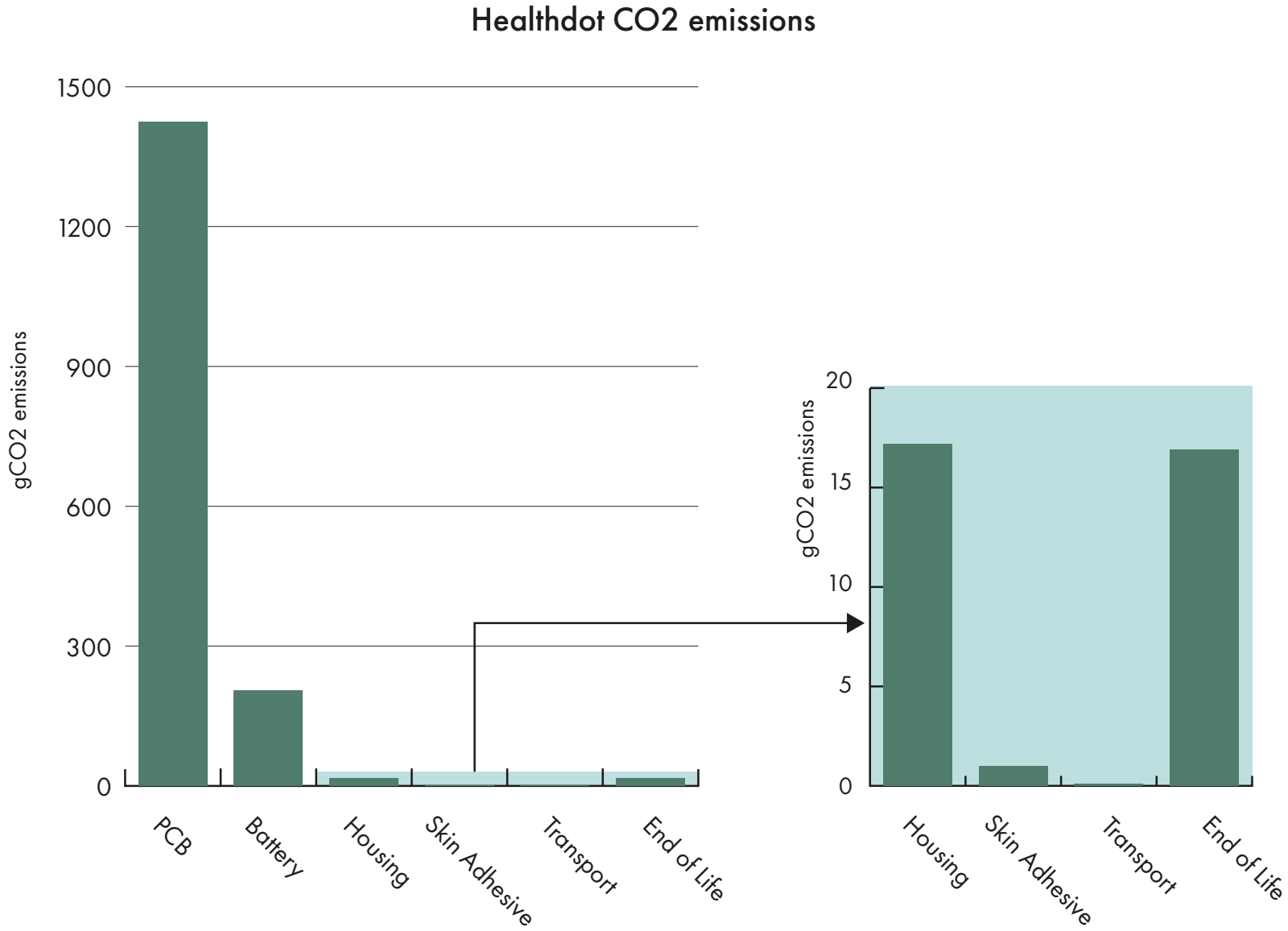


Figure 5.6: The Healthdot's LCA results

6 • Stakeholders

In this chapter, the two core stakeholders of this product - the Original Equipment Manufacturer (OEM) and the hospital - will be discussed, followed by an exploration of the possibilities for the hospital.

The OEM – in this context Philips – is responsible for manufacturing the product. Philips is a company producing both healthcare and consumer products, primarily focusing on health-related items (Philips, n.d.-a). They need to ensure a high level of quality, take responsibility for the product's safety and need to be a reliable partner.

The hospital – in this case study the Erasmus MC in Rotterdam – uses the product. The Erasmus MC is a university medical centre specializing in delivering complex medical care, with over 30.000 patients being admitted each year (Erasmus MC Foundation, n.d.-a). They are accountable for providing quality healthcare and procuring the products that support this goal.

While the Erasmus MC manages its own sterilisation department, smaller hospitals commonly rely on third-party service providers for this. These service providers take care of the collection, cleaning and sterilisation of used surgical equipment. Although the Erasmus MC serves as the example hospital in this thesis, concepts shown later in Chapter 10 will consider 3rd party services as well.

Within the hospital, the doctor, nurse and patients are also stakeholders in this system. However, the requirements of doctors, nurses and patient are already part of the hospital's requirements, as a result of their internal processes. As such they are viewed as secondary stakeholders to the hospital.

6.1 Possibilities of the Hospital

During a conversation with the procurement department from the Erasmus MC (personal communication, 02-05-2023), it became clear that logistics in a hospital are complex and demanding. An example was given that illustrated that hospitals are already quite taxed when it comes to cleaning: cleaning more clothing, such as gowns, would involve additional collection, separation, and washing processes, adding to the existing workload. Similarly, another idea to separate a type of plastic for recycling would require a second waste handler, as the current waste handler could not

manage this type of plastic. That means that instead of one you now have two people going through the hospitals to pick up waste, which further burdens the system.

When discussing whether the hospital would be willing to be the product owner, an interesting perspective was raised regarding the manufacturer's intent. If an OEM creates a reusable product but would still use a linear model (e.g., buy more sell more), it may not show genuine intent towards circularity from Philips, leading to concerns about trust and quality of the device.

In a second conversation with a sustainability manager from the Erasmus MC (personal communications, 27-06-2023), it was mentioned that the hospital already reuses some portable devices, notably the Holter monitors, which are wearable ECG devices which monitor the patient for up to 48 hours.

After use, the devices are returned to the polyclinic where the data is downloaded and analysed. Cleaning of these kinds of devices is simple and can be done by anyone using alcohol wipes. The Healthdot could follow a similar cleaning schedule. Alternatively, the Central Sterilisation Service also disinfects products, such as endoscopes. However, not all hospitals have an internal sterilisation service.

6.2 Take-Aways

I9: Circularity requires a broader mindset. It significantly changes the approach, scope and boundaries of your project, requiring a more holistic approach.

I10: Integrate your stakeholders in the design process. Stakeholders hold valuable knowledge, they have ideas on what is and isn't possible, both in the current systems and the system you are designing. Within a stakeholder, different departments will give you different perspectives, possibilities and information.

I11: The stakeholders are going to execute your system, involving them in your process might make it easier for them to accept the solution.

I12: The circular actions and intentions of an OEM hold meaning to the buyer. If an OEM remains the owner of the product, it demonstrates their active involvement in the product's circularity, while if it is sold via a linear model you could question their intent.

7 • Barriers and Opportunities

In this chapter, barriers and opportunities for the circularity of the redesigned Healthdot are described. First, barriers and opportunities for the system are given, followed by the device.

These barriers and opportunities are identified based on the previous analyses and conversations, and affect the circularity of the Healthdot as a product and as a system. They can be found in Table 7.1.

7.1 The System

The system of the Healthdot focuses mostly on its logistics. Currently, limited infrastructure exists for the reuse of small medical products that are given to patients to take home. Some medical products, such as the Holter monitors, are already reused in the hospital. Adding the Healthdot to these internal logistics is a realistic option. However, the question is if this is still feasible or viable if the amount of returned devices would increase tenfold.

In the LCA from Section 5.2, it became clear that the PCB has a major impact. Therefore it should be the goal of the system to preserve this energy as much as possible, by for example keeping it in the cycle for longer or making sure it can be properly recycled, if all else fails.

7.2 The Device

The current Healthdot is not suited for reuse, remanufacturing or recycling. It cannot be recharged, its patch can't be replaced and the device is glued shut, meaning it is impossible to get inside without destructive measures. Another issue is data. After use, personal data is located on the device, which should be cleared before it is reused.

Modifying the Healthdot to include a charging method and communication to update personal data should be possible. In Section 1.1, a rechargeable sensor is mentioned, and data communication is possible with the device as it already uploads data to a network.

In between patients, the Healthdot should be cleaned. It is conisdered a non-critical item, similar to a finger oximeter, because it only comes into contact with intact skin (Rowan et al., 2023). This means that disinfecting the Healthdot with something like hydrogen peroxide or alcohol is sufficient for cleaning, and sterilisation is not needed (Rutala & Weber, 2013), which was confirmed by the Erasmus MC.

7.3 Take-Aways

I13: No red flags are identified for the Healthdot, meaning it can be modified to work in a circular system.

I14: Your product might only need minor changes to become circular.

I15: Solutions can be found both in other MWS and in other medical categories, but also in completely different product categories, such as wireless charging from smartwatches.

System

Barrier	Reference
Return logistics are limited and rely heavily on the patient	Chapter 6

Opportunity	Reference
Small medical products are already reused in a hospital	Chapter 6
PCB can be reused	Chapter 5
Reusable MWS exist	Chapter 1

Device

Barrier	Reference
The Healthdot is not suited for reuse	Chapter 5
The Healthdot is not suited for remanufacturing or recycling	Chapter 5
The device might contain personal data	Chapter 5
The Healthdots need to be cleaned between patients	Chapter 5

Opportunity	Reference
Reusable medical devices exist	Chapter 1; 6
Disinfection is sufficient for cleaning the Healthdot	Chapter 6; 7
The Healthdot already has data-connecting abilities	Chapter 5

Table 7.1: Overview of barriers and opportunites

8 • Design Requirements and Criteria

This chapter outlines the requirements and criteria for both the system and the product.

The requirements for the system can be found in Table 8.1 & 8.2, while those for the device can be found in Table 8.3 & 8.4. These requirements are derived from the finding detailed in the previous section and are cross-referenced to their respective chapters.

Moreover, this section also includes requirements from upcoming sections, such as the design process for the new system. These requirements and criteria are listed here to give a coherent overview. They stem from brainstorm sessions and concept evaluations.

	System Requirements	Reference
SR1	The new system has to create less e-waste per use-cycle than the current system	Chapter 2
SR2	The new system has to create less CO2 emissions per use-cycle than the current system	Chapter 2
SR3	The new system has to fit the definition given in Chapter 3	Chapter 3
SR4	The new system has to enable multiple uses of the PCB on patients	Chapter 5

Table 8.1: Requirements for the system

	System Criteria	Reference
SC1	The system should create as little CO2 emissions as possible	Chapter 2
SC2	The system should create as little e-waste as possible	Chapter 2
SC3	The system should work as an example for other MWS	Chapter 2
SC4	The device should be as easily reusable as possible	Chapter 6
SC5	The system should cycle the PCB as many times as possible	Chapter 5
SC6	The system should minimize downtime between patients	Chapter 6
SC7	The system should guarantee the hospital that is will have enough Healthdots at all times	Chapter 6
SC8	The materials and parts should stay in the loop as long as possible	Chapter 3
SC9	The system should incentivise all users to act as sustainable as possible	Chapter 3
SC10	The system should be maximally profitable for the OeM	Chapter 6

Table 8.2: Criteria for the system

Device

	Device Requirements	Reference
DR1	The new device has to have less CO2 impact at the end of its life when compared to the current device	Chapter 2
DR2	The new device has to have less e-waste at the end of its life when compared to the current device	Chapter 2
DR3	The new device is part of the system described in Chapter 10	Chapter 10
DR4	The new device has to have the same functionality as the current or better	Chapter 2
DR5	The new device has to be able to be traced throughout its life cycle	Chapter 6
DR6	The device has to have a data connection which allows sharing of recorded data and modification of the stored data	Chapter 11
DR7	The device's communication protocol is an open or shared standard	Chapter 10
DR8	There has to be an indication of the device status when charging or modifying data	Chapter 10
DR9	The device has to be able to be charged without compromising the device	Chapter 10
DR10	If the device has a rechargeable battery, then the device has to use an open or shared charging standard	Chapter 10
DR11	If the device has a replaceable battery, then the device has to use an open or shared battery standard	Chapter 10
DR12	The device has to be able to be charged or have its batteries replaced at the hospital	Chapter 10
DR13	The device and patch have to be seperable from each other	Chapter 10
DR14	The patient has to be able to separate the patch from the device without any tools	Chapter 10
DR15	The new device has to be able to be disinfected with alcohol	Chapter 6; 7
DR16	Residue from the patch should be soluable in the cleaning solution (alcohol)	Chapter 10
DR17	The device has to have smooth surfaces for disinfection	Chapter 10
DR18	The new device has to be able to be recycled in its seperate components	Chapter 5
DR19	The components of the device have to be seperable at the factory in a non-destructive way	Chapter 5; 11
DR20	Parts of the system that cannot be reused have to be recyclable in common waste streams	Chapter 5; 11

Table 8.3: Requirements for the device

Device

	Device Criteria	Reference
DC1	The solution should create as little CO2 impact as possible	Chapter 2
DC2	The solution should create as little e-waste as possible	Chapter 2
DC3	The solution should work as an example for other MWS	Chapter 2
DC4	The device should be as easily reusable as possible	Chapter 6
DC5	Machines that the hospital has to purchase should be as cheap as possible	Chapter 11
DC6	The solution should be as maintainence-free as possible	Chapter 11
DC7	The solution should be as simple as possible	Chapter 11
DC8	The device should minimize cycle times	Chapter 6
DC9	The device has to be checked for its quality as quickly as possible	Chapter 11
DC10	The solution should instil the maximum amount of trust in the hospital staff	Chapter 11
DC11	The solution should take up as little space as possible	Chapter 11
DC12	The solution should be as time efficient as possible	Chapter 11
DC13	The solution should have a minimal chance of failing	Chapter 11
DC14	The solution should resist tampering from the patient	Chapter 11
DC15	The solution gives the maximum form-freedom to the OeM's design team	Chapter 11

Table 8.4: Criteria for the device

Part four

design

9 • Design of the Future Circular System: SecondSense

In this chapter, I present SecondSense, a potential solution to make MWS circular. First, the concept is introduced, and then its secondary parts are discussed in more detail. Finally, a comparison is made with the original Healthdot.

SecondSense is a product-service-system, which allows easy and quick reuse of multiple MWS. It consists of two parts: SenseFlow and the SenseCab. SenseFlow describes how the sensors flow through the circular system, while the SenseCab enables easy reprocessing of the sensors.

With SenseFlow, medical wearable sensors are returned to the hospital after use where they are cleaned and prepared for the next use. The manufacturer remains the owner of the sensor, being responsible for the quality of the sensors and for what happens at the sensor's end-of-life. The hospital cleans and controls the sensors, after which they are placed in the SenseCab. The SenseCab is a universal device that can update, charge and disinfect different sensors from different manufacturers, and makes them ready for reuse. When a sensor is needed, simply grab the sensor and the required patch, and you're ready to sense!

9.1 Context: five years from now

For the design of SecondSense it was decided to design for use in a future context, as remote monitoring – or telehealth – is expected to become more common in the future for a variety of treatments (Siwicki, 2023). More telehealth would lead to more sensors being used in and out of hospitals. For this reason, a future context five years ahead from now was chosen. In this context, it is assumed that there are multiple medical wearable sensors that are reusable. These sensors are used both internally and externally and need to be managed by the hospital.

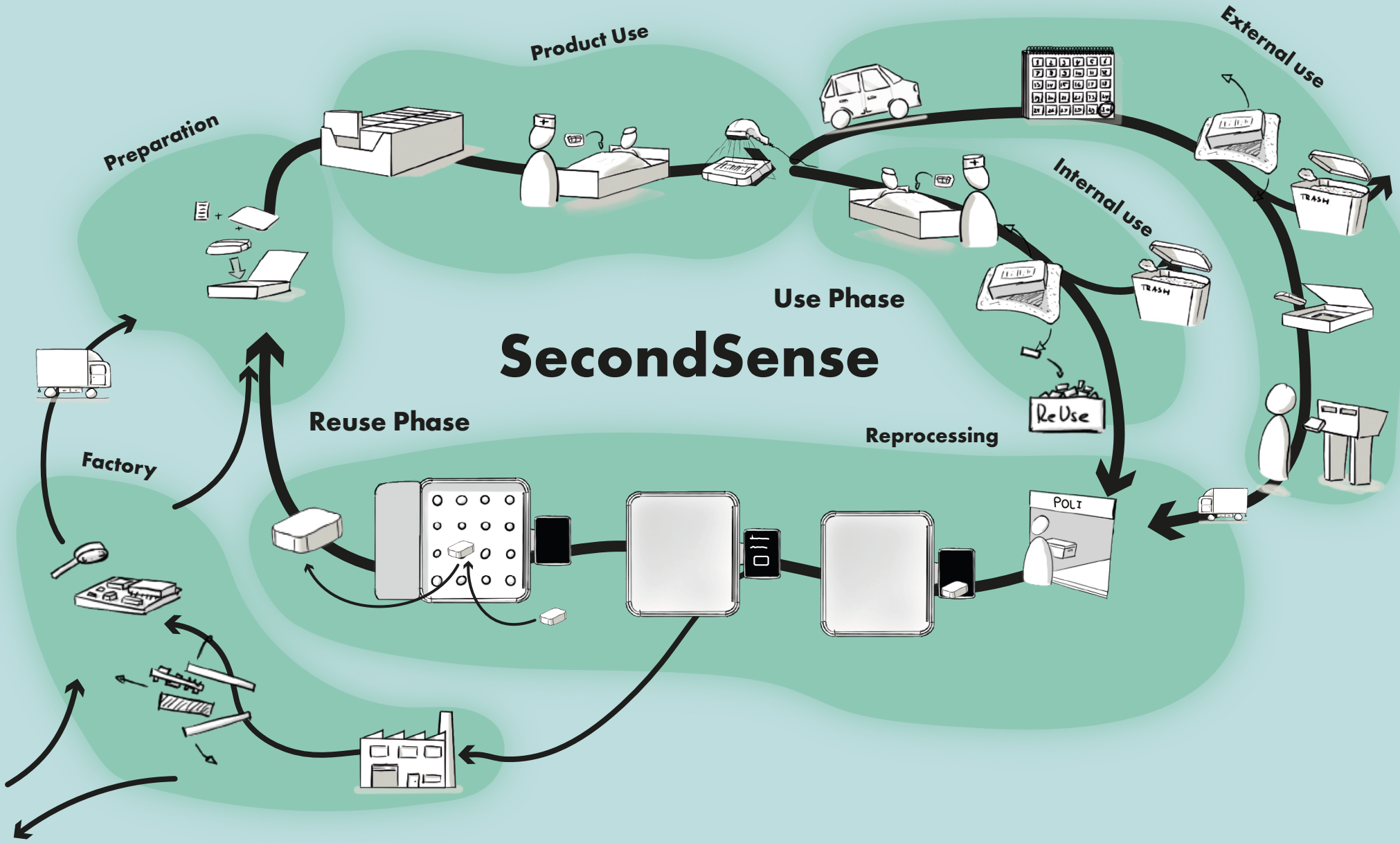


Figure 9.1: An overview of the SecondSense sytem

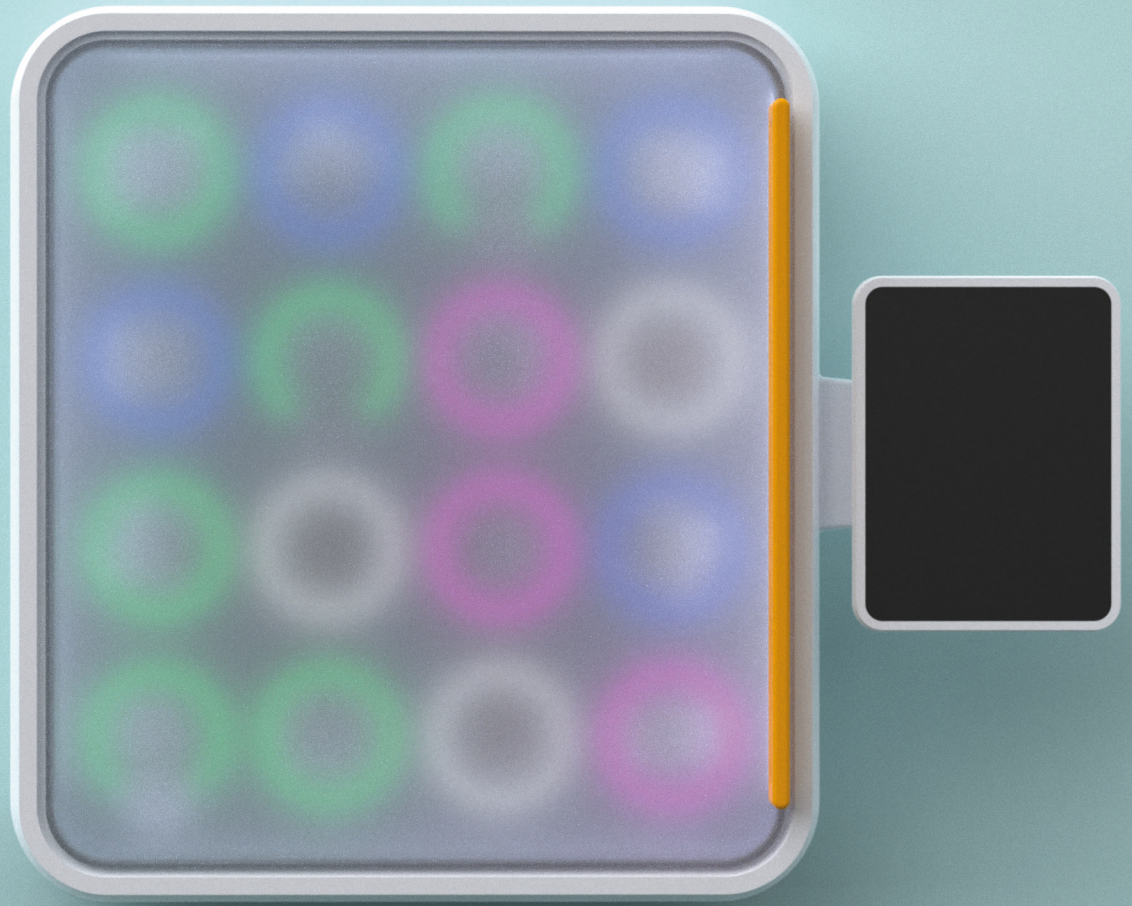


Figure 9.2: Front view of a closed SenseCab:

Figure 9.3: Angled view of an open SenseCab

9.2 SenseFlow

The SecondSense system's circular flow is called SenseFlow. It consists of two core phases: the use phase and the reprocessing phase. The use phase describes the use of the sensor, both internal and external of the hospital. The reprocessing phase focusses on cleaning and preparing the sensor for another use, as well as handling the rejected sensors. This flow is described in Figure 9.4, and further detailed in the following sections.

The business model is based on the access and performance model from Bocken (2016). The OEM – here Philips – stays owner of the MWS, while the hospital pays per use. This gives the OEM control over the end-of-life of the sensor, reducing spillage, and incentivises the OEM to design long-lasting products; the more a sensor can be used, the more profit they make.

The actions required by the stakeholders – The hospital and the OEM, Philips – can be summarized by the following list:

- The hospital applies the Healthdot on the patient
- The hospital removes internally used Healthdots from the patient
- The patient sends their externally used Healthdots back to the Hospital
- The hospital takes care of collecting the used Healthdots, inspecting them and cleaning them
- Philips provides support, supplying new patches and – when needed – new Healthdots
- Philips takes care of old and rejected Healthdots

9.2.1 Use phase

The use phase of SenseFlow describes how the sensor is used, from application to collection. When a sensor is needed, a nurse takes the required sensor – in this case, a Healthdot – from the SenseCab, along with the required patches and other materials. The nurse then places the Healthdot on the patient and activates it, linking it to the patient. If the patient stays in the hospital, the Healthdot is removed by a nurse when it is no longer needed. The used patch is disposed of and the Healthdot is returned to the policlinic to be reprocessed.

When the patient goes home with the Healthdot, the patient removes the Healthdot when it is no longer needed. After removing it, they separate the Healthdot from the patch – which is disposed of – and the Healthdot is sent back to the hospital.

As you might notice, the use phase is still largely similar to the product journey described in Section 5.1. This is because no significant changes were made to the working of the sensor; the application and use stay the same. The difference is that some extra preparation is needed before use and the sensor has to be collected after use.

9.2.2 Reprocessing Phase

The reprocessing phase of SenseFlow describes how the sensor is prepared for another use. When the Healthdot is returned to the policlinic, it is inspected for damages and cleaned with an alcohol wipe. The Healthdot is then scanned to check if it is still safe to use, and is placed in the SenseCab. In the SenseCab, the Healthdot is updated and personal data is removed, it is UV-disinfected and finally charged, all automatically.

When it is time to use the Healthdot, it is scanned again to register its movement and prepared with a new patch.

Healthdots that don't make the safety check are collected separately and sent back to Philips. Here they are taken apart, the PCB is checked to see if it can last another life cycle and the casing of the sensor is recycled. Philips sends new Healthdots and patches to the hospital to be used again.

9.3 SenseCab

The SenseCab is the enabler of the SenseFlow system; it allows easy reprocessing of the used sensors (Figure 9.5-9.11) The SenseCab is responsible for charging, removing and updating data, and disinfecting the sensors. The sensors are placed inside the cabinet on a wireless charging plate, where they are charged, personal data is removed and software is updated. The cabinet contains UV-LEDs which disinfect the sensors during their charge (Messina et al., 2015). The frosted glass front door protects the nurses from harmful UV light. When interacting with the SenseCab, the UV lights turn off and the glass door turns transparent for a quick overview of the sensors and their statuses. The touch screen on the front allows the staff to see the detailed status of the sensors inside without opening the cabinet, while the LED rings offer a quick status update.

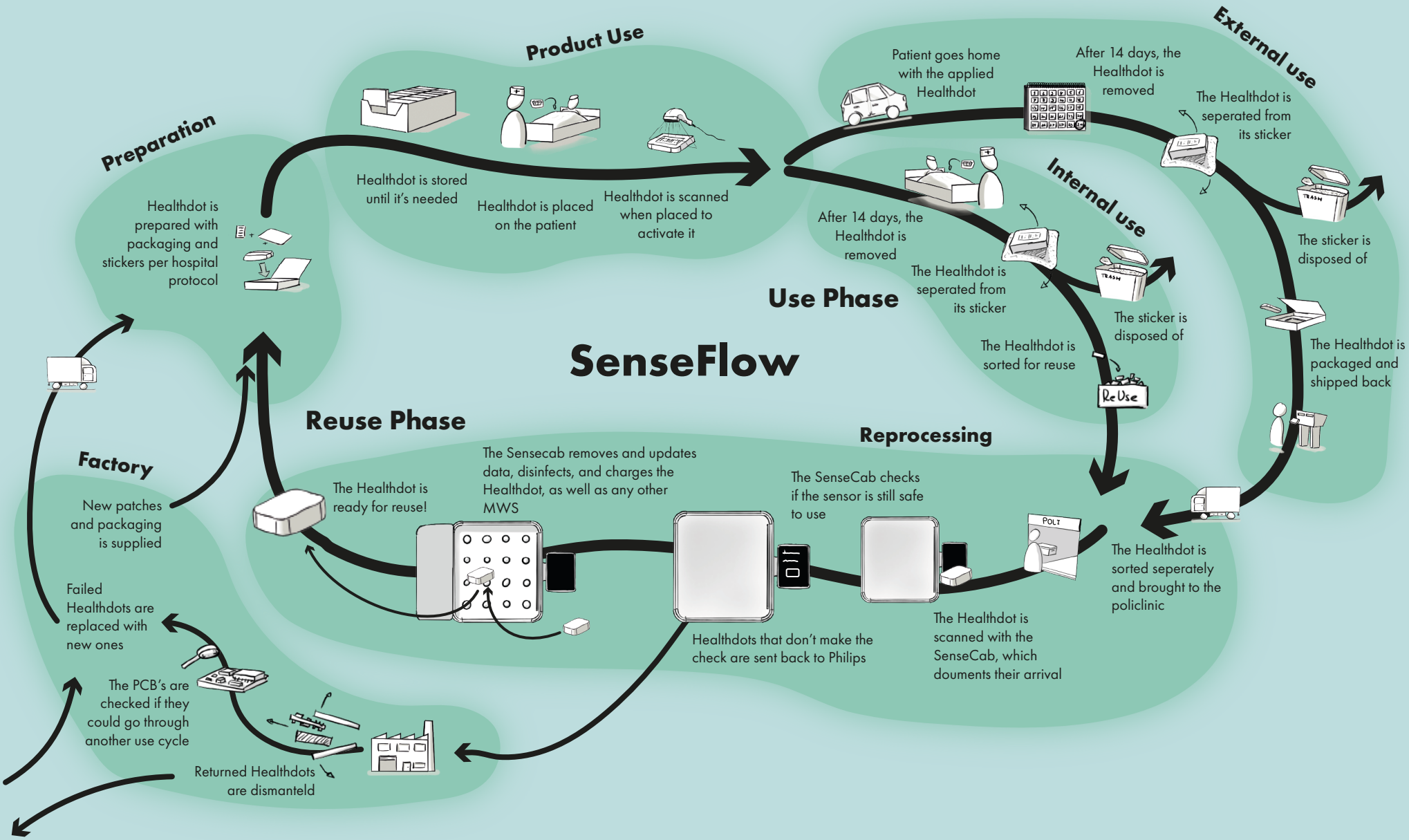


Figure 9.4: SecondSense's circular flow, SenseFlow, with description for its activities.

16 Sensors

The SenseCab can handle 16 sensors at once, as demonstrated here by different dummy sensors

Figure 9.5: Front view of an open SenseCab

Wireless Charging Puck

Magnets hold the sensors against the wireless charging puck, which charges the sensor and connects it to the SenseCab.

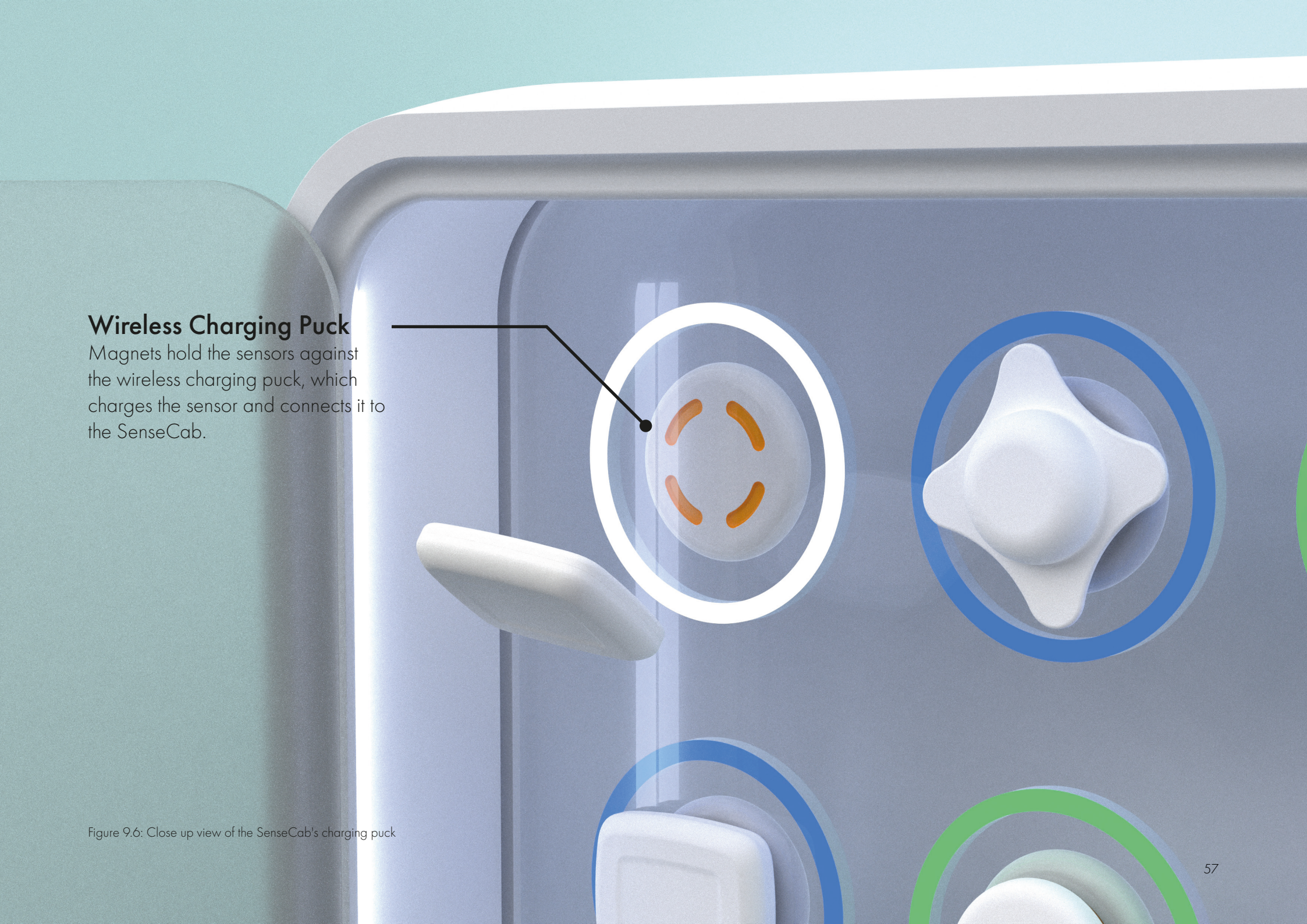


Figure 9.6: Close up view of the SenseCab's charging puck

Figure 9.7: Close up describing the SenseCab's LED ring

Frosted Glass

The frosted glass protects the nurses near the machine from its UV-light. When interacting with it, it quickly defrosts to give the user a quick overview of the sensors inside.

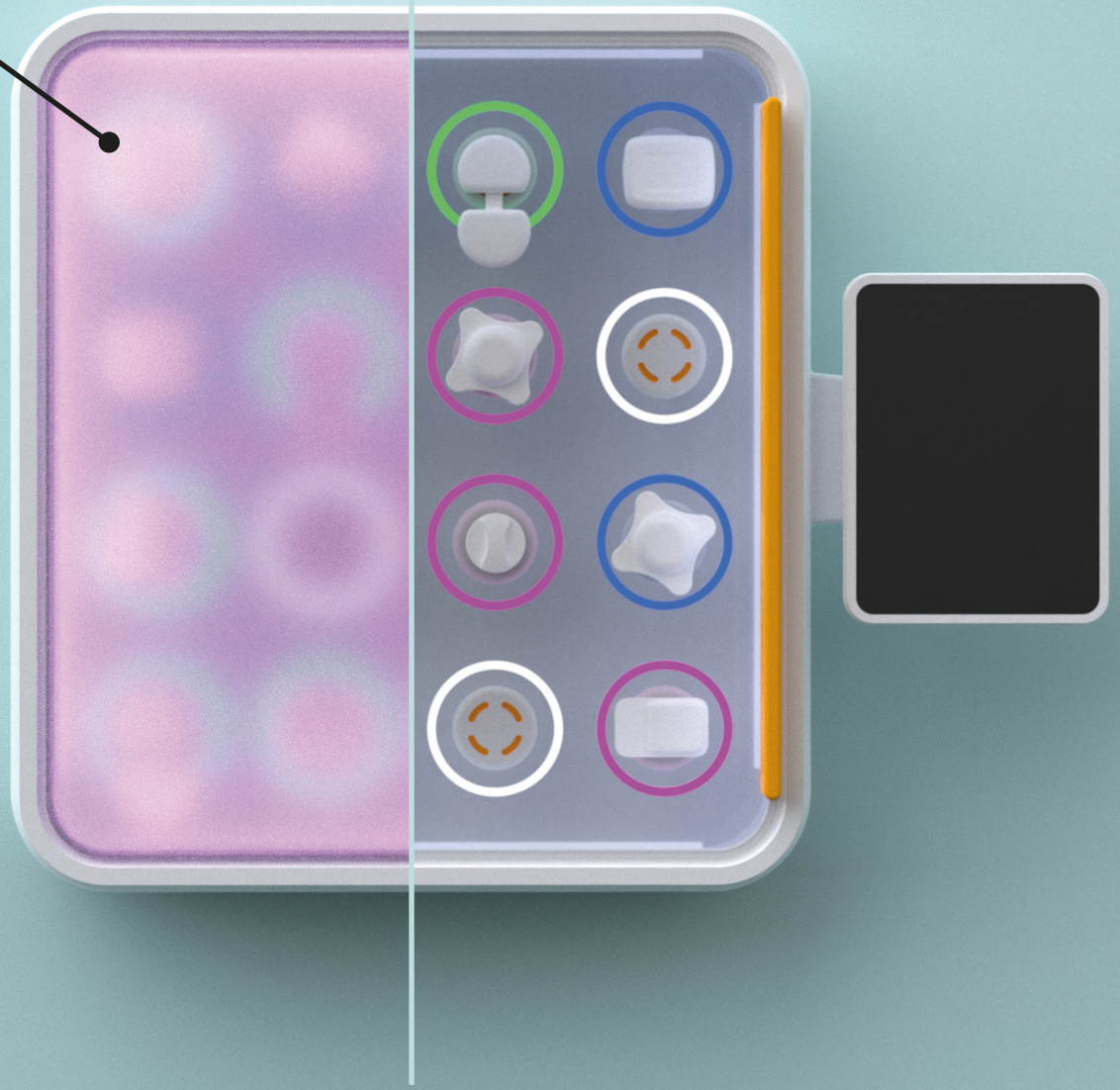


Figure 9.8: SensCab's frosted glass system

Figure 9.9: SenseCab Interface

Four Orientations

The cabinet can be placed in a total of four orientations, giving policlinics maximal placement freedom.

Figure 9.10: Multiple orientations for the SenseCab

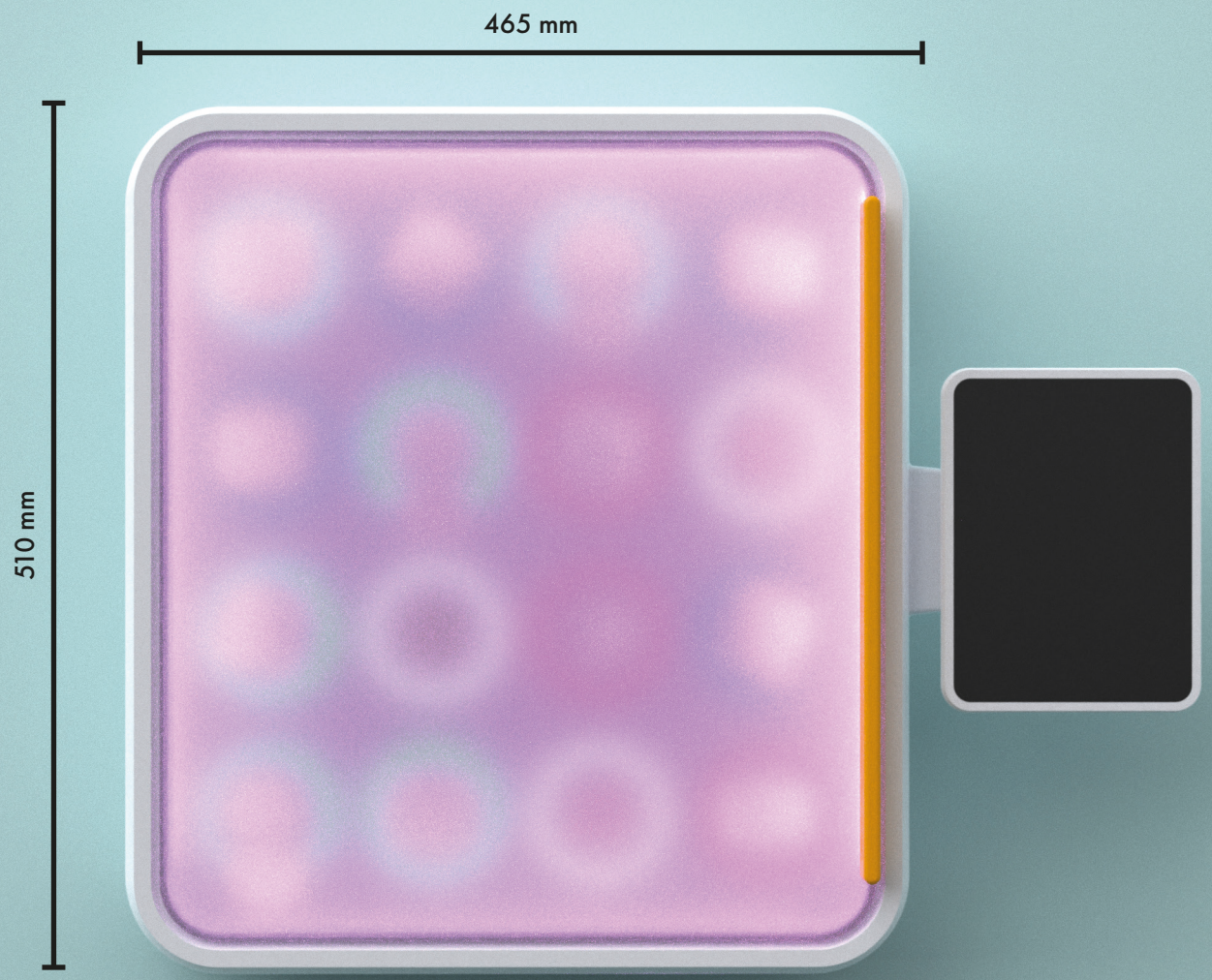


Figure 9.11: SenseCab's Sizing

9.4 LCA Comparison

To assess the impact of SecondSense, a fast-track LCA is conducted to compare SecondSense to the Healthdot. The LCA is performed similarly to the LCA from Section 5.2, using the Idemat database (Stichting Sustainability Impact Metrics, n.d.-a). However, as this is a fast-track LCA, the same limitations apply to the LCA performed in Section 5.2, which is that due to the nature of this fast-track LCA, several assumptions had to be made. As a result, no specific amounts for CO2 are mentioned, but approximations are offered instead.

Since the specific design details of the senor are not known, it is assumed that it requires approximately 40% more resources, such as more electronics and a larger housing due to additional electronics for charging and NFC. It is assumed it the sensor is made from the same materials, except for the battery, which is changed to a lithium battery as these are common in rechargeable electronics. Finally, it is assumed that the sensor travels the same 120 km from Eindhoven to Rotterdam as the original Healthdot, and that it is used outside of the hospital in 50% of the use cases.

As the SenseCab is now required to charge the sensor, this impact also has to be counted towards the sensor's total impact. It is assumed that the SenseCab last 5 years; if one sensor lasts 10 cycles or 14 days, this would total 140 days, and with 16 charging spaces this would imply that approximately 200 sensors would use the SenseCab. For the fast-track LCA, it is assumed that the SenseCab's eco-impact is similar to that of a laptop from the Idemat database (Stichting Sustainability Impact Metrics, n.d.-a). The results of this LCA can be seen in Figure 9.12, and the detailed calculations can be found in Appendix F.

As can be seen in Figure 9.12, the SecondSense system result in a 45% reduction in CO2 after 5 uses,and 60% after 10 uses. While the initial impact of the system is higher, because the sensor is reused efficiently with minimal transport and reprocessing impacts, SecondSense is estimated to break even after just three uses of the sensor.

It is important to note that this analysis does not consider an economical evaluation – comparing the reduced impact with the additional costs of designing a long- or longer-lasting sensor – as this was considered out of scope for this thesis.

In this fast-track LCA, a worst-case scenario is assumed when it comes to the eco-impact. This is done to avoid a positive bias towards this concept and to more objectively validate the reduction in CO2 impact.

For example, it is estimated that the SenseCab's real-world impact could be up to 70% lower than currently estimated. For example, in a fast-track LCA, its impact is estimated at 140 kg of CO2 (Appendix F), while the Idemat Database estimated 570 kg of CO2 for a laptop. Changing this in the LCA would improve SecondSense impact after 10 uses to 75%.

Another worst-case assumption is the SenseCab's split over the sensors. When a sensor is in use, it's charging spot is empty and can be used by different sensors, it does not need to be reserved for one specific sensor. This could split the SenseCab's impact over even more sensors, for example over 1000, and would also improve SecondSense impact after 10 uses 75%. Combining these two improvements would reduce the impact after 10 uses by 80%.

Another possibility to reduce the impact of the sensors would be by reusing the PCB, as is currently done in the Healthdot 5.0 that is being developed by Philips. The impact of the production of the sensor would be reduced by 35% when using a PCB twice, and by over 50% by using it five times. This could be achieved by disassembling the rejected sensors at the factory and testing the harvested PCBs to see if they still qualify. Combining the reused PCB from the Healthdot 5.0 with the SecondSense concept presented here would significantly improve the sensor's circularity.

9.5 Take-Aways

I16: The proposed redesign shows that it is possible to reduce the CO2 emissions and e-waste from MWS using a simple solution that allows reuse, without complex machinery or expensive equipment. It proposes a universal approach to circularity, a system that can be shared amongst different OEMs to make it easy to reuse a variety of MWS.

I17: Further reductions in the device's impact will yield more short-use (1-5 uses) improvements, while changes in the system's efficiency will yield more long-use (6+) improvements.

I18: Don't look at your system and device in isolation. Take other products that exist in your context into consideration, as a combined solution might be beneficial to all.

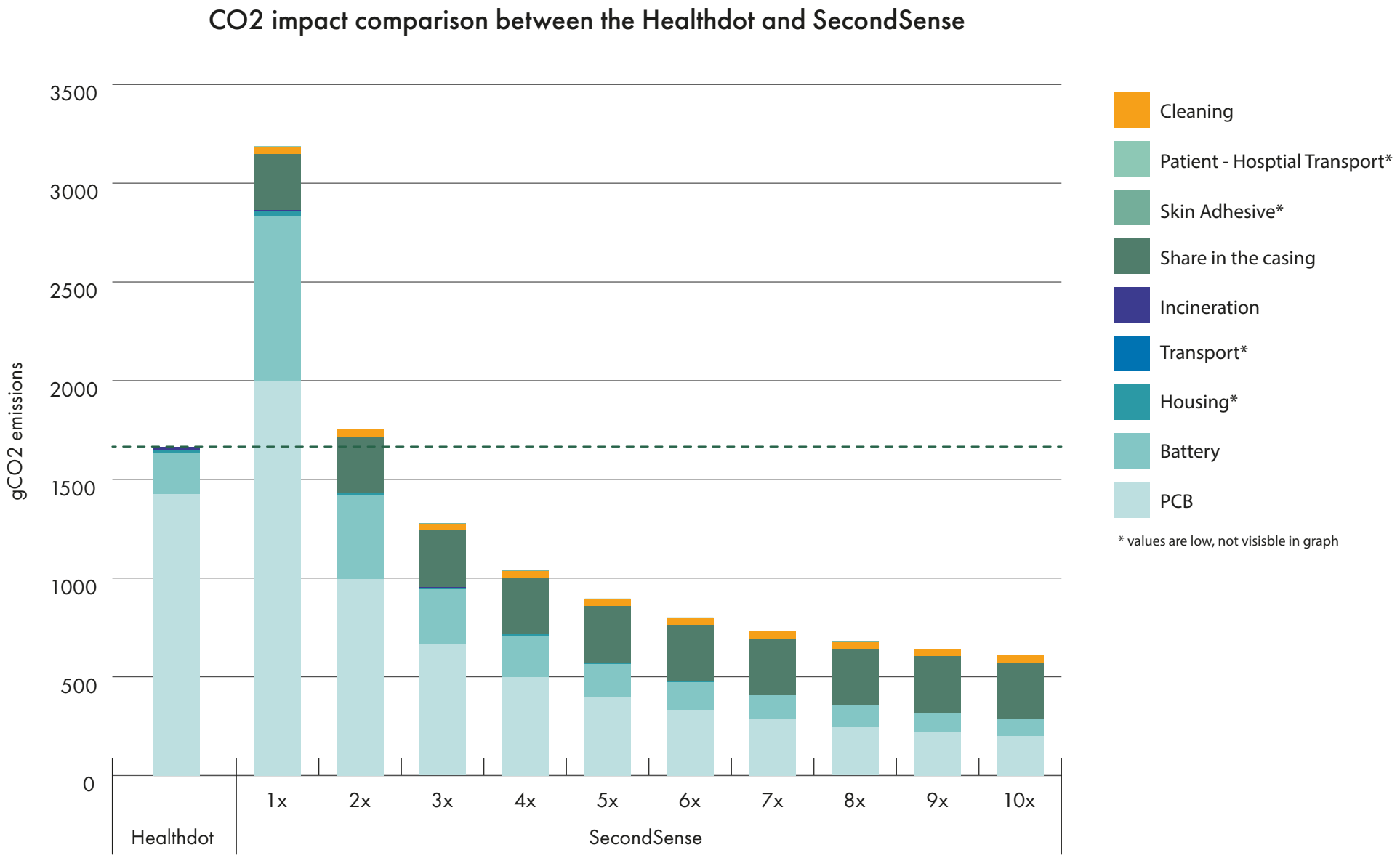


Figure 9.12: CO2 impact comparison between the Healthdot and SecondSense

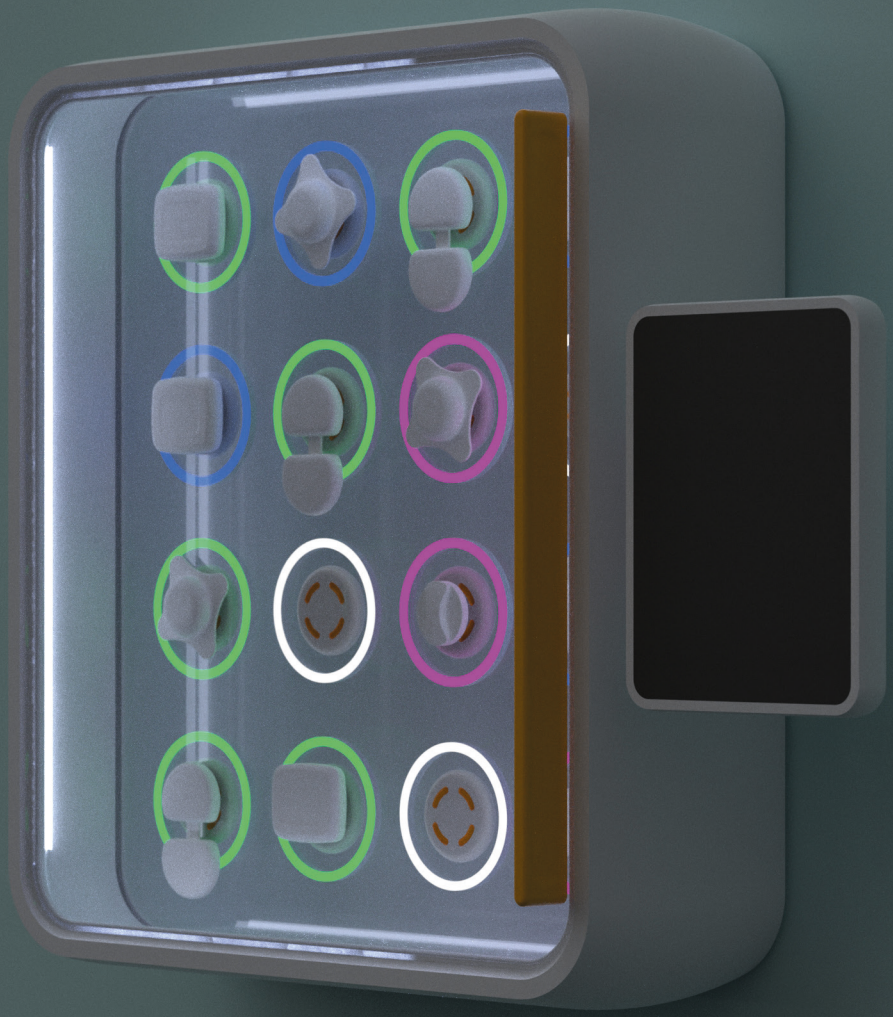


Figure 9.13: Night view of the SenseCab

10 • Designing SenseFlow

In this chapter, the design process which led to SenseFlow is described. First, an overview is given of the process, after which the subsequent design steps are described in more detail. Finally, two final concepts are described, and arguments are given for the choice for SenseFlow.

10.1 Design Process

The design process that was followed can be roughly described in Figure 10.1, which shows the different phases and includes references to their relevant sections.

First, in the Ideation phase, the literature described in Chapter 4 was used as a starting point, which resulted in system possibilities (Section 10.2). These where then used to create concepts (Section 10.3), after which a choice was made for the final design, SenseFlow, described previously.

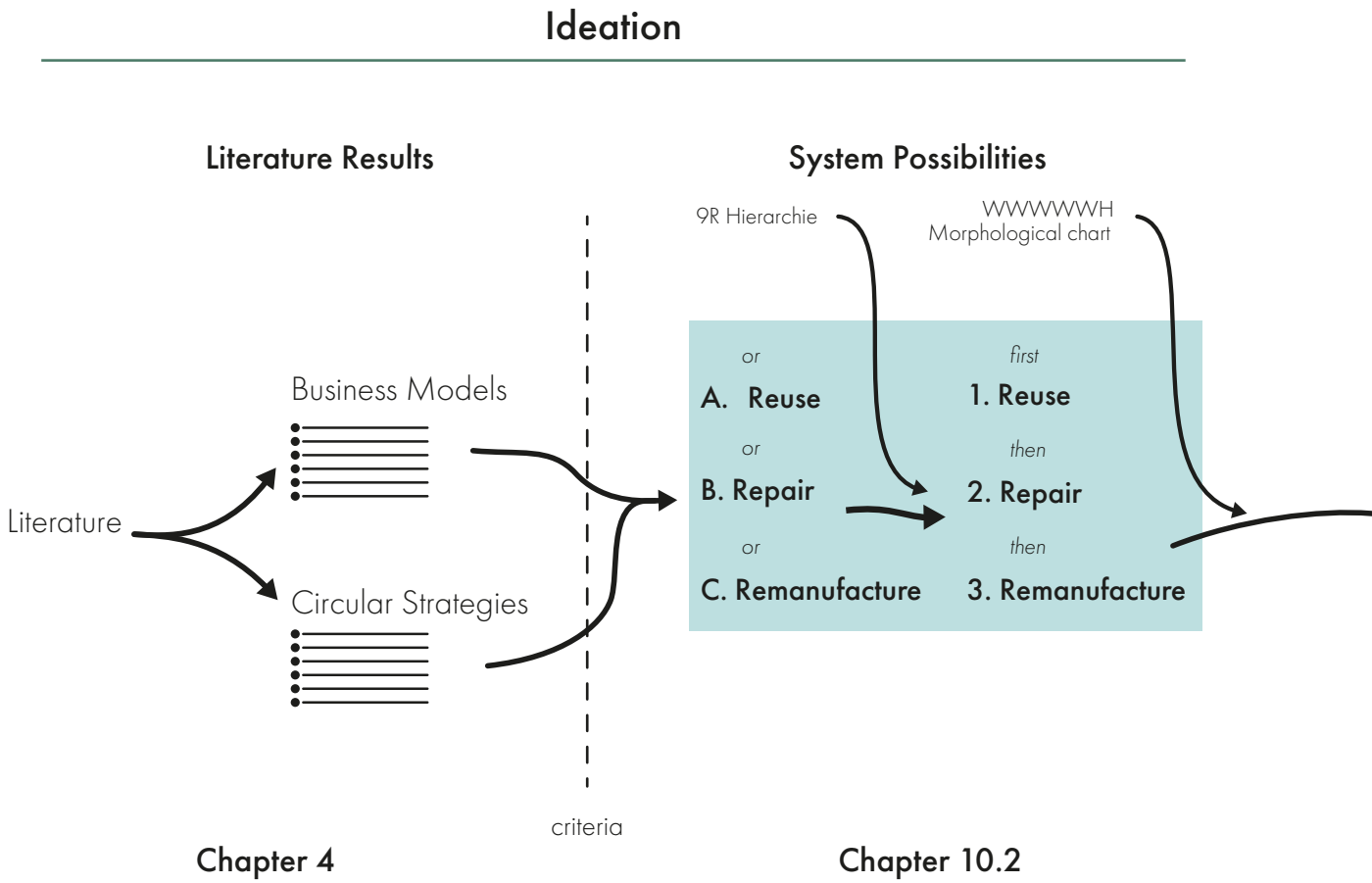


Figure 10.1: High-level overview of the process of designing SenseFlow

Concepting

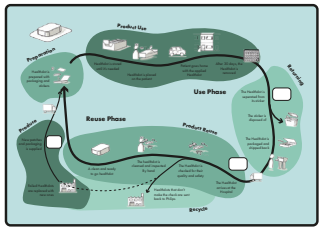
Final System

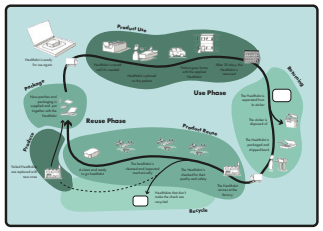
First Iteration

Second Iteration

Final Iteration

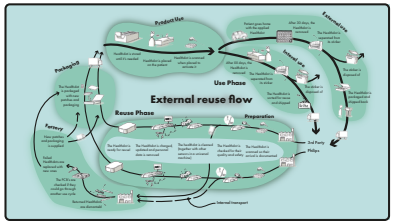
Design Review



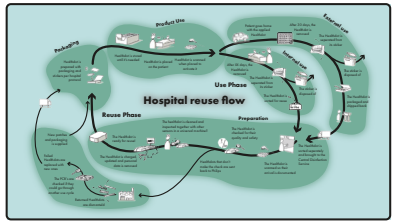


iterate + scamper

Factory Reprocessing

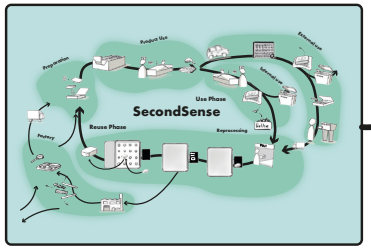


Hosptial Reprocessing



LCA

criteria



Designing SenseCab

Chapter 10.3

Chapter 9.2

10.2 Circular Strategies and Business Models

The first step in the design process was choosing the circular strategy and business model, as these play a crucial role in the design of your system. The circular strategy outlines how your system will align with the circular economy, such as whether you will prioritise reuse or remanufacturing. On the other hand, the business model describes the roles and actions of stakeholders, including responsibilities, ownership, and cleaning processes. The choices made here will have a significant impact on the design of both your system and the accompanying sensor.

To identify suitable circular strategies and business models, they were assessed on the requirements from Chapter 8, the results of which can be seen in Table 10.1 & 10.2. It was found that reuse, repair and remanufacture are three fitting circular strategies. Likewise, access and performance, classic long-life model, and encourage sufficiency are three suitable business models. Together, these could result in a circular sensor.

The three circular strategies were together into one solution, based on the inertia principle: "Do not repair what is not broken, do not remanufacture something that can be repaired, do not recycle a product that can be remanufactured. Replace or treat only the smallest possible part in order to maintain the existing economic value of the technical system."(Stahel, 2010). This led to ideation on questions such as: Who will be responsible? Who will clean the sensor? Who will own the sensor?

To give Philips an incentive to design sustainable and long-lasting products, they should aim for a steady revenue from the concept in this business model. In a more linear economic model (e.g. buy more sell more), no matter how durable the Healthdot is, Philips would need to continuously sell more products to generate revenue. Considering that the access and performance model is the only one among the three options that provide a continuous revenue stream, it appears to be the best fit for this case.

Circular Strategies	Description	Less e-waste when compared to current concept	Less CO2 when compared to current concept	Fits Definition given in Chapter 3	Enables multiple uses of PCB's
Refuse	Descriptions given in Figure 3.2	Y	Y	Y	-
Rethink		Y	Y	Y	-
Reduce		Y	Y	Y	N
Reuse		Y	Y	Y	Y
Repair		Y	Y	Y	Y
Remanufacture		Y	Y	Y	Y
Repurpose		Y	Y	Y	N
Recycle		M	M	M	N
Recover		M	N	N	N

Table 10.1: 9R-Strategies assessed on their fit to the requirements from Chapter 8

Business Models	Description	Less e-waste when compared to current concept	Less CO2 when compared to current concept	Fits Definition given in Chapter 3	Enables multiple uses of PCB's
Access and performance	Providing the capability or services to satisfy user needs without needing to own physical products	Y	Y	Y	Y
Classic long-life	Business models focused on delivering long-product life, supported by design for durability and repair for instance	Y	Y	Y	Y
Extending product value	Exploiting the residual value of products - from manufacture to consumers, and then back to manufacturing – or collection of products between distinct business entities	Y	Y	M	M
Encourage sufficiency	Solutions that actively seek to reduce end-user consumption through principles such as durability, upgradability, service, warranties and reparability and a non-consumerist approach to marketing and sales	Y	Y	Y	Y
Extending residual value	Exploiting the residual value of resources: collection and sourcing of otherwise "wasted" materials or resources to turn these into new forms of value	M	M	M	N
Industrial symbiosis	A process- orientated solution, concerned with using residual outputs from one process as feedstock for another process, which benefits from geographical proximity of businesses	M	M	M	N

Table 10.2: Business models assessed on their fit to the requirements from Chapter 8

10.3 Two Concept Designs

The chosen strategies and business model were used to start the ideation process, which let to multiple concepts described in Appendix G. The two final concepts are described here: Hospital Reprocessing and Factory Reprocessing.

Both concepts are focussed on the reuse of the Healthdot through reprocessing. They share the same use phase, which is largely similar to the one described in Section 5.2, aside from changes in preparation and the fact that the Healthdot is now collected after use, instead of disposed of.

Additionally, both concepts share the same business model: a product-service-system. Philips is and will remain the owner of the Healthdots. Every time the hospital activates a Healthdot, Philips gest a notification and can bill the hospital for its use. The hospital does not pay for new Healthdots, as this is provided by the service element.

Finally, the two concepts differ in their reprocessing phases. The hospital concept is focussed on internal reprocessing in the hospital, whereas the factory concept is focussed on external reprocessing.

10.3.1 Hospital Reprocessing

This concept focuses on internal reprocessing, as can be seen in Figure 10.2. After use, the Healthdot is sorted internally where it is reprocessed, either at the Central Sterilisation Service or at the policlinic, depending on hospital preference. Rejected Healthdots are returned to the factory, which supplies the hospital with replacement Healthdots and new patches.

Key Stakeholder Actions

- The hospital collects Healthdots used in the hospital internally
- The patient sends their used Healthdots to the hospital
- The hospital takes care of collecting the used Healthdots, inspecting them and cleaning them
- Philips provides support, new patches and – when needed – new Healthdots
- Philips takes care of old and rejected Healthdots

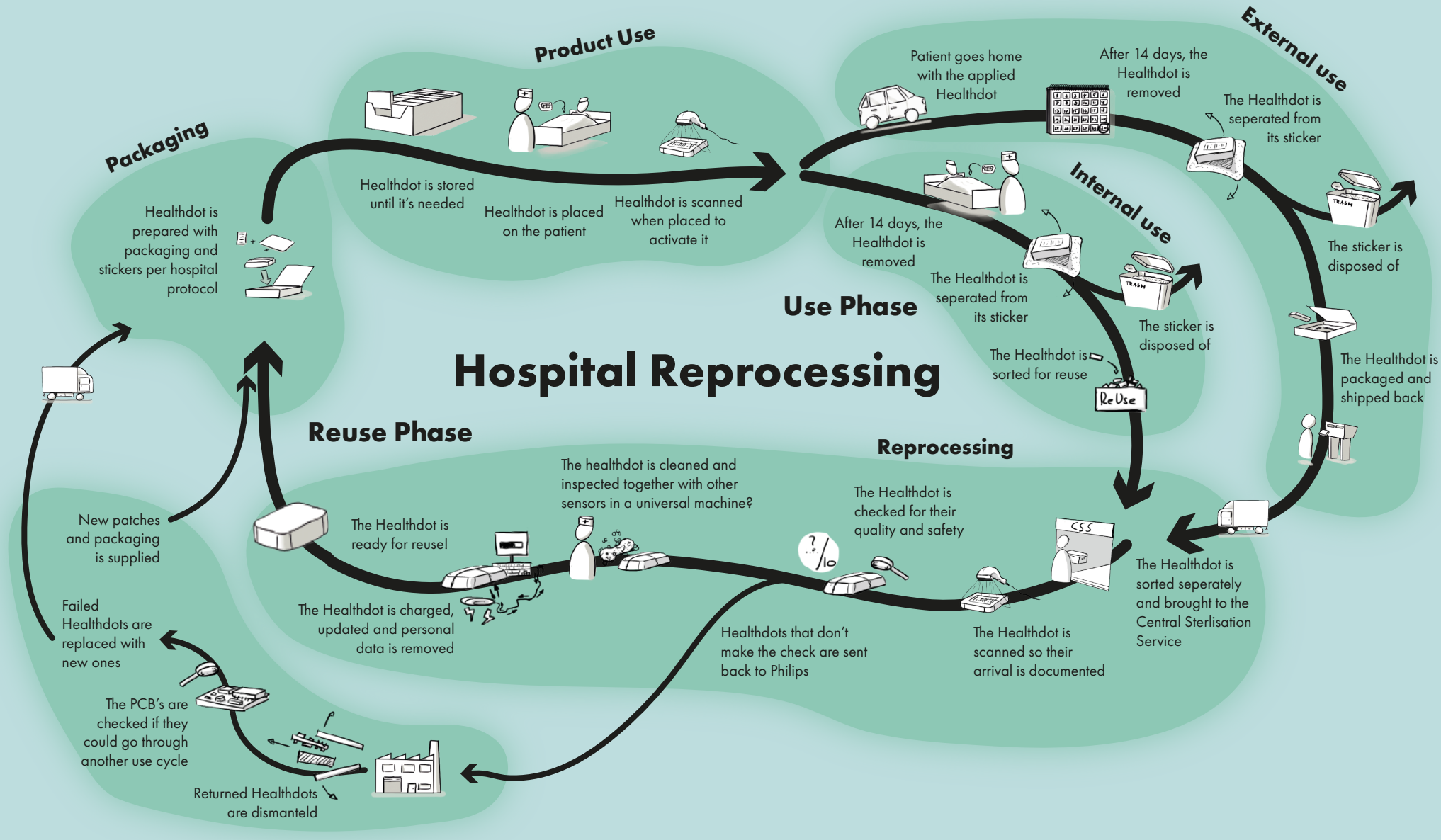


Figure 10.2: Hospital reprocessing concept

10.3.2 Factory Reprocessing

This concept focusses on external reprocessing, as can be seen in Figure 10.3. After use, the Healthdot is sent to either the OEM's factory or a 3rd party service provider, where the Healthdot is reprocessed – this would depend on the location of the factory relative to the hospital. The 3rd party service provider would send rejected Healthdots back to the OEM factory, while the OEM factory would be the sole provider of new patches and replacement Healthdots.

Key Stakeholder Actions

- The hospital takes care of collecting the internally used Healthdots and sends them to either Philips or a 3rd party
- The patient sends their used Healthdot directly to Philips or a 3rd party.
- At the collection facility, the Healthdots are inspected, cleaned and prepared.
- Philips provides support, new patches and – when needed – new Healthdots
- Philips takes care of old and rejected Healthdots

10.3.3 Concept Reviews

Both concepts were reviewed in two sessions, one with representatives from Philips (n=1) and Games for Health (n=3) and one with a representative from the Erasmus MC (n=1).

The first topic that came up was the chosen scenario. For this thesis, a scenario where the Healthdot is sent back to the hospital was chosen, due to the scope. However, what if the Healthdot would be returned at a 'trustworthy medical location', such as a pharmacy or a general practitioner? This would change how the Healthdot would be returned, and in turn, also affect how it would be reprocessed. For example, the pharmacy could also do reprocessing, or will the pharmacy sort the devices per hospital? A change in scenario can have a large impact on your design.

A second topic that was discussed is the interchangeability of the different parts of the concepts. You can split each concept into two flows and combine these, see Figure 10.4. For this thesis, the choice is made for just one system. However, in practice it might be desirable for hospitals to be given a choice on how to reuse these products. Smaller hospitals might prefer external reprocessing because they lack infrastructure, while larger hospitals might have no issues with that and can handle a shorter loop.

Finally, the topic of universality came up. All parties agreed that in a system like this, MWS should be compatible with the same system to make it feasible. If a hospital has to reprocess multiple different sensors and they would all have a unique cable, machine and reprocessing steps, this would become an impossible task. This is why it is important to use or develop a standard which is shared amongst different sensors. A real-world example is the standardized phone charger. Most readers of this thesis will remember the chaos of the first phones all using different charging cables. Nowadays almost all of them use the same charger, making it easy to recharge a variety of different phones.

In the conversation with the Erasmus MC, some concerns came up. Most notably the question of 'how do you make sure that you have enough Healthdots?". If you run out of Healthdots, do you get sent more sensors? Or are you able to track were they are in use? This is important for the hospital to know because procedures are planned based on the available material, and is something that the system should accommodate. However, for this thesis, it was determined out of scope to integrate this into the current concept.

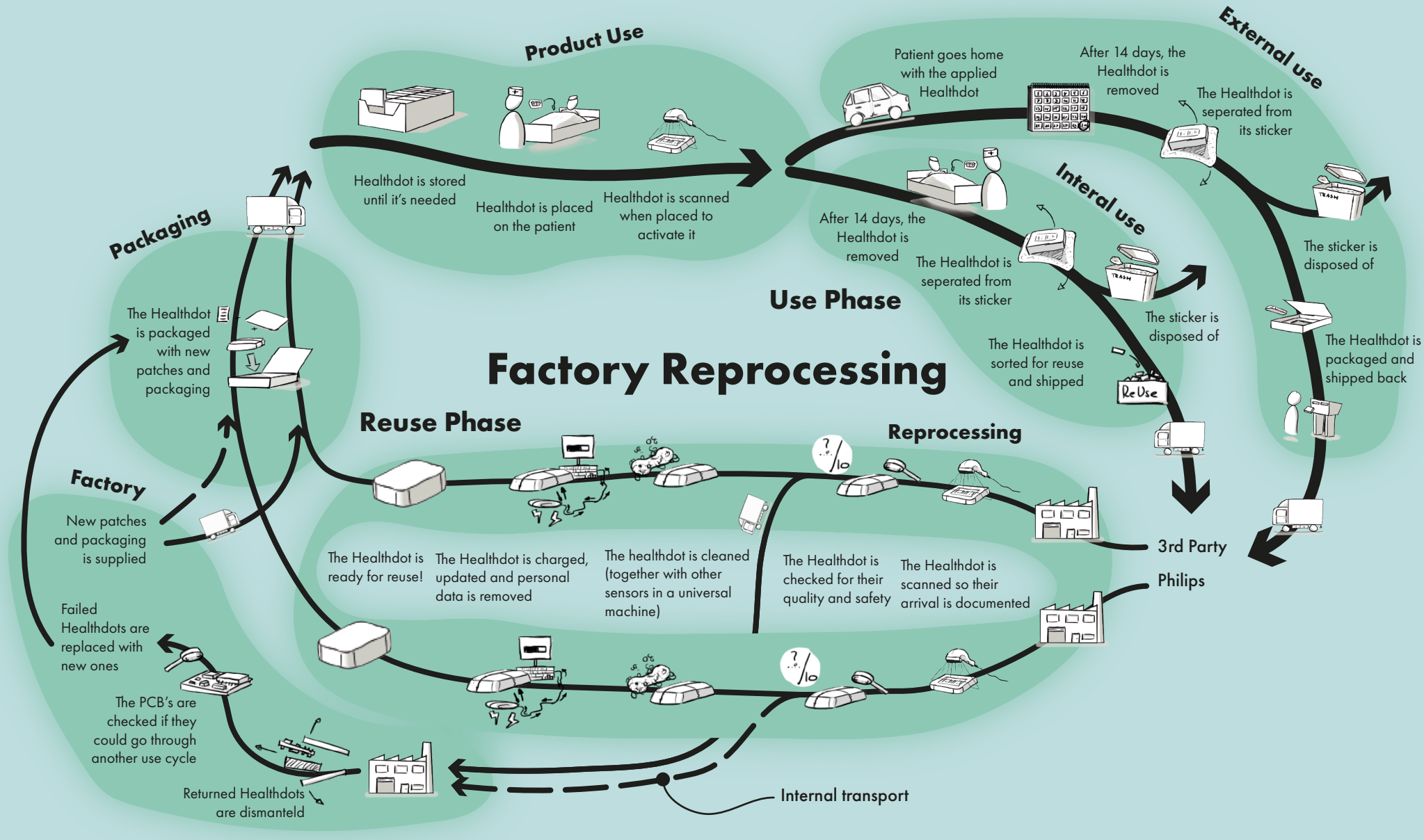


Figure 10.3: Factory reprocessing concept

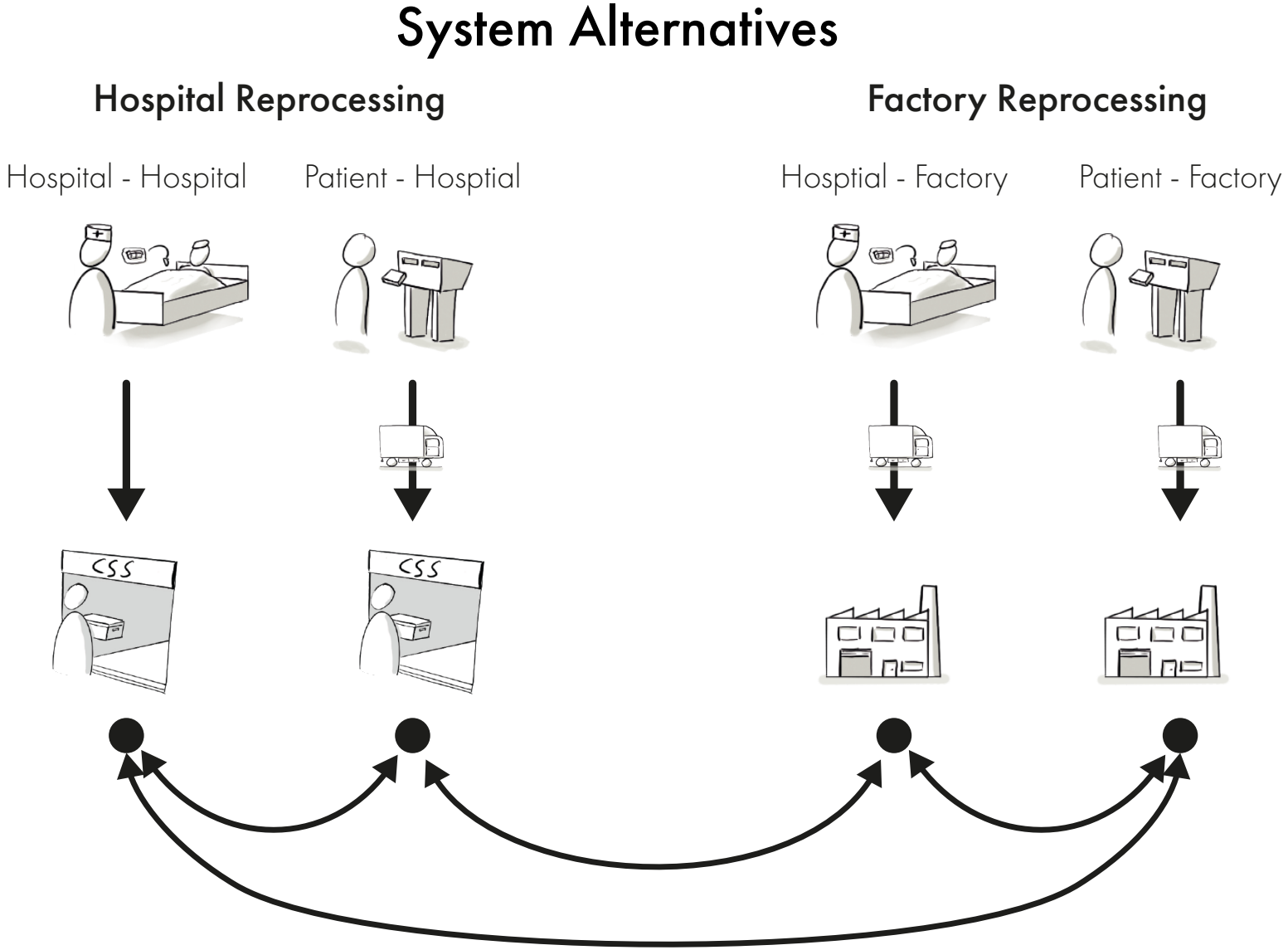


Figure 10.4: Different flows from the two concepts combined

10.4 Concept Comparison

To choose the final design, the two concepts described previously were compared. First, a fast-track LCA was performed, after which they were scored on the requirements and criteria from Chapter 8.

10.4.1 LCA

A fast-track LCA was performed to analyse the differences between the concepts using the 2023 Idemat database (Stichting Sustainability Impact Metrics, n.d.-a). It is assumed that both concepts have the same product design and that their reprocessing process has the same impact. This results in the manufacturing stage, end-of-life stage and use of consumables having the same amount of impact, and thus they can be considered out of bounds. The concept's impact will be based on the distance travelled in transport, as can be seen in Figure 10.5.

Both concepts go through 10 measuring cycles of 14 days, and it is assumed that 50% of these cycles end outside the hospital at the patient's home. For the transport distances, it is assumed that the distance from the Erasmus MC in Rotterdam to Philips is Eindhoven is representative. While the average patient lives only 5 km away from a hospital (CBS, 2023), transport from the patient to the hospital is assumed to be 30 km because of the use of a postal service.

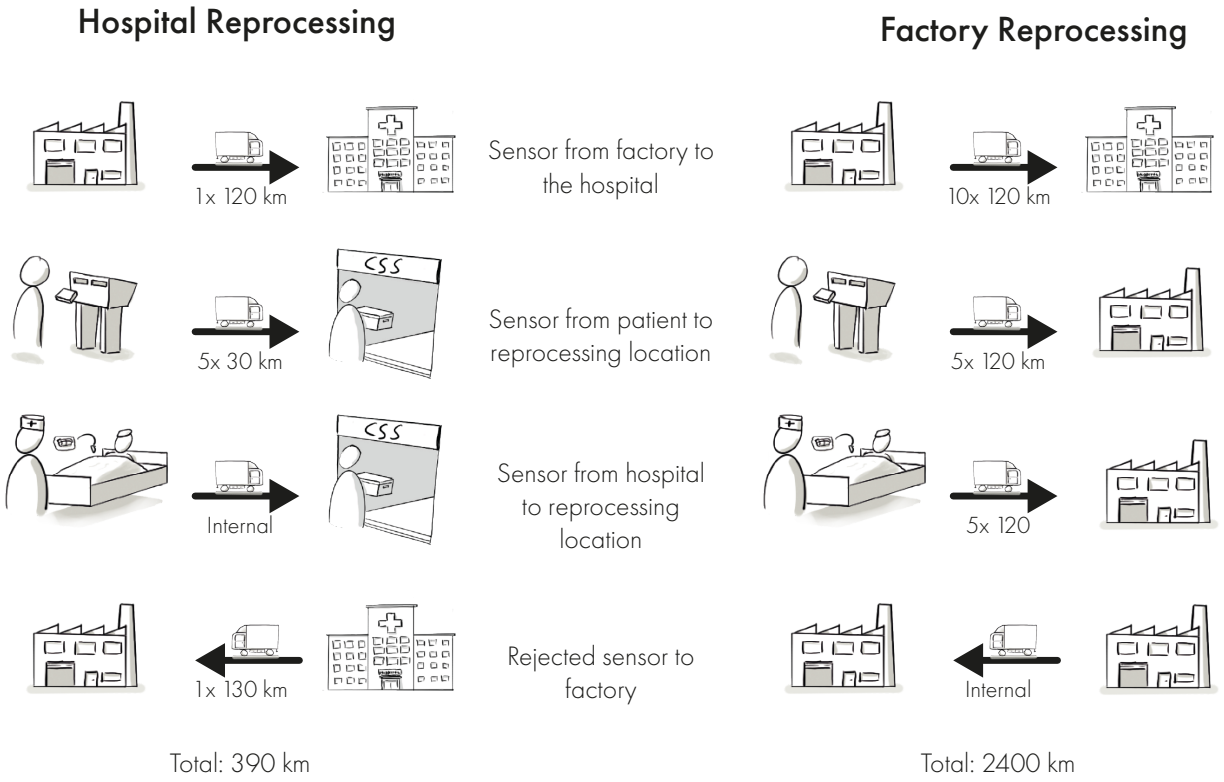


Figure 10.5: Transport distances for the two concepts

In Figure 10.6 the results can be seen. Reuse at the factory has roughly five times the impact when compared to reuse at the hospital because the latter has a major reduction in transport. While this LCA gives a good idea, a more detailed LCA which includes differences in reprocessing impact and end-of-life will most likely give different results, however, this was out of scope for this thesis.

10.5 Weighted Criteria

Both concepts were compared based on the list of criteria from Chapter 8. They were rated on a scale of 1 (poor) to 5 (excellent) based on how well they executed the criteria, the result of which can be seen in Table 10.3.

Based on these results, the choice was made for Hospital Reprocessing. This concept works best in the scenario described in Section 5.1 and is expected to be more inspiring in the results for product design. Because this concept describes both the policlinic and the central sterilisation service as possible reprocessing locations, due to the nature of this thesis the choice was made to specify the reprocessing location to be at the policlinic.

10.6 Take-Aways

I19: Circular Strategies and Business Models form the backbone of your system: they determine the flow and the product requirements that follow, and they are linked together, as choosing one affects your options for the other.

I20: Instead of focussing on only one strategy, such as reuse, try to incorporate more strategies such as repair and manufacturing and see if that offers further improvements.

I21: The classic 'who, what, where, why, when, how' questions can be useful to find challenges in your systems that you might have missed.

I22: The system you design relies heavily on your scenario, with minor changes having big effects. For example, a change in the return method can result in completely different results. This is similar to I6 from Chapter 5.

I23: LCA's can give valuable insights when comparing concepts

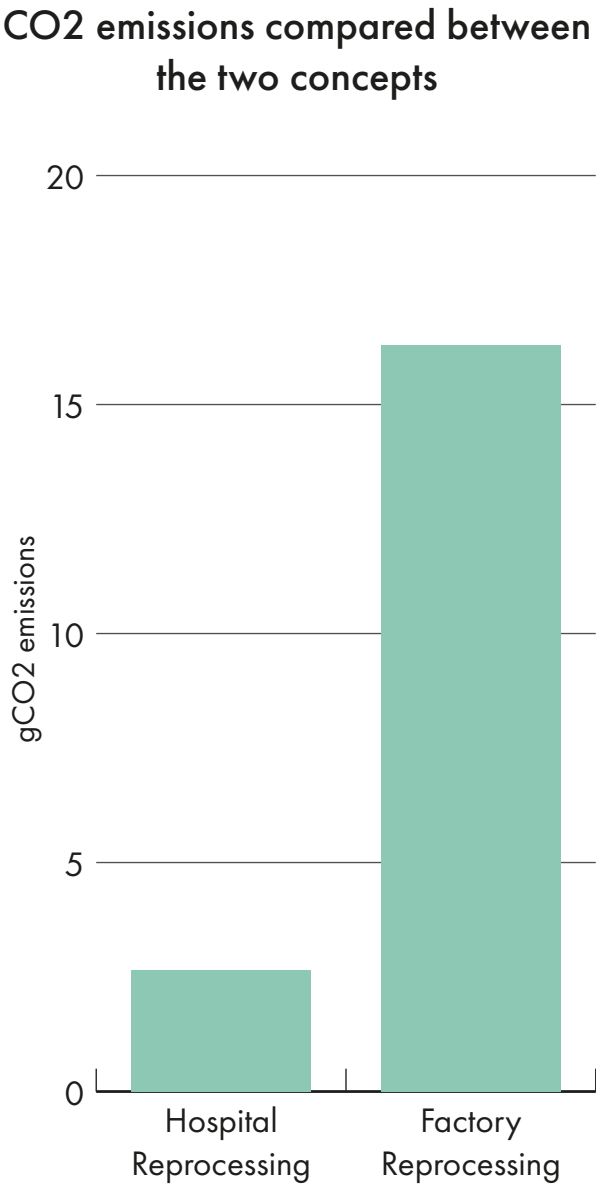


Figure 10.6: CO2 emission compared between the two concepts

	System Requirements	Hospital	Factory
1	The new system has to create less e-waste per use-cycle than the current system	Y	Y
2	The new system has to create less CO2 emissions per use-cycle than the current system	Y	Y
3	The new system has to fit the definition given in Section 3.2	Y	Y
4	The new system has to enable multiple uses of the PCB on patients	Y	Y
	System Criteria		
1	The system should create as little CO2 emissions as possible	5	2
2	The system should create as little e-waste as possible	5	5
3	The system should work as an example for other MWS	5	3
4	The device should be as easily reusable as possible	4	4
5	The system should cycle the PCB as many times as possible	5	5
6	The system should minimize downtime between patients	5	2
7	The system should guarantee the hospital that is will have enough Healthdots at all times	3	4
8	The materials and parts should stay in the loop as long as possible	5	5
9	The system should incentivise all users to act as sustainable as possible	4	4
10	The system should be maximally profitable for the OeM	5	4

Table 10.3: The two concept compared to the criteria from Chapter 8

11 • Designing SenseCab

In this chapter, the design process and the outcomes that led to the SenseCab are discussed. First, the design process is described, after which the design challenges are discussed. Finally, the concepts are presented and the choice for the final design is discussed.

11.1 Design Process

The design process that I followed can be roughly described by Figure 11.1. First, the SenseFlow system was analysed for its unresolved challenges, which led to the identification of two design challenges. These challenges were used as a foundation for the ideation process, in which four concepts were developed. These were then compared, and the SenseCab emerged as the chosen solution. Finally, last iterations and details were added to the design.

This design sprint focuses on problems that exist in the system, and it is important to note that these are not unique to the Healthdot. As a result, the outcomes of this design sprint should be applicable to more sensors than just the Healthdot.

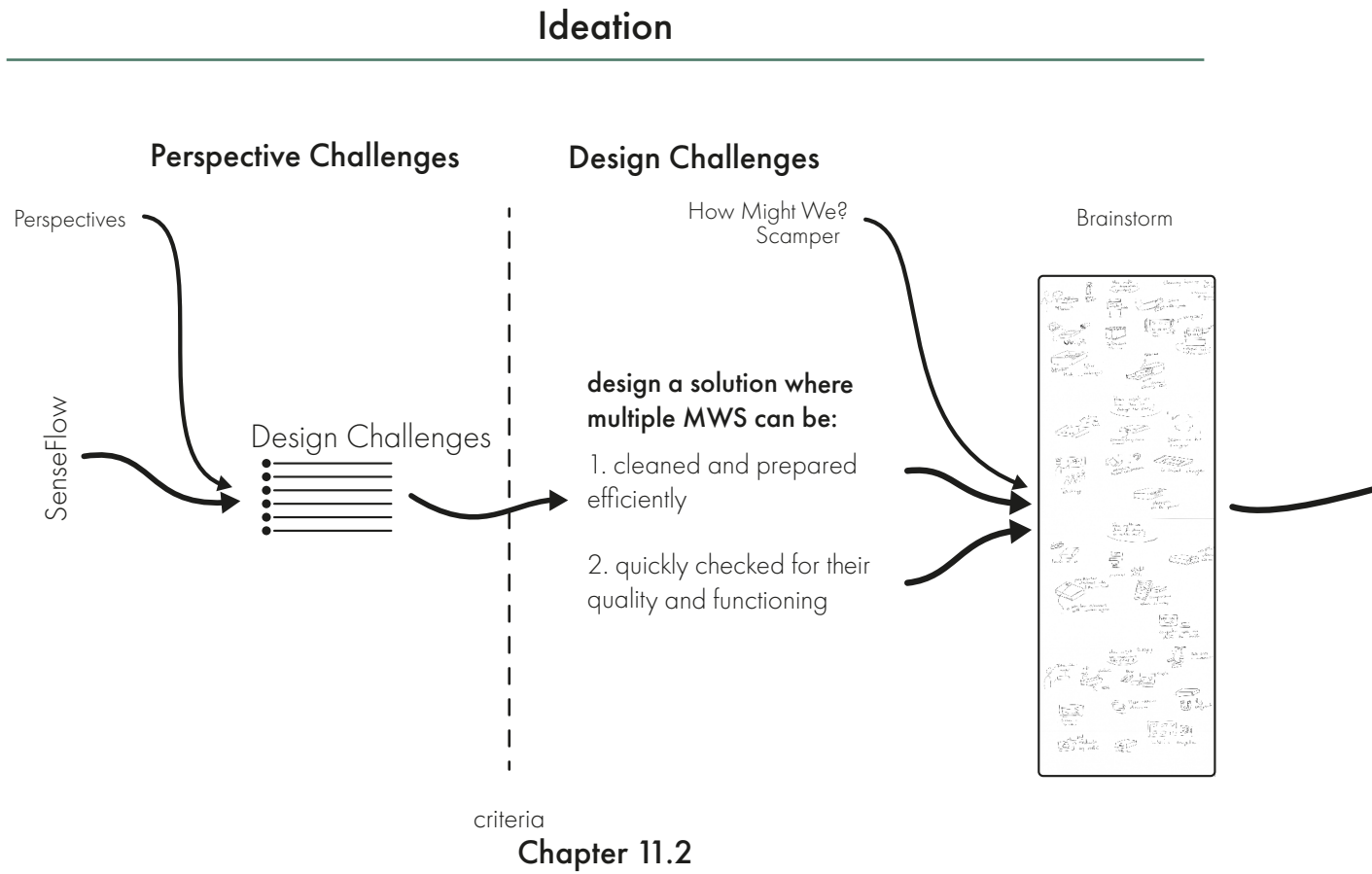
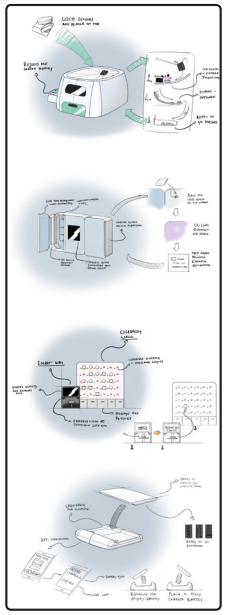


Figure 1011: High-level overview of the process of designing the SenseCab

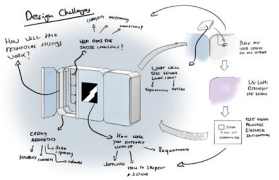
Concepting

SenseCab

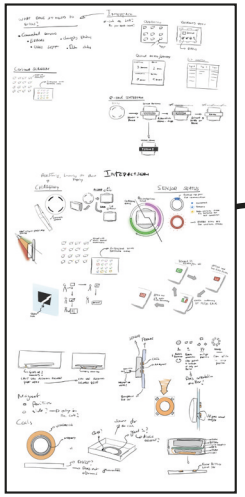
Four Concepts



criteria

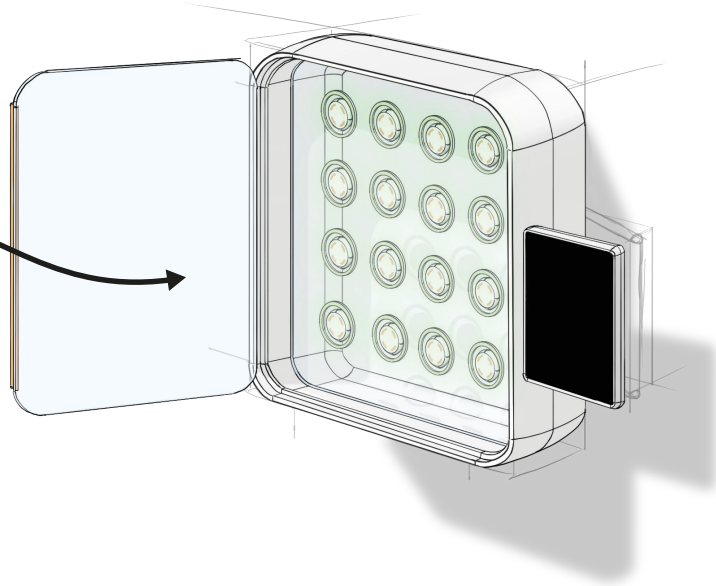


Design Challenges



Chapter 11.3

Final Design



Chapter 9.3

11.2 Design Challenges

To create an enabler for the SenseFlow system, it is important to know what inhibits or blocks the circularity of the system. To achieve this, I identified challenges in the system by taking on the perspective of different stakeholders, users and topics. The results from this brainstorm were then organised into clusters on the SenseFlow map, which resulted in multiple design challenges, which can be found in Figure 11.2. A list of challenges and additional maps per perspective Appendix H. It is important to note that this overview is not exhaustive, and other designers may identify different challenges from the same perspectives.

While many of these challenges are important to the success of this system, I can only focus on three due to the scope of this thesis. To determine these challenges, I first filtered them on their relevance to the scope and then selected the most critical ones. Criticality, in this context, refers to the challenges' importance to the success of the system and the extent of the knowledge gap they present. For instance, challenge 6 How do you know where your devices are' addresses the need for device control and prevention of device loss. However, since similar systems are already in use within hospitals, this may not represent a significant knowledge gap. The results of this process can be found in Appendix H. The chosen challenges are translated into the following design challenges:

11.2.1 Design Challenge 1

Design a solution where multiple MWS from different brands can be cleaned and prepared efficiently.

This design challenge is based on challenges 16 and 17 and focuses on the preparation of the Healthdot. Preparation involves tasks such as charging, modifying data, and making it ready for another use.

Sub challenges

- How do you clean the device?
- How do you charge the device?
- How do you communicate with the device?

11.2.2 Design Challenge 2

Design a solution where multiple MWS from different brands can be quickly checked for their quality and functioning

This design challenge is based on challenge 14 and focuses on controlling the quality and safety of the Healthdot. The Healthdot should be inspected to ensure that it is still safe and functional for reuse.

Sub challenges

- How do you make sure it is not damaged?
- How do you make sure it still has uses left?
- How do you make sure it is still functioning properly?

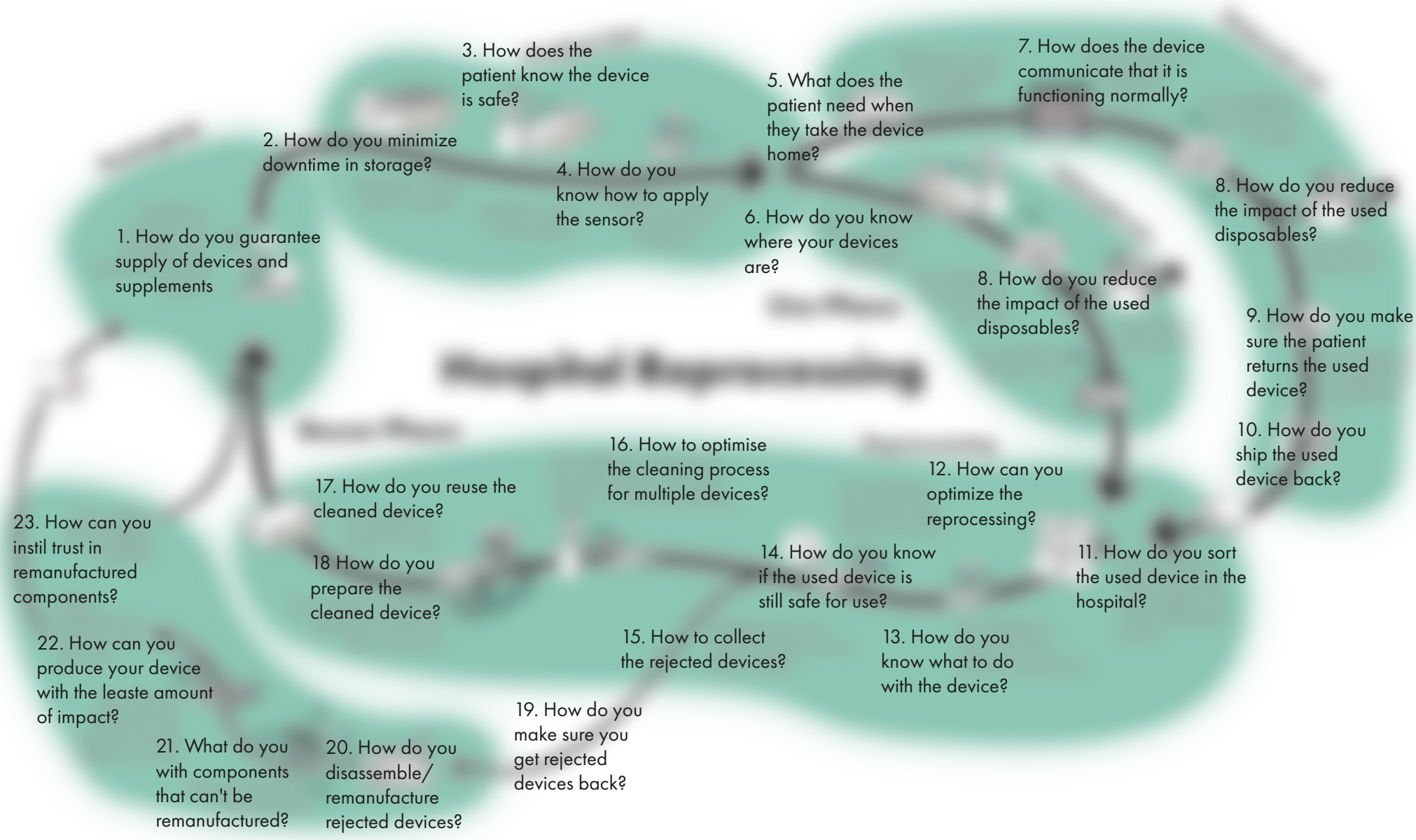


Figure 11.2: Overview of design challenges

11.3 Concept Designs

Next, a brainstorm session was done on the sub-challenges, the results of which can be found in Appendix I. This resulted in the following four concepts: The Auto Pro, the Smart Scan + Wall Charge, the SenseCab and Standardised Batteries. The four concepts can be seen in Figure 11.3 and are described in the following paragraphs, with a more detailed description and image available in Appendix J.

AutoPro is an automatic reprocessing machine. Sensors are placed on top, after which the machine disinfects and charges the sensor. Sensors that are ready for use can be found in a collection box, while rejected sensors are ejected in a separate container.

Smart Scan + Wall Charge is a combination of two products. A basic wireless charging wall offers a starting point, by charging the devices, while a nurse cleans and updates the devices. A second device, the Smart Scan, can be purchased later and takes care of updating the device and doing a visual inspection. AI will be able to determine whether or not a sensor is still safe, leading to many more uses than the prescribed 10.

SenseCab is an all-in-one solution. The sensor is placed inside, where it is automatically disinfected, updated and charged. A screen shows the information on the status of the sensors, and the UV lights are turned off when the cabinet is opened.

Standardised Batteries use shared batteries between MWS. This allows MWS to quickly return to use. After a quick disinfection, replace the empty battery with a fully charged battery. The empty battery is cleaned and placed in a charging wall. The nurse has to manually scan the MWS to manage its data.

11.4 Concept Comparison

To choose between these four concepts, I have compared them to the criteria outlined in Chapter 8 using the datum method (Boeijen et al., 2013, p. 147). In this method, one of the concepts is used as a reference (datum) against which the other concepts are compared. This was done twice, using Standardised Batteries and SenseCab as the datum, both weighted and unweighted. One datum is shown in Table 11.1, as all four datums gave the same outcome. These can be found in Appendix K.

Based on the results of the datums and supporting arguments, I have selected SenseCab as the final concept. It outperforms the other concepts by a small margin, and in addition to that, I believe it is a concept that is both realistic and imaginable, while also inspiring a future perspective.

11.5 Final Iteration

Finally, a last iteration was done to the design on the SenseCab. I have analysed the concept to identify the major challenges, the process and results of which can be found in Appendix L. This resulted in the final design, shown in Figure 11.4 and presented in Chapter 9. These challenges can be summarised as follows:

1. Charging: How will the device charge and stay attached to the cabinet?
2. Interaction: How do you know the status of the device?
3. Interface: What information does the interface share with the user?
4. Design: What will the aesthetics of the cabinet look like?

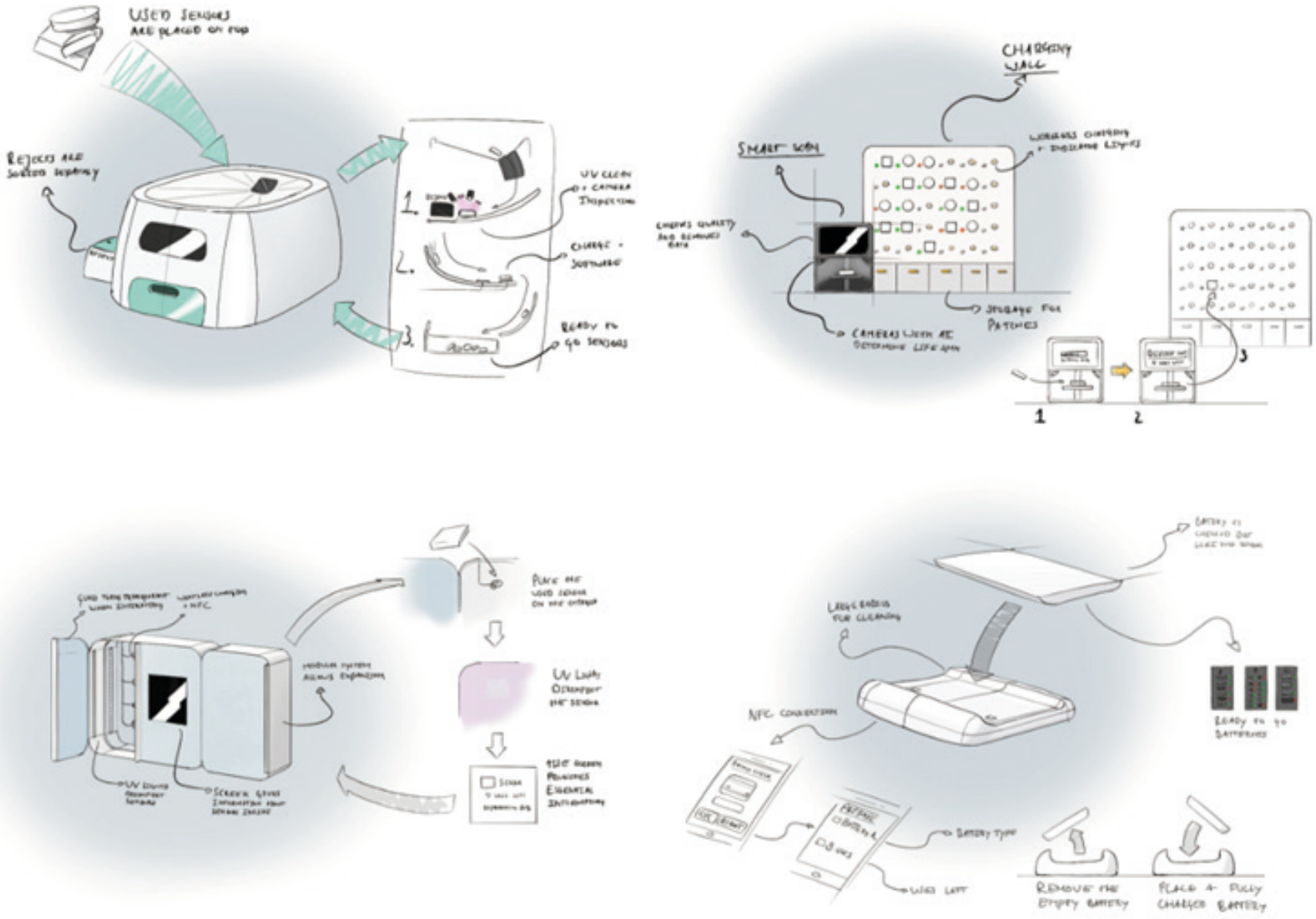


Figure 11.3: Four concepts for the design challenges

	Device Criteria	Standardised Batteries	SenseCab	Smart Scan + Wall Charge	AutoPro
1	The solution should create as little CO2 impact as possible	3	2	1	1
2	The solution should create as little e-waste as possible	3	2	2	2
3	The solution should work as an example for other MWS	3	5	4	4
4	The device should be as easily reusable as possible	3	4	4	5
5	Machines that the hospital has to purchase should be as cheap as possible	3	2	1	1
6	The solution should be as maintainence free as possible	3	3	3	1
7	The solution should be as simple as possible	3	4	4	5
8	The device should minimize cycle times	3	2	2	1
9	The device has to be checked for its quality as quickly as possible	3	3	4	4
10	The solution should instil the maximum amount of trust in the hospital staff	3	4	5	4
11	The solution should take up as little space as possible	3	3	3	3
12	The solution should be as time efficient as possible	3	4	3	5
13	The solution should have a minimal chance of failing	3	4	2	1
14	The solution should resist tampering from the patient	3	4	4	4
15	The solution gives the maximum form-freedom to the OeM's design team	3	5	4	3

Table 11.1: One datum method to compare the four concepts

11.6 Take-Aways

I24: The device is an enabler for the system. Identify the challenges that the system has and determine which ones your device should solve.

I25: The design process for the device doesn't differ much from a regular design process. It is based on the requirements that result from the system designed previously.

I26: The design of the system determines circularity at a high level: How will your product stay in the loop and get used as much as possible? The design of the product determines the circularity at a lower level: How much impact is created when using the product, and how easily can it be reprocessed or remanufactured?

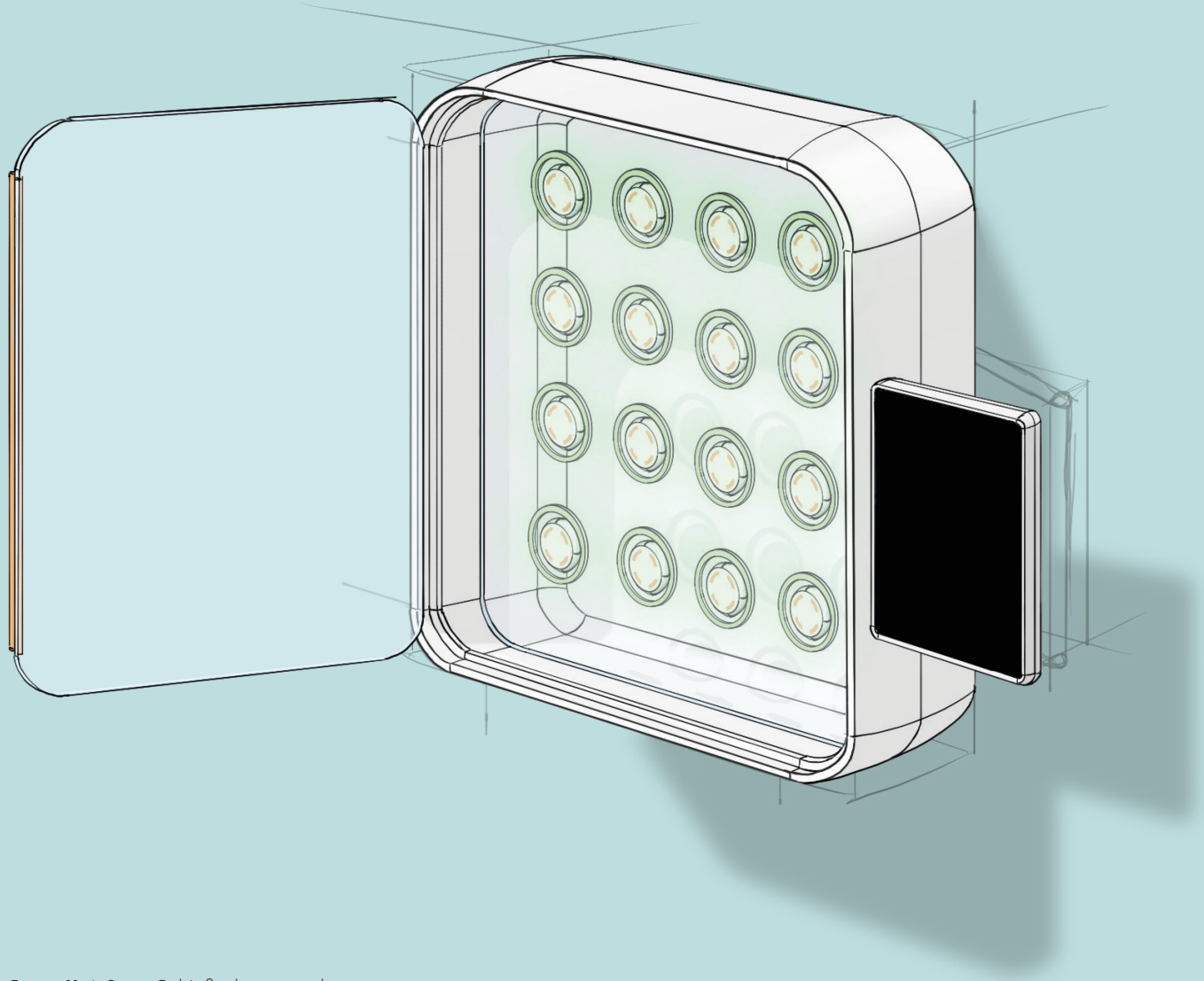


Figure 11.4: SenseCab's final concept design

Part five

recommendations

12 • Conclusion and Recommendations

This chapter concludes the thesis. First, the design goal and methodology are described, after which the research questions from Chapter 2 are answered. Recommendations are given for designers working with Medical Wearable Sensors (MWS), and finally, the implications of this thesis are described.

12.1 Design Goal

The Healthcare sector has a large environmental footprint; 7% of Dutch national CO2 emissions are created by healthcare (Gupta Strategists, 2019), with an average of 2,4kg of waste per patient per day (Singh et al., 2022). With the introduction of the Healthdot, a medical wearable sensor, Philips aims to improve healthcare by allowing transitional care, which frees up bed space and can reduce hospital emissions.

Medical wearable sensors (MWS) are a group of medical devices that wirelessly sense bio measurements, such as heart rate or ECG signals. While these devices can improve healthcare by allowing transitional care, many are single-use devices that are disposed of after use, adding to the already large amount of hospital waste. They are especially harmful because they contain electronics, which are toxic to both humans and the environment (Lin et al., 2022; Ogunseitan, 2022; Wirtu & Tucho, 2022).

The circular economy is one way to reduce the CO2 emissions and e-waste generated by these products. However, no previous research was found that specifically addresses the circular design of MWS. To address this knowledge gap, this thesis aims to present insights for designers to be used in the design process to improve the circularity of MWS. This process is guided by the research question "What should designers keep in mind when designing circular MWS?", and is supported by the following:

1. RQ1: What is the circular economy?
2. RQ2: What is the current status of the Healthdot?
3. RQ3: What could a circular MWS look like

12.2 Methodology

To answer these questions, a case study was executed, focussing on the redesign of a MWS. In this case study, the design challenge is formulated as follows: "to improve the circularity of the Philips Healthdot".

Initially, an exploration of existing literature was performed to gain an understanding of the circular economy and to find existing solutions for design strategies and business models. Subsequently, an analysis of the Healthdot and its context was conducted to identify barriers and opportunities, which resulted in design requirements for a circular redesign. Furthermore, a Life-Cycle Analysis (LCA) analysed the Healthdot's eco-impact.

These results were used as a basis for the development of SecondSense, a proposed circular MWS system consisting of two parts: SenseFlow and SenseCab. Through a comparative LCA, SecondSense's environmental impacts were compared with the Healthdot, showing major reductions in CO2 emissions. Conclusively, the insights generated during the design process were used to create recommendations for designers.

12.3 Findings

This section answers the three research questions described in Chapter 2.

RQ1: What is the circular economy

The circular economy refers to a system that is restorative by intention (Ellen MacArthur Foundation, 2013a), and unlike the linear 'take-make-waste' model, ensures that resources are kept in use as long as possible. A common framework to visualise the principles of the circular economy is the Adapted Value Hill (Figure 12.1). It illustrates the rule of thumb that the shorter you keep the circular loop, the more value you maintain and the more circular you become. The framework combines the Value Hill (Achterberg et al., 2016), with the 9R model (Potting et al., 2017). However, it is important to note that this is a simplified version of the circular economy. These frameworks are explained in more detail in Chapter 3.

There are many definitions for the circular economy; in one instance, 114 different definitions were found in different papers (Kirchherr et al., 2017). For this thesis, an adaption of Geisendorf & Pietrulla's (2018) definition is used: "the value of products and materials is maintained,

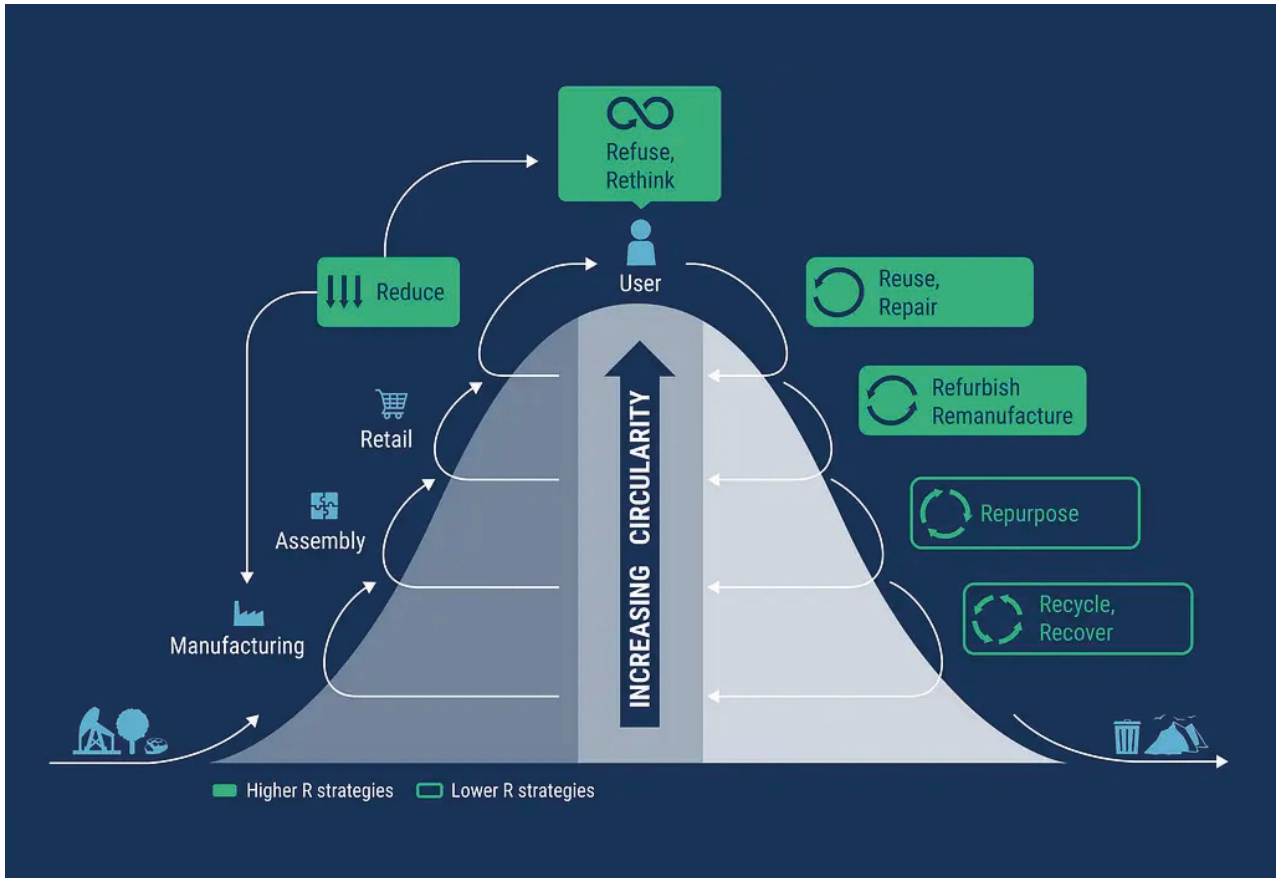


Figure 12.1: Adapted Value Hill (Metabolic Institute, 2021)

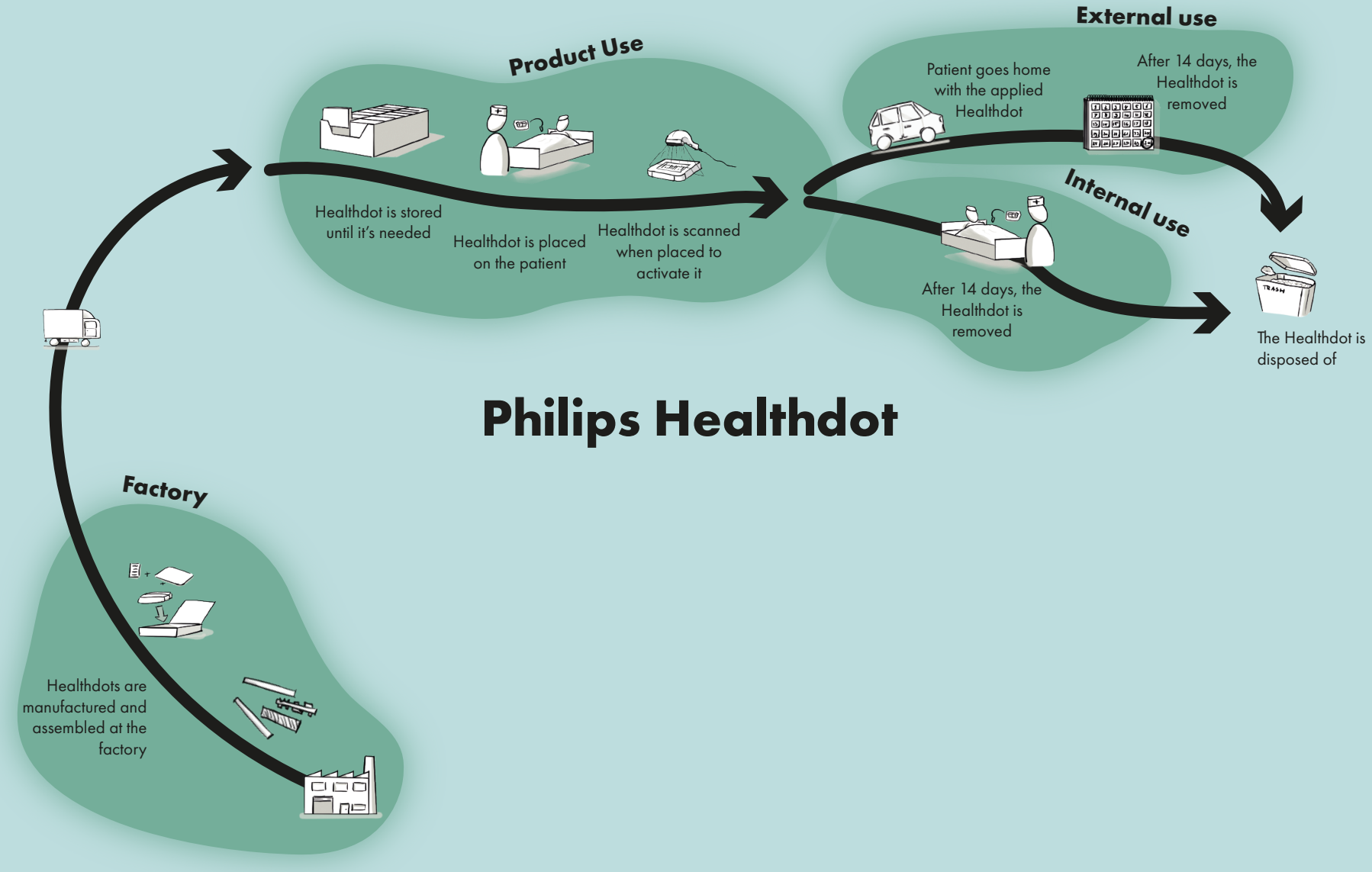


Figure 12.2: The Healthdo't product journey

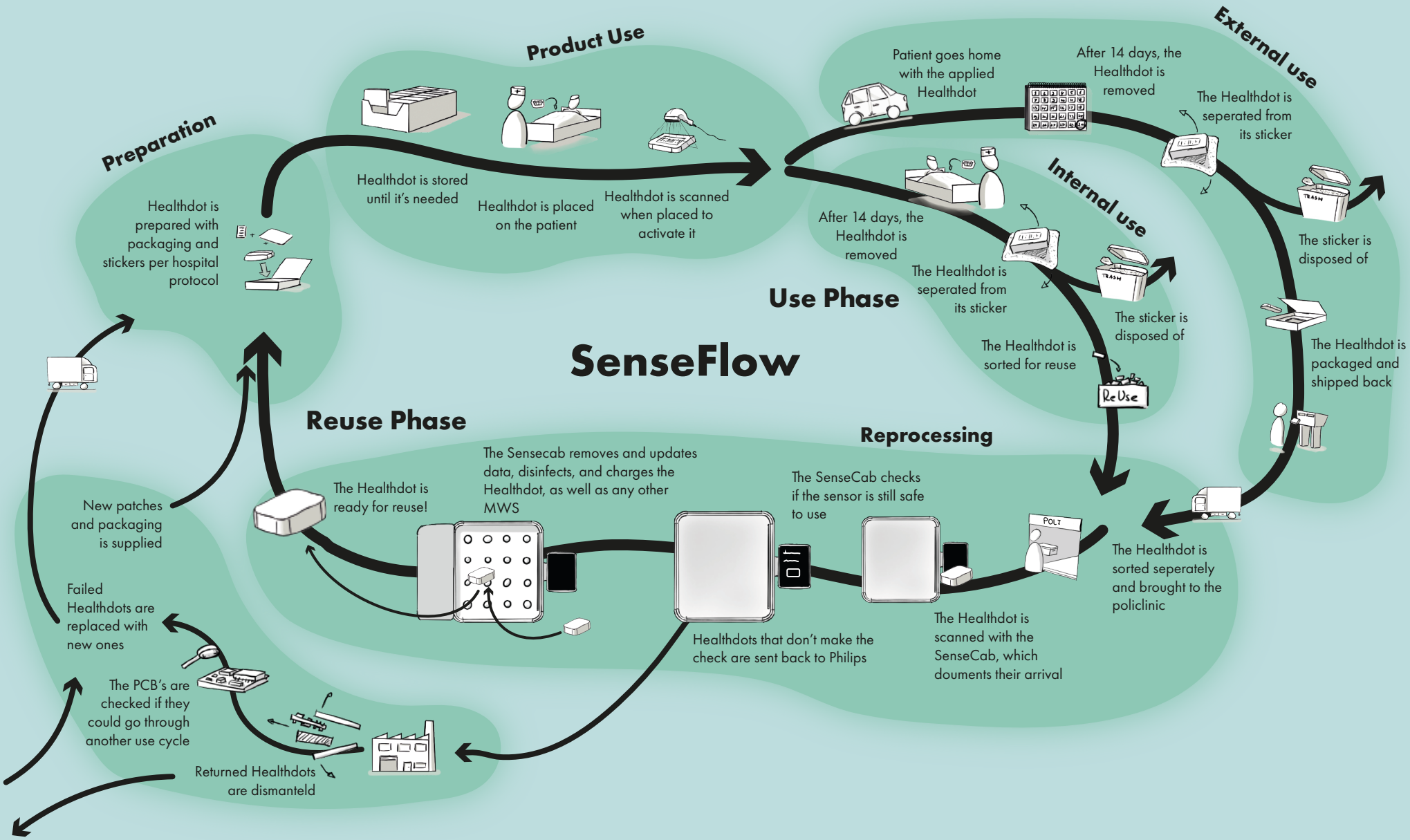


Figure 12.3: The SenseFlow system

waste is avoided, and resources are kept within the economy when a product has reached the end of its life and is restorative in nature.". This definition is found to be conclusive in defining the circular economy, while simultaneously being simple enough to work with. The phrase 'restorative in nature' has been added to the original definition, to better capture the restoring aspect of a circular economy.

Research has been done towards circular design strategies and business models. Multiple frameworks exist that describe different design strategies (Bocken et al., 2016; Kane et al., 2018; Moreno et al., 2016) and different business models sector (Bocken et al., 2016; Guzzo et al., 2020; Kane et al., 2018; Moreno et al., 2016). These served as a starting point for ideation for the case study.

RQ2: What is the current status of the Healthdot

The Healthdot is a simple device, with its major parts being a Printed Circuit Board (PCB), a battery, an upper and lower casing and a skin adhesive patch. It is glued shut, and after use, it has to be disposed of, as the battery is empty. Recycling is difficult due to the device being glued shut. Philips is currently developing a new, circular version of the Healthdot of which the PCB can be easily removed.

Its most common use is post-operative, where it is applied by a nurse to the patient, after surgery. The patient either stays in the hospital, where the Healthdot is removed by a nurse or goes home, and the patient removes the Healthdot. After use, the Healthdot is disposed of. This product journey is described in more detail in Figure 12.2.

The Healthdot's environmental impact is analysed in an LCA, the results are shown in Figure 12.4. The PCB is the largest source of CO2 emissions by a far margin. Combined with the fact that e-waste is toxic and difficult to recycle, the reuse of the PCB should be a priority in a circular system.

RQ3: What could a circular MWS look like?

To show what a circular MWS and its system could look like, SecondSense was developed. SecondSense is a product-service-system, which allows quick and easy reuse of MWS. This system consists of two parts: SenseFlow and SenseCab. SenseFlow describes how the MWS flows through the system (see Figure 12.3), while SenseCab enables easy reprocessing (Figure 12.4-12.6).

After use, medical wearable sensors are returned to the policlinic. Internally used sensors can be collected in the hospital, while externally used sensors are returned by post. At the policlinic, the sensors are cleaned with an alcohol wipe, after which they are placed in the SenseCab. The SenseCab removes and updates data, UV-disinfects and charges the sensors.

The Original Equipment Manufacturer (OEM) stays the owner of the sensors and the hospital pay-per-use. This gives the OEM control over the end-of-life of the sensor and gives an incentive to the OEM to design long-lasting products; the more a sensor can be used, the more profit they make.

SecondSense is not a solution specific to the Healthdot, but one that can be shared across sensors and manufacturers. By using standardised charging and communication methods, the SenseCab can be used with a multitude of different MWS, if their manufacturer chooses to.

In an LCA the Healthdot and SecondSense were compared for their environmental impact. It was found that in a worst-case scenario, SecondSense reduces CO2 emissions by 45% after 5 uses, and 60% after 10 uses, as can be seen in Figure 12.4. In a best-case scenario, it is assumed SecondSense could reduce CO2 emissions by upwards of 80% after 10 uses.

As mentioned earlier, most of the sensor's impact comes from its electronics. If these would be reused, as is the case with the new Healthdot that is being developed by Philips, the sensor's impact could be reduced by 35% if the PCB was reused once, and over 50% if the PCB would be reused 5 times.

It was found that in a circular system, reductions in the sensor's initial impact, such as the electronics, yield the most improvements in short-term (1-5) use, while reductions in its use phase, such as reprocessing steps, yield more improvements on long-term (5-10) use.

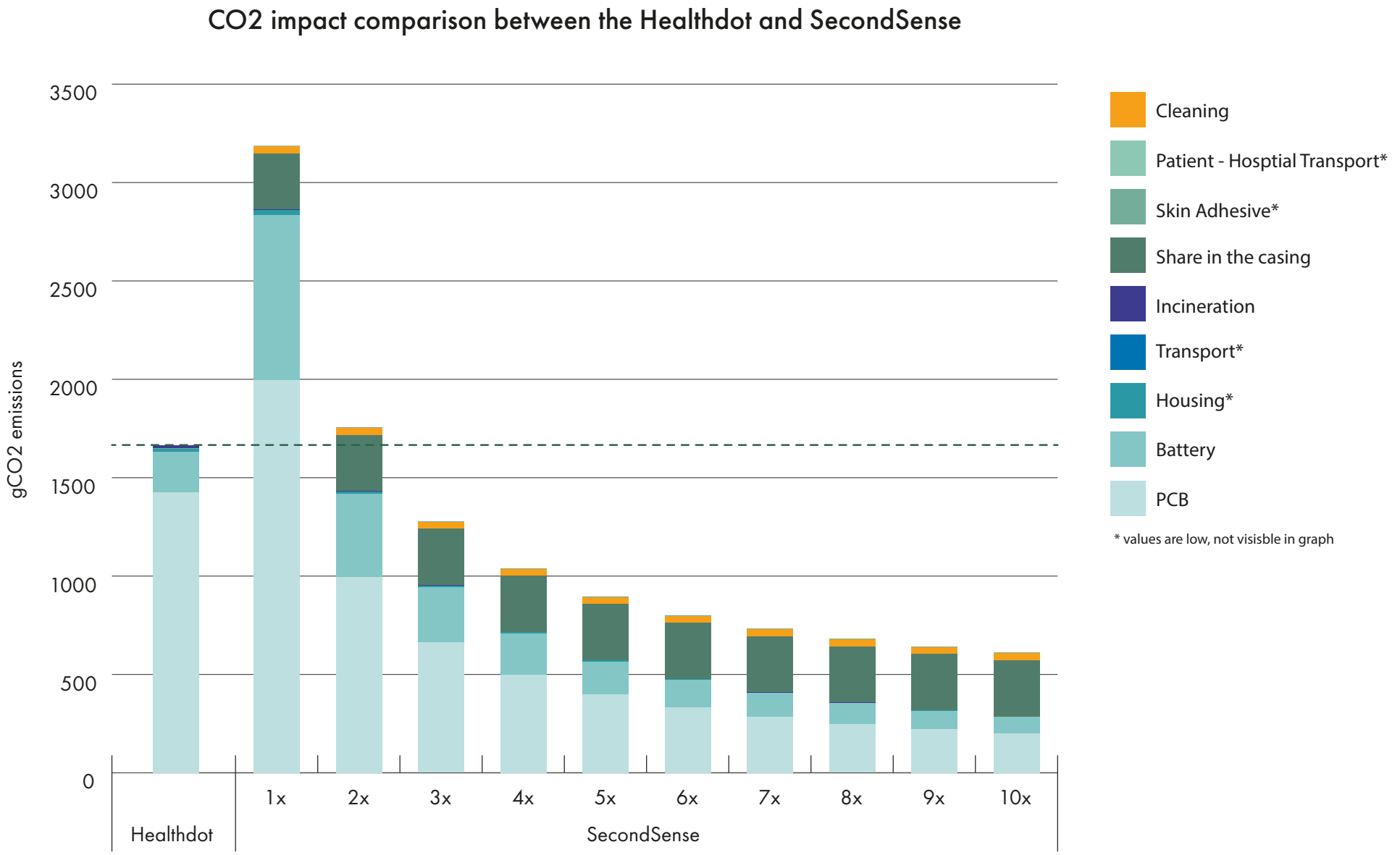


Figure 12.4: CO2 impact comparison between the Healthdot and SecondSense

Figure 12.4: Front view of the SenseCab

Figure 12.5: A sensor being placed in the SenseCab

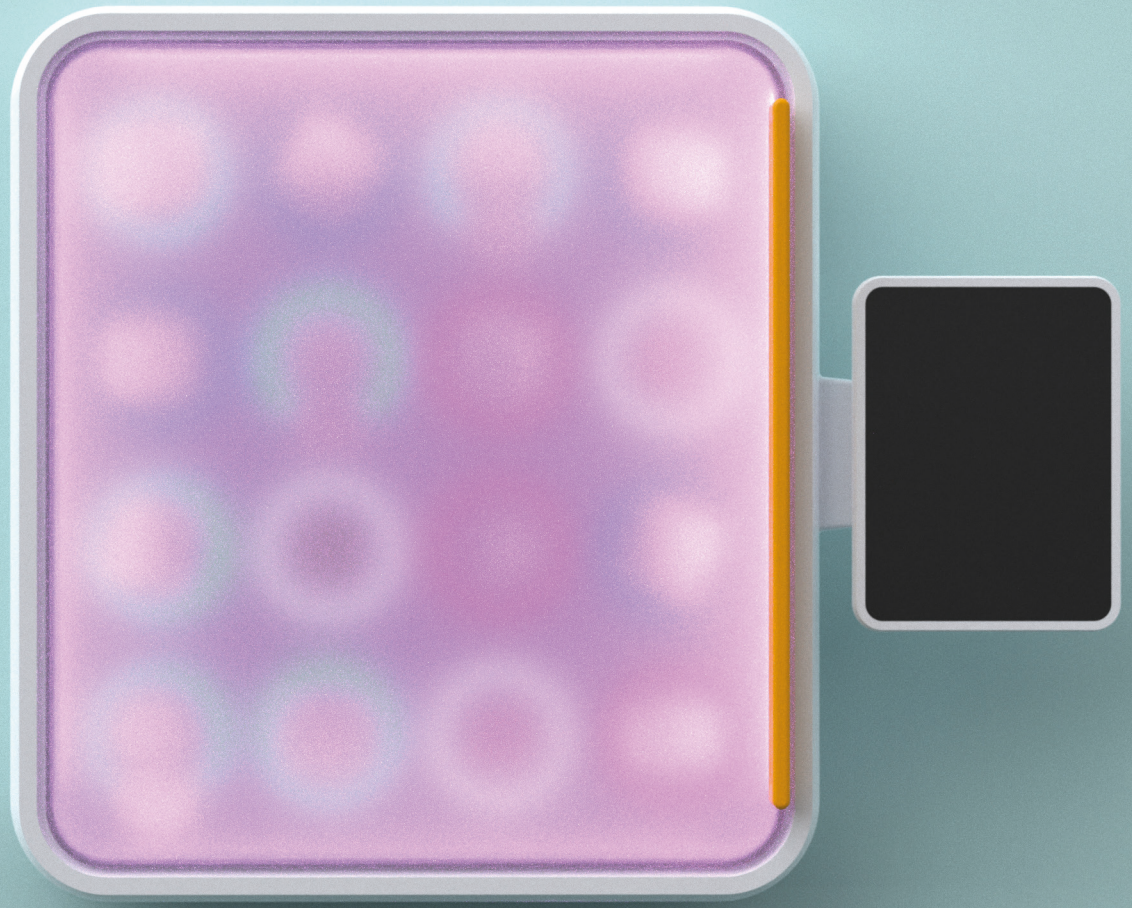


Figure 12.4: Front view of the SenseCab during a disinfection cycle

12.4 Recommendations for Designing Circular MWS

Based on the outcomes of the case study, recommendations are formulated that address the knowledge gap that exists when it comes to designing circular MWS, described above. They offer a starting point for designers and engineers to create circular solutions for MWS.

12.4.1 Circular design vs. classic design

FFirst, a brief comparison is given to highlight the differences between a 'circular design process' and a 'classic design process'.

While circular systems can be complex, their circular design process is in essence similar to a 'classic' product design process. Initially, a context is determined, subsequently, product requirements are set up and finally, a concept is developed. However, in a circular design process, there is a consideration not only of the product's use phase but also of how the product – in whole or in part – can be retained within the circular loop. A circular design process demands extended effort, as it involves designing a system that retains the device, in addition to designing the device itself. It adds complexity to the process.

Circular systems are complex because they describe more than a linear system, as is illustrated by the difference between Figure 12.2 and 12.4. However, designing for the circular economy doesn't have to be complex, as a structured approach is maintained.

The following sections describe two sets of recommendations for designing circular MWS, with applicability extending to the design of other circular products.

12.4.2 Understand the principles of the circular economy and how to design for it

To effectively design for the circular economy, comprehending its core principles is a must. Thus, the first set of recommendations centres on creating an understanding of the circular economy.

R1: Gain a solid understanding of the basic principles of the circular economy

Multiple frameworks exist that describe the principles of the circular economy. A good starting point is the Adapted Value Hill, described above in Section 12.3.1, as it is intuitive yet comprehensive. However, it is also simplified and should be considered a rule of thumb. Chapter 3 of this thesis describes the principles of the circular economy in more detail.

R2: Research circular design strategies and business models for the design challenge

There is an extensive amount of research, which describes effective combinations of design strategies and business within the circular economy. The second recommendation is therefore to research and choose circular design strategies, relevant to your design challenge. In Chapter 4 circular design strategies and business models are described in more detail, and in Section 10.2, a potential approach for choosing between strategies and business models is described.

R3: Determine what defines circular economy

As discussed in Section 3.1, there are varied interpretations of how the circular economy is defined, which is why it is recommended to determine what definition for the circular economy is used. Firstly, a definition aids decision-making by aligning perspectives on what is circular; secondly, it can be used to create requirements and criteria, both at a system and concept level.

12.4.3 Structure your design process

The second set of recommendations centres on structuring the circular design process. To design a circular MWS, the design involves both a system and a product. The system consists of a circular strategy, outlining how the product will remain in the circular loop, and a business model, describing how an OEM can generate profit. The product, in this context a sensor, functions as an enabler, designed to facilitate actions prescribed by the system to ensure its integration within the circular loop.

R4: First, determine how the system is going to be circular, then design the product so that it enables this system.

The circularity of the product is primarily determined by the system, which shapes the requirements for the product. For this reason, it is recommended to first determine how the product will become circular, by determining the strategy of the system. This results in design requirements and criteria, describing what the product should facilitate.

As mentioned earlier, a structured approach is necessary when designing circular MWS. In this section, a structured approach based on the outcome of this thesis is suggested.

R4.1 Take additional care when determining the boundaries.

Begin by establishing the project's context and boundaries. Describe aspects such as product use, user, stakeholder and potential reprocessing entities. Scoping and boundaries are important in any design project; however, this study revealed that even slight adjustments to these boundaries could yield in a completely different system, as detailed in Section 5.1. This subsequently affects the product as well.

R4.2 Determine a detailed system outline

Next, determine the circular strategy and business model. A recommended starting point is the literature mentioned in Chapter 4. These factors collectively shape the functioning of the system, which in turn dictates the requirements and criteria for the product. For instance, if the chosen circular strategy focuses on reprocessing, the device needs to be able to withstand cleaning, whereas a remanufactured-oriented approach would demand easy disassembly.

Because the system lays the groundwork for defining product requirements, it is a must to craft a comprehensive summary of supporting activities. I recommend developing a high-level overview of the system at a minimum, similar to Figure 12.3. This outline should describe the necessary actions needed to maintain the product within the system. In this context, involved stakeholders should be determined and their associated tasks.

R4.3 Analyse the system to formulate requirements

With the system defined, analyse it to formulate requirements and criteria. The product's central role within the system involves enabling the actions required by stakeholders to sustain circularity. If modifying an existing product, minor adjustments might suffice to align it with these requirements.

R4.4 Integrate the classic design process into the circular system

At this point, product requirements have been determined which leads to a circular product. The process shifts towards a more conventional design process. It is recommended to use a method familiar to you for the generation of ideas, concepts and final design. However, remain mindful of the circularity objectives defined earlier.

12.4.4 Final notes

Throughout the design process, two activities stand out that can boost circularity.

R5: Use fast-track LCAs for conceptual insights

The first activity revolves around using Fast-Track LCA's to quickly evaluate concepts, gaining insights on environmental impact within the designs. This helps determine what parts of the current product are most worthwhile to save, where improvements lie as well as compare ideas and concepts for their circularity.

R6: Involve stakeholders in the design project

The second activity focuses on involving stakeholders in the project. Stakeholders hold valuable knowledge for any design project. In a circular system, they are especially relevant, given their familiarity with the system. Moreover, they become central actors in the circular system; for instance, they might collect and reprocess your product. Involving them in the design process can increase the likelihood of these stakeholders adapting the solution.

12.5 Implications

Finally, the implication of this thesis on the design of circular MWS, the environment and academia are described, concluding this thesis.

12.5.1 The potential of circular MWS

Firstly, this thesis has demonstrated that a simple yet effective solution can be used to reuse MWS with minimal changes to its design. A universal solution that could be used across platforms is proposed, enabling easy reprocessing of a variety of sensors within a high-performance environment like hospitals. It offers valuable insights and recommendations for the design process, serving as an inspiration for future designers. Moreover, it introduces companies like Philips to innovative possibilities, that extend beyond their current circularity efforts, and suggests that cooperation between OEMs is important in a circular economy.

12.5.2 Environment

Secondly, the SecondSense concept illustrates that a circular system in which MWS are reused can yield a substantial CO2 reduction. The thesis highlights possible improvements that could further decrease these emissions. Additionally, it underlines the benefits of localised reuse, encouraging OEMS to explore new solutions aimed specifically at reusing devices within a hospital setting.

12.5.3 Academia

Lastly, the thesis underlines how academic research focused on circular design strategies and business models contributes to and can be utilised in a practical application of circular design. This is achieved by using academic research as a starting point for the development of a circular system. Furthermore, this thesis adds to this research by providing recommendations for designers, which can be used as a starting point for future circular design processes, not just for the design of MWS.

In conclusion, the implications of this thesis could extend beyond the design SecondSense and have been demonstrated to add value to the design of medical wearable sensors, the environment and academia.

13 • Limitations and Further Research

Due to the nature of this thesis, assumptions and limitations naturally come into play. In this chapter, the limitations of this thesis are discussed, and recommendations for further research are given. First, the limitations to the scope and boundaries of this thesis are examined, followed by the validation process with stakeholders and the LCA results. Lastly, constraints related to the recommendations are addressed.

13.1 Scope and Boundaries

Given the constrained timeframe of this thesis, it was not possible to cover all aspects of the. This led to scoping, where the following elements were considered out of scope, for the following reasons.

13.1.1 Medical Regulations

Firstly, medical regulations and laws were not taken into account. These regulations dictate the rules and standards to which medical devices should adhere. For instance, a reusable device has to be certified for a certain amount of reuse, and may not be reused beyond this limit.

While the assumption that SecondSense aligns with regulations seems reasonable, as reusable MWS were found, it is not verified. It is plausible that major changes to the design need to happen, potentially impacting the circularity of the device or even preventing the device from becoming circular. Further research into the regulations that apply to MWS, and SecondSense in specific, is recommended.

13.1.2 Return Location

Secondly, an early decision regarding the return method of the Healthdot was necessary in this thesis. Based on prior work and the DiCE context, it was presumed that the Healthdot is returned via postal service. As discussed in Section 10.3, a different return location will likely yield a different system. Further research is recommended to validate the current return method as well as to explore alternative options, such as pharmacy or general practitioner-based returns. This area is scheduled for research within DiCE and was thus excluded from this thesis's scope.

13.1.3 Economical Viability

Thirdly, the economic viability of the concept is not analysed in this thesis. While a back-of-the-envelope estimation suggests viability, due to the sensor being able to be sold multiple times despite higher costs, no conclusions are drawn. Further research is recommended to assess the concept's economic viability.

13.2 Validation with Stakeholders

While the concept is an improvement in environmental impact, it is not validated by stakeholders. Although concepts for SenseFlow were discussed and validated in conversations with stakeholders, the SenseCab design is based solely on the results of these conversations. The SenseCab, the final iteration of SenseFlow, and their combination are not validated by stakeholders or users. Subsequent research is recommended to evaluate the device with the stakeholders mentioned in this thesis.

13.3 Life Cycle Analysis Results

Fast-track LCAs were used to compare concepts and validate findings. However, as noted in the report, results of fast-track LCAs are indicative, as they rely on assumptions and databases that may might not accurately reflect the actual situation. Still, these LCAs are presumed to offer a reasonable indication, and it is believed that a detailed LCA will yield similar results. Detailed LCAs were beyond the scope of the thesis due to time constraints. Further research is recommended to better understand the environmental impacts of the Healthdot and the SecondSense system.

13.4 Recommendations

Finally, limitations also apply to the recommendations presented earlier. These recommendations are based on my personal experiences. While efforts were undertaken to ensure objective recommendations, inherent biases are difficult to eliminate entirely.

This thesis marks my first venture into a circular design project of this scale, meaning it was a learning project. Consequently, the recommendations partially reflect my personal perspective and learning process. Peer students provided feedback on these recommendations, however, they were not validated. Further research is advised for the validation of these recommendations, such as co-creation sessions involving designers and engineers.

14 • Personal Reflection

In this final chapter, I will reflect on my personal process: what did I learn, what would I do again and what would I do differently?

First of all, thank you so much for reading my thesis. These 100 pages and eighteen thousand words are the result of half a year of hard work, sweat and tears – no blood, luckily. I hope you found it inspiring, and that it motivates you to design circular and sustainable solutions.

A question most people ask a master's student after their graduation, is either 'Would you do it again?' or 'Would you want to continue with your project?'. I would have to answer yes to both. I thoroughly enjoyed learning more about the circular economy, developing this system and especially seeing that it contributes to a better world. I feel that I can look back with pride on both my learning process, as well as my result.

In this thesis, I learned that circular design is complex and requires a different, additional process. However, as long as you have a clear goal, it doesn't have to be difficult. I found the project challenging, as I've never worked with sustainability at this scale and I've never designed a system, let alone of this complexity.

If I would do the thesis again, I would repeat the design process. I believe it was the right process to start with, by determining and designing the system and following that up with requirements and the product. While it was a struggle at times to balance design strategies and business models, which I expect to become better with more experience.

The biggest change that I would make to this thesis next time, concerns the structure. I think the design goal with which I started this project was a little undefined for me, and if I'd do the project again I would further define the project goal, creating a more concrete design goal. I always felt structure is essential for me, however, I also believe that because I had this open project, I could create the result I have now. Maybe it is time to rethink this.

What I would do differently in my design process, is to involve stakeholders more and do LCAs earlier in the design process.

It was difficult to connect to hospitals. Partially, because it was difficult to get in touch with the right person, but also because I think I was too busy trying to understand the system before talking to stakeholders and experts. However, talking with experts would have likely helped me understand the system as well. Once talking to them, I got useful information and insights. For me, this is a lesson to be more in touch with stakeholders and bring their expertise into play earlier, instead of trying to do it all by myself.

In my process, I would use more LCAs. I think if I could have used LCAs at more points in the process, and would have gotten more valuable insights out of them. However, now that I have experience with LCAs, I expect to use them more in my decisions in the future.

With this reflection, I close my thesis. This marks the moment where I go from being a student in design to an active practitioner, to make it as circular as possible. However, I want to never stop learning.

Again, thank you so much for reading. If you want to learn more about this topic, feel free to shoot me a message.

Kind regards,

Matthijs

references

References

Achterberg, E., Hinfelaar, J., & Bocken, N. M. P. (2016). Master circular business with the value hill.

ATsens. (n.d.). TOTAL ECG Monitoring Solution, AT-Heart. Retrieved 17 August 2023, from https://www.atsens.com/en/sub_01_1.html

BioTelemetry. (2020, November 24). EPatch. BioTelemetry, a Philips Company. https://www.gobio.com/epatch/

Blum, N. U., Haupt, M., & Bening, C. R. (2020). Why "Circular" doesn't always mean "Sustainable". Resources, Conservation and Recycling, 162, 105042. https://doi.org/10.1016/j.resconrec.2020.105042

Bocken, N. M. P., 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

Boeijen, A., Daalhuizen, J., Zijlstra, J., & Schoor, R. van der. (2013). Delft Design Guide (2nd ed.). BIS Publishers.

Buijs, J. A., & van der Meer, J. (2013). Integrated creative problem solving. Eleven International Publishing.

CBS. (2023, June 23). StatLine—Nabijheid voorzieningen; afstand locatie, regionale cijfers. https://opendata.cbs.nl/statline/#/CBS/nl/dataset/80305ned/table?fromstatweb

Corbin, L., Laláková, E., Quigley, S., Valkov, M., & Dijkstra, A. (2021). FINANCING CIRCULAR ECONOMY INNOVATION IN THE NETHERLANDS. Metabolic Institute. https://www.metabolic.nl/publications/financing-circular-economy-innovation-netherlands/

Corvellec, H., Stowell, A. F., & Johansson, N. (2022). Critiques of the circular economy. Journal of Industrial Ecology, 26(2), 421–432. https://doi.org/10.1111/jiec.13187

de Zorgambassade. (2022). Wij zijn al gestart. Doe je mee?

Ellen MacArthur Foundation. (2013a). Towards the Circular Economy Vol. 2: Opportunities for the consumer goods sector | Shared by Business. https://emf.thirdlight.com/link/coj8yt1jogq8-hkhkq2/@/preview/1?o

Ellen MacArthur Foundation. (2013b). Towards the Circular Economy vol.1.

Erasmus MC Foundation. (n.d.-a). About Erasmus MC - Erasmus MC. Retrieved 7 August 2023, from https://www.erasmusmc.nl/en/pages/about-erasmusmc

Erasmus MC Foundation. (n.d.-b). De groene IC - Erasmus MC Foundation. Retrieved 23 June 2023, from https://erasmusmcfoundation.nl/projecten/de-groene-ic/

European Commission. (n.d.). DIgital health in Circular Economy | DICE Project | Fact Sheet | HORIZON | CORDIS | European Commission. Retrieved 24 May 2023, from https://cordis.europa.eu/project/id/101060184

European Commission. (2023, April 19). Hulpmiddelen > 00884838116900— EUDAMED. https://ec.europa.eu/tools/eudamed/#/screen/search-device/c0b93cba-75e6-48c3-8b0a-6fbe5bf0cffd

European Parliament. (2020, December 23). E-waste in the EU: Facts and figures (infographic) | News | European Parliament. https://www.europarl.europa.eu/news/en/headlines/society/20201208STO93325/e-waste-in-the-eu-facts-and-figures-infographic

Forti, V., Baldé, C. P., Kuehr, R., & Bel, G. (n.d.). The Global E-waste Monitor 2020.

Geisendorf, S., & Pietrulla, F. (2018). The circular economy and circular economic concepts-a literature analysis and redefinition. Thunderbird International Business Review, 60(5), 771–782. https://doi.org/10.1002/tie.21924

Gupta Strategists. (2019). Een stuur voor de transitie naar duurzame gezondheidszorg.

Guzzo, D., Carvalho, M. 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

Health Care Without Harm. (2019). Health Care's climate footprint.

Hummels, C., & Frens, J. (2009). The reflective transformative design process. CHI '09 Extended Abstracts on Human Factors in Computing Systems, 2655–2658. https://doi.org/10.1145/1520340.1520376

iRhythm. (n.d.). Zio Monitoring. Retrieved 17 August 2023, from https://www.irhythmtech.com/providers/zio-service/zio-monitors

Kane, G. M., Bakker, C. A., & Balkenende, A. R. (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

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

Kirchherr, J., Yang, N.-H. N., Schulze-Spüntrup, F., Heerink, M. J., & Hartley, K. (2023). Conceptualizing the Circular Economy (Revisited): An Analysis of 221 Definitions. Resources, Conservation and Recycling, 194, 107001. https://doi.org/10.1016/j.resconrec.2023.107001

Lefebvre, E., Romero, A., & Lefebvre, Louis. A. (2011). Healthcare and the e-waste tsunami: The specific issues of e-medical equipment.

Lin, S., Ali, M. U., Zheng, C., Cai, Z., & Wong, M. H. (2022). Toxic chemicals from uncontrolled e-waste recycling: Exposure, body burden, health impact. Journal of Hazardous Materials, 426, 127792. https://doi.org/10.1016/j.jhazmat.2021.127792

MacNeill, A. J., Hopf, H., Khanuja, A., Alizamir, S., Bilec, M., Eckelman, M. J., Hernandez, L., McGain, F., Simonsen, K., Thiel, C., Young, S., Lagasse, R., & Sherman, J. D. (2020). Transforming The Medical Device Industry: Road Map To A Circular Economy: Study examines a medical device industry transformation. Health Affairs, 39(12), 2088–2097. https://doi.org/10.1377/hlthaff.2020.01118

Masimo. (n.d.). Masimo—Centroid. Retrieved 17 August 2023, from https://www.masimo.com/products/sensors/centroid/

Messina, G., Burgassi, S., Messina, D., Montagnani, V., & Cevenini, G. (2015). A new UV-LED device for automatic disinfection of stethoscope membranes. American Journal of Infection Control, 43(10), e61–e66. https://doi.org/10.1016/j.ajic.2015.06.019

Metabolic Institute. (2021, February 17). New mechanisms for cities and finance to drive Dutch circular economy innovation. Metabolic. https://www.metabolic.nl/news/new-mechanisms-for-cities-and-finance-to-drive-dutch-circular-economy-innovation/

Miliute-Plepiene, J. (2021). Reusability and the potential environmental impact of small electronics.

Moreno, M., De Los Rios, C., Rowe, Z., & Charnley, F. (2016). A Conceptual Framework for Circular Design. Sustainability, 8(9), 937. https://doi.org/10.3390/su8090937

Ogunseitan, O. A. (2022). Side Effects of the Electronic Health Care Revolution: Toxic E-waste. World Neurosurgery, 167, 2–3. https://doi.org/10.1016/j.wneu.2022.07.124

Oxford Learner's Dictionaries. (n.d.). sustainable adjective—Definition, pictures, pronunciation and usage notes | Oxford Advanced Learner's Dictionary at OxfordLearnersDictionaries.com. Retrieved 31 May 2023, from https://www.oxfordlearnersdictionaries.com/definition/english/sustainable?q=sustainable

Philips. (n.d.-a). About us. Philips. Retrieved 7 August 2023, from https://www.philips.com/a-w/about.html

Philips. (n.d.-b). Healthdot apply sensor caresetting. Retrieved 5 July 2023, from https://www.philips.nl/c-dam/b2bhc/nl/landing/healthdot/healthdot-apply-sensor-caresetting.jpg

Philips. (n.d.-c). Healthdot Wearable Biosensor, 30u./Pack. Philips. Retrieved 20 June 2023, from https://www.philips.se/healthcare/product/00884838103719/philips-healthdot-wearable-biosensor

Philips. (n.d.-d). Philips Healthdot | Commercial Page. Philips. Retrieved 24 May 2023, from https://www.philips.se/healthcare/e/healthdot

Potting, J., Hekkert, M., Worrell, E., & Hanemaaijer, A. (2017). CIRCULAR ECONOMY: MEASURING INNOVATION IN THE PRODUCT CHAIN.

Rowan, N. J., Kremer, T., & McDonnell, G. (2023). A review of Spaulding's classification system for effective cleaning, disinfection and sterilization of reusable medical devices: Viewed through a modern-day lens that will inform and enable future sustainability. Science of The Total Environment, 878, 162976. https://doi.org/10.1016/j.scitotenv.2023.162976

Rutala, W. A., & Weber, D. J. (2013). Disinfection and sterilization: An overview. American Journal of Infection Control, 41(5, Supplement), S2–S5. https://doi.org/10.1016/j.ajic.2012.11.005

Singh, N., Ogunseitan, O. A., & Tang, Y. (2022). Medical waste: Current challenges and future opportunities for sustainable management. Critical Reviews in Environmental Science and Technology, 52(11), 2000–2022. https://doi.org/10.1080/10643389.2021.1885325

Siwicki, B. (2023, January 23). Three 2023 telemedicine trends that advance the 'new normal' in healthcare. Healthcare IT News. https://www.healthcareitnews.com/news/three-2023-telemedicine-trends-advance-new-normal-healthcare

Stahel, W. (2010). The Performance Economy. Springer.

Stichting Sustainability Impact Metrics. (n.d.-a). Idemat and Ecoinvent, and eco-costs midpoint tables. Sustainability Impact Metrics. Retrieved 17 July 2023, from https://www.ecocostsvalue.com/data-tools-books/

Stichting Sustainability Impact Metrics. (n.d.-b). LCA. Sustainability Impact Metrics. Retrieved 8 August 2023, from https://www.ecocostsvalue.com/lca/

van Hamersveld, M. (2019). Strategic Design of a Medical Consumable: From product to circular service. http://resolver.tudelft.nl/uuid:00975f34-bfb3-4289-8aca-51ed498c9ceb

VitalConnect. (n.d.). Cardiac Monitoring. VitalConnect. Retrieved 17 August 2023, from https://vitalconnect.com/cardiac-monitoring/

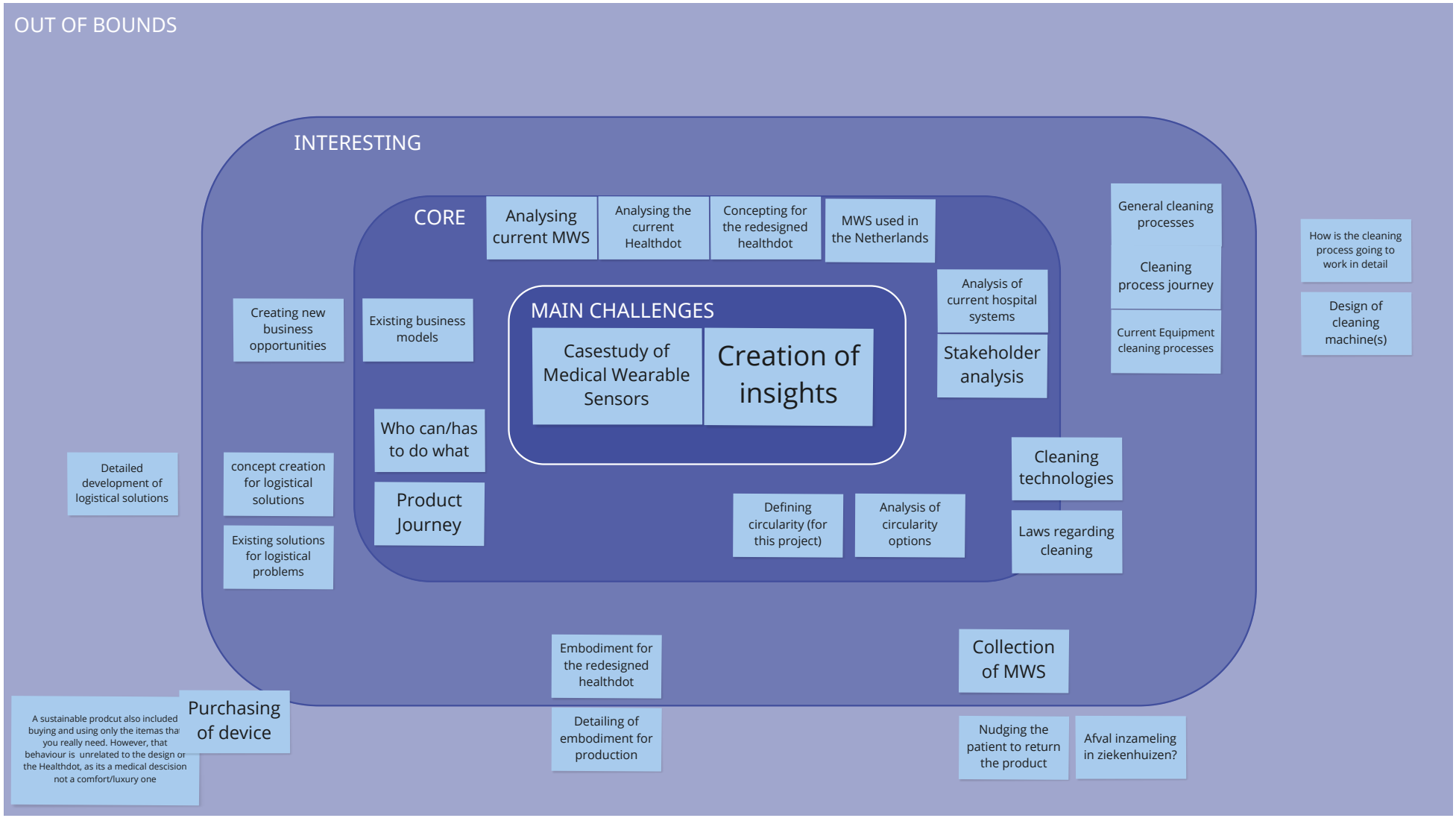
Vivalink. (n.d.). Wearable ECG Monitor | Continuous Cardiac & Heart Patch | Vivalink. Retrieved 17 August 2023, from https://www.vivalink.com/wearable-ecg-monitor

WEEE Forum. (2023, January 23). DiCE - Digital Health in a Circular Economy | WEEE Forum. https://weee-forum.org/projects-campaigns/dice/

Wells, C. I., Xu, W., Penfold, J. A., Keane, C., Gharibans, A. A., Bissett, I. P., & O'Grady, G. (2022). Wearable devices to monitor recovery after abdominal surgery: Scoping review. BJS Open, 6(2), zrac031. https://doi.org/10.1093/bjsopen/zrac031

Appendices

A • Scope


OUT OF BOUNDS
INTERESTING
CORE
Analysing current MWS
Analysing the current Healthdot
Concepting for the redesigned healthdot
MWS used in the Netherlands
General cleaning processes
Cleaning process journey
Current Equipment cleaning processes
How is the cleaning process going to work in detail
Design of cleaning machine(s)
Analysis of current hospital systems
Stakeholder analysis
Creating new business opportunities
Existing business models
MAIN CHALLENGES
Casestudy of Medical Wearable Sensors
Creation of insights
Who can/has to do what
Product Journey
Cleaning technologies
Laws regarding cleaning
Detailed development of logistical solutions
concept creation for logistical solutions
Existing solutions for logistical problems
Defining circularity (for this project)
Analysis of circularity options
Embodiment for the redesigned healthdot
Detailing of embodiment for production
Collection of MWS
Nudging the patient to return the product
Afval inzameling in ziekenhuizen?
Purchasing of device
A sustainable prodcut also included buying and using only the itemas that you really need. However, that behaviour is unrelated to the design or the Healthdot, as its a medical descision not a comfort/luxury one

B • Reflective Transformative Design Process

To structure the project, I will use the Reflective Transformative Design Process (RTDP) with elements from the integrated Creative Problem Solving model (iCPS). Both methods feel very similar to me and have elements I like; what I like about RTDP is that it provides structure between activities by asking me to reflect in between activities to determine the next, and what I like about iCPS is that it implies project management and requires a greater overall view of the project. In the images below both models can be seen (RTDP on the left, iCPS on the right).

B.1 Integrated Creative Problem Solving

Integrated Creative Problem Solving is "a structured, iterative model that helps with developing novels and useful solutions to open problems in groups" (Delft Design Guide, 2020). It consists of four activities: Content finding, information finding, acceptance finding and project management. Content finding is subdivided into three processes: Problem finding, idea finding and solution finding. The project management process runs continuously and manages when the other three processes are done. These are managed simultaneously and executed without a prescribed order. It is up to me to determine which process is done and when.

What I like about this project is that there is a focus on project management to determine which process needs to be done and when. What I dislike is that it does not contain a (dedicated) validation process and that the three phases feel separated from each other. The Delft Design Guide calls this separation essential.

B.2 Reflective Transformative Design Process

This method is new to me and comes from the design faculty in Eindhoven that "gives students grip on the design process yet leaves room for innovation" (Hummels & Frens, 2009). In this method, the designer has five activities to choose from, without a specific order. These activities are ideating, envisioning, validating, analysing and doing. The activities are split between Drive (vertical axis), which focuses on information gathering, and Strategies (horizontal axis), which focuses on information generation. It would be up to me to determine which method is best at that moment. Essential to the model is the reflection that takes place when switching between activities.

What I like about this model is that it is focused on information and its flow, seeing how both axes are centred on information collection. I like this perspective on information. It feels very focussed on exploring and gaining new knowledge, but because you create this vision as well it gives you some handles to keep it relevant. What I dislike is that it feels like it misses a managing element or a moment where you step back and look at the bigger picture.

B.3 Comparison

I have analysed both methods to see how they compare to one another, and I have attempted to combine both methods into one visual. In comparing the two methods and while making this visual I learned more about both methods and how they are similar and different.

RTDP is focused on the flow of information, how you gather it and how you generate it. This information is then spread across the different activities by doing, envisioning, analysing, validating or ideating. iCPS is focused on creating a structure to work efficiently with a team. It dedicates three different roles (facilitator, problem owner and resource group), whereas RTDP does not focus on a group or an individual. iCPS

focuses on project management first and foremost, and from that managing perspective you look at what the next activity is going to be.

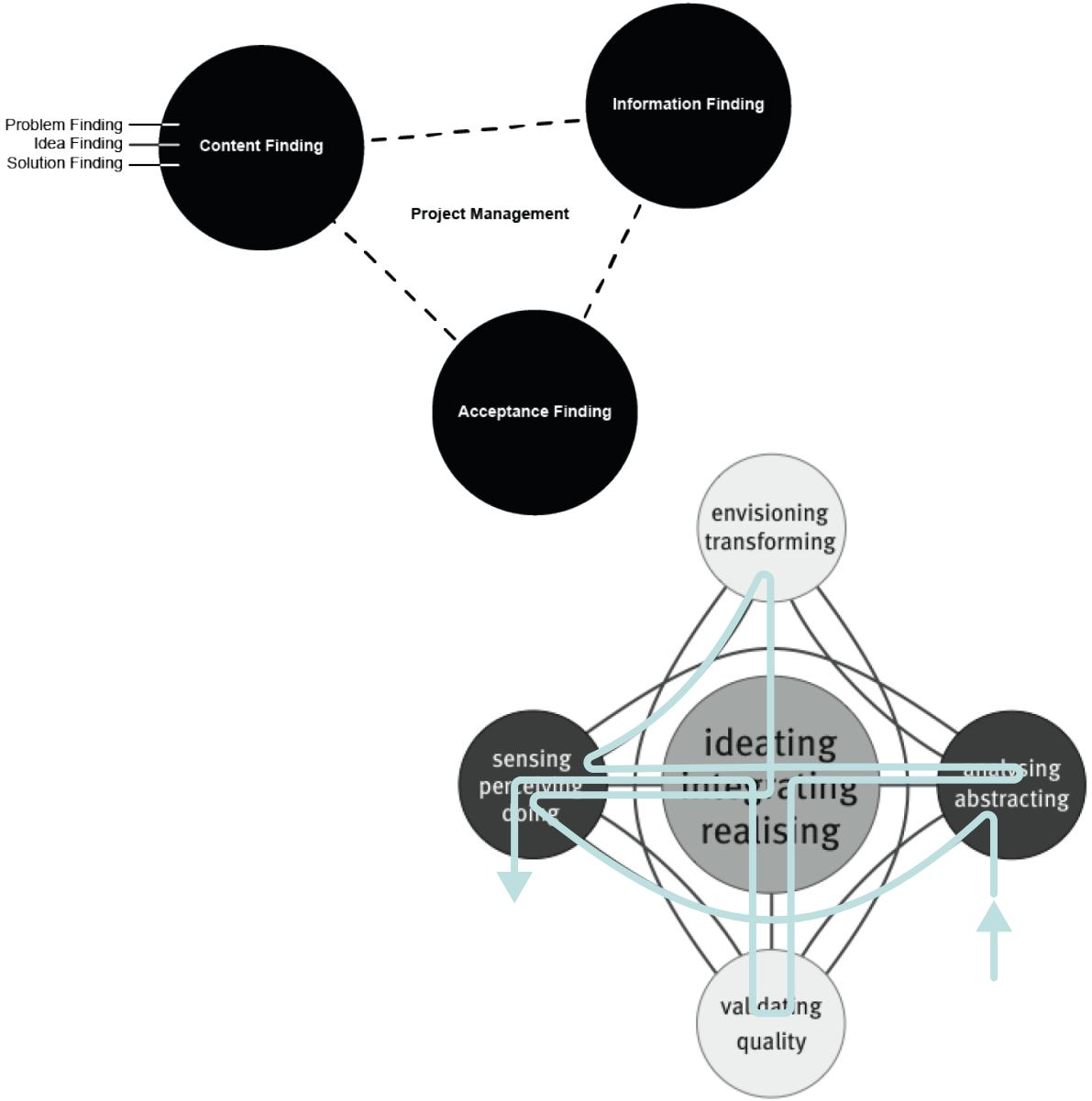
I looked at what activities/processes and how they fit into one another. I found that acceptance finding (iCPS) can't easily be placed in the RTDP model. Information is a major part of RTDP but feels like a smaller part of iCPS, perhaps because the models share a different perspective on what information is.

B.4 Conclusion

I will use the RTDP model with the project management and acceptance finding parts of the iCPS model because I prefer the freedom and information flow of RTDP.

I plan to use the RTDP method in combination with sprints to manage my project. With a vision to guide me and to be able to reflect on (e.g. am I still working towards my goal), I will use weekly sprints to set up my activities. Combined with weekly sprints to manage activities. I know that having a clear-cut goal makes a project much easier for me, so these reflections will be a key activity.

I also want to try out co-creation sessions. I think in this project, with its wide reach and being a big system, getting experts together in a co-creation session will be very valuable and will give many good insights. How I'm going to apply this in my project is yet to be determined.



C • Insight overview

I1: There are many interpretations of what the circular economy means. Deciding on a definition that fits the vision of you and your team can help you in making decisions, however, keep the discussion open as you will likely run into situations where your definition is not closing.

I2: Models such as the 9R model and the adapted value hill offer a good but simple starting point for designing for the Circular Economy.

I3: Circularity can sometimes be counter intuitive. Validate your ideas with tools such as the Life-Cycle Analysis (LCA), further described in Section 5.2.

I4: A lot of research is done on how to design for the circular economy which offers a great starting point. Try to find examples of your product – or something similar – that already feature circular economy actions.

I5: The circular economy requires you to design the system and context of your product, more than you might be used to from a classic product design process.

I6: It is important to choose the right scenario and context, as small changes here can drastically influence the outcome of your design.

I7: LCA's are a valuable tool to understand where the impact lies in your product, or why your product isn't circular. If you could only save one component, which one would it be and why? For example, the PCB has the biggest impact on the Healthdot, so it makes sense to make this part last as long as possible.

I8: LCA's can be tricky, as minor changes in your assumptions can drastically change its outcomes. Test different assumptions in your LCA to see how these affect the impact of your product.

I9: Circularity requires a broader mindset. It significantly changes the approach, scope and boundaries of your project, requiring a more holistic approach.

I10: Integrate your stakeholders in the design process. Stakeholders hold valuable knowledge, they have ideas on what is and isn't possible, both in the current systems and the system you are designing. Within a stakeholder, different departments will give you different perspectives, possibilities and information.

I11: The stakeholders are going to execute your system, involving them in your process might make it easier for them to accept the solution.

I12: The circular actions and intentions of an OEM hold meaning to the buyer. If an OEM remains the owner of the product, it demonstrates their active involvement in the product's circularity, while if it is sold via a linear model you could question their intent.

I13: No red flags are identified for the Healthdot, meaning it can be modified to work in a circular system.

I14: Your product might only need minor changes to become circular.

I15: Solutions can be found both in other MWS and in other medical categories, but also in completely different product categories, such as wireless charging from smartwatches.

I16: The proposed redesign shows that it is possible to reduce the CO2 emissions and e-waste from MWS using a simple solution that allows reuse, without complex machinery or expensive equipment. It proposes a universal approach to circularity, a system that can be shared amongst different OEMs to make it easy to reuse a variety of MWS.

I17: Further reductions in the device's impact will yield more short-use (1-5 uses) improvements, while changes in the system's efficiency will yield more long-use (6+) improvements.

I18: Don't look at your system and device in isolation. Take other products that exist in your context into consideration, as a combined solution might be beneficial to all.

I19: Circular Strategies and Business Models form the backbone of your system: they determine the flow and the product requirements that follow, and they are linked together, as choosing one affects your options for the other.

I20: Instead of focussing on only one strategy, such as reuse, try to incorporate more strategies such as repair and manufacturing and see if that offers further improvements.

I21: The classic 'who, what, where, why, when, how' questions can be useful to find challenges in your systems that you might have missed.

I22: The system you design relies heavily on your scenario, with minor changes having big effects. For example, a change in the return method can result in completely different results. This is similar to I6 from Chapter 5.

I23: LCA's can give valuable insights when comparing concepts

I24: The device is an enabler for the system. Identify the challenges that the system has and determine which ones your device should solve.

I25: The design process for the device doesn't differ much from a regular design process. It is based on the requirements that result from the system designed previously.

I26: The design of the system determines circularity at a high level: How will your product stay in the loop and get used as much as possible? The design of the product determines the circularity at a lower level: How much impact is created when using the product, and how easily can it be reprocessed or remanufactured?

D • Design Strategies and Business Models

Design Strategies

Slowing Loops

Designing long-life products

- Design for attachment and trust
- Design for reliability and durability

Design for product-life extension

- Design for ease of maintenance and repair
- Design for upgradability and adaptability
- Design for standardization and compatibility
- Design for dis- and reassembly

Closing Loops

- Design for a technological cycle
- Design for a biological cycle
- Design for dis- and reassembly

Business Models

Slowing Loops

Access and performance
Providing the capability or services to satisfy user needs without needing to own physical products

Classic long-life model
Business models focused on delivering long-product life, supported by design for durability and repair for instance

Extending product value
Exploiting the residual value of products - from manufacture to consumers, and then back to manufacturing – or collection of products between distinct business entities

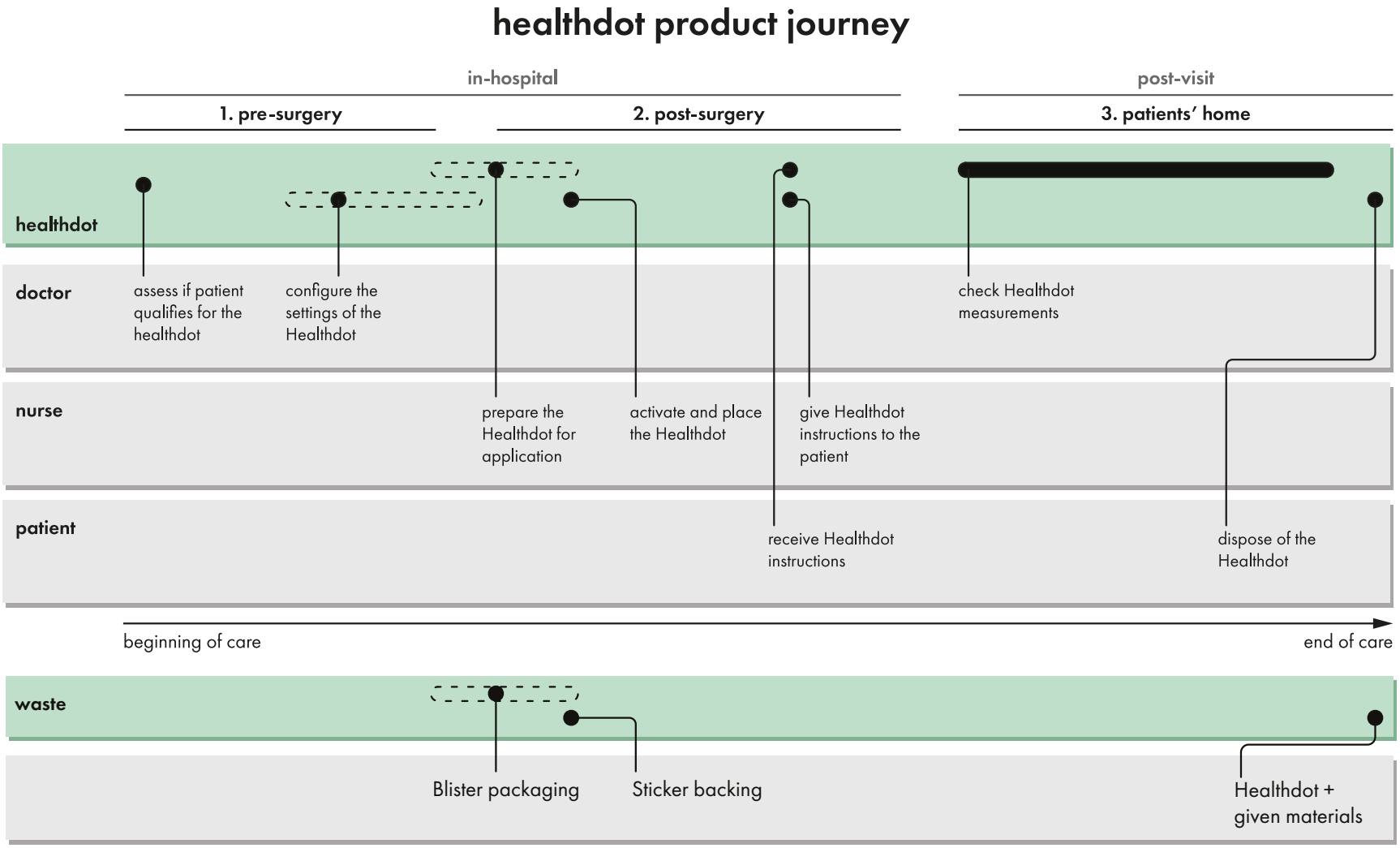
Encourage Sufficiency
Solutions that actively seek to reduce end-user consumption through principles such as durability, upgradability, service, warranties and reparability and a non-consumerist approach to marketing and sales

Closing Loops

- **Extending resource value**
- **Industrial symbiosis**

Adapted from Bocken et.al. (2016) and Moreno et.al. (2016)

E • Product Journey



F • LCA Sheets

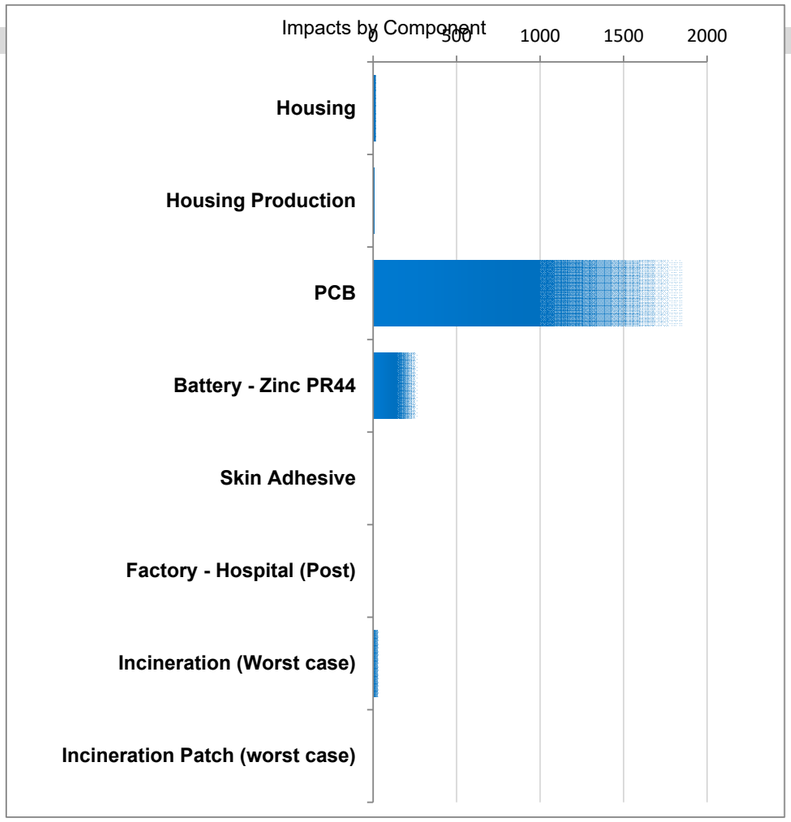
Healthdot LCA

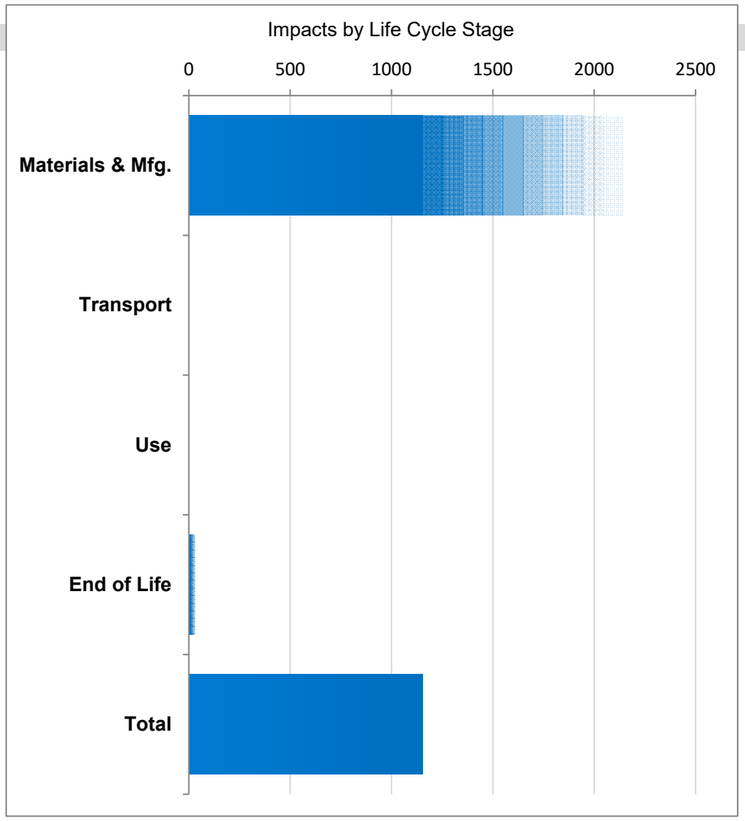
Manu item	database name	Eco-intensity (impacts per kg)	Mass per item (kg)	Items per func.unit (#)	Uncertainty %	Notes	Calculated Impact
Housing	Idemat2023 ABS (Acrylonitrile butadiene styrene)	3,10	0,004	1,0	30%	(ABS + PA, unknown mix, A	12,4
Housing Production	Idemat2023 injection moulding, incl production site	1,20	0,004	1,0	30%		4,8
PCB	Idemat2023 PCB = Printed Circuit Board (including ICs)	475,02	0,003	1,0	30%		1425,0
Battery - Zinc PR44	Idemat2023 NiMH battery for laptops (54 Wh per kg)	61,02	0,002	2,0	30%	NiMd used as replacement	205,0
Skin Adhesive	Idemat2023 PET amorphous	1,01	0,001	1,0	30%	Nylon used as estimate	1,0
							1648,3

Transport		Eco-Intensity (impacts/ ton-km)	Mass per item (ton)	Distance per item (km)	Uncertainty %	Notes	Calculated Impact
Factory - Hospital (Post)	Idemat2023 Truck+trailer 24 tons net (min weight/volume ratio 0,32 ton/m3) (tkm)	0,09	0,000013	120,00	30%		0,1
							0,0
total transport						**0**	0,0

Use	Eco-Intensity (impacts/MJ or other)	Amount per item (MJ or other)	Items per func.unit (#)	Uncertainty %	Notes	Calculated Impact
						0,0

End of Life		Eco-Intensity (impacts/kg)	Mass per item (kg)	Items per func.unit (#)	Uncertainty %	Notes	Calculated Impact
Incineration (Worst case)	Idemat2023 ABS (Acrylonitrile butadiene styrene) waste incineration with el	1,39	0,012	1	100%		16,7
Incineration Patch (worst case)	Idemat2023 PET (Polyethylene terephthalate) waste incineration with electri	0,158	0,001	1	30%		0,2
							0,0
total end-of-life						**17**	





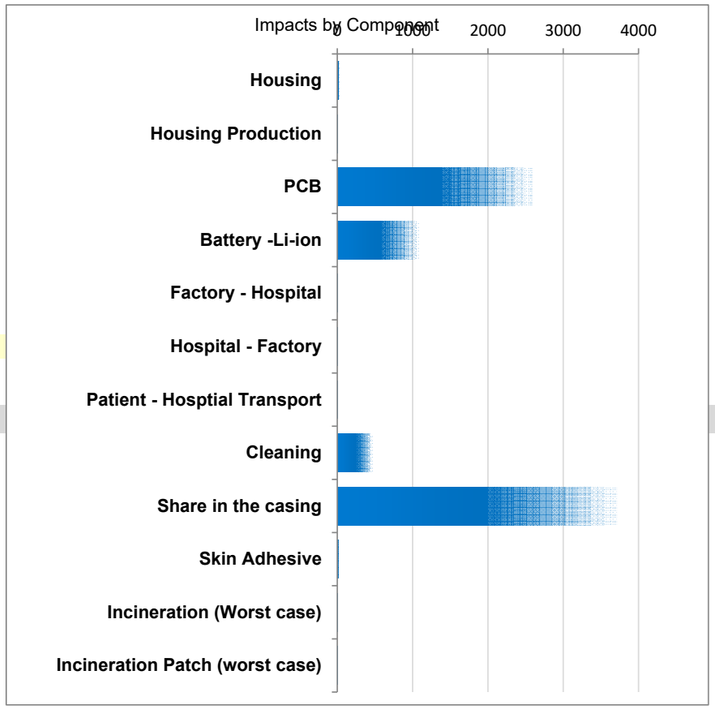
SecondSense

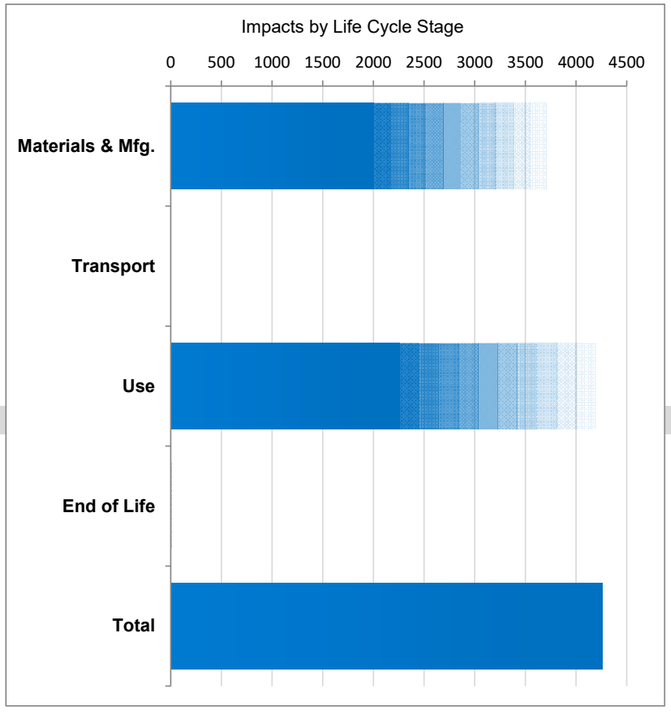
Manu item	database name	Eco-intensity (impacts per kg)	Mass per item (kg)	Items per func.unit (#)	Uncertainty %	Notes	Calculated Impact
Housing	Idemat2023 ABS (Acrylonitrile butadiene styrene)	3,10	0,006	1,00	30%		17,36
Housing Production	Idemat2023 injection moulding, incl production site	1,20	0,006	1,00	30%		6,7370732
PCB	Idemat2023 PCB = Printed Circuit Board (including ICs)	475,02	0,0042	1,00	30%		1995,0685
Battery -Li-ion	Idemat2023 Lithium-ion LiCoO2 laptop battery (180 Wh/kg	80,34	0,010	1,00	30%		841,338
							0
subtotal		weight check:	0,026		30%	**2861**	2860,5036

Transport		Eco-Intensity (impacts/ ton-km)	Mass per item (ton)	Distance per item (km)	Uncertainty %	Notes	Calculated Impact
Factory - Hospital	Idemat2023 Truck+trailer 24 tons net (min weight/volume ratio 0,32	0,0905	0,000013	120,00	30%		0,1411934
Hospital - Factory	Idemat2023 Truck+trailer 24 tons net (min weight/volume	0,0905	0,000013	120	30%		0,1411934
total transport						**0**	0

Use		Eco-Intensity (impacts/MJ or other)	Amount per item (MJ or other)	Items per func.unit (#)	Uncertainty %	Notes	Calculated Impact
Patient - Hosptial Transport	Idemat2023 Truck+trailer 24 tons net (min weight/volume	0,091	0,000026	5	30%		0,0117083
Cleaning	Idemat2023 Ethanol (alcohol), bio-based from agricultural	1,455	0,025	10	30%		363,86575
Share in the casing	Idemat2023 Computer laptop, 15 inch display	570,509	0,005	1	30%	Laptop as placeholder	2852,5426
Skin Adhesive	Idemat2023 PET amorphous	1,01	0,001	10	30%		10,053171
							0

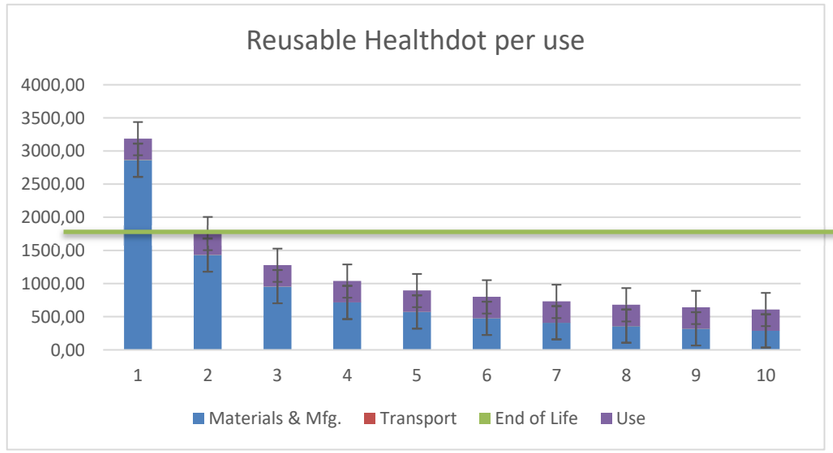
End of Life		Eco-Intensity (impacts/kg)	Mass per item (kg)	Items per func.unit (#)	Uncertainty %	Notes	Calculated Impact
Incineration (Worst case)	Idemat2023 ABS (Acrylonitrile butadiene styrene) waste in	1,39	0,022	0,1	100%		3,0655608
Incineration Patch (worst case)	Idemat2023 PET (Polyethylene terephthalate) waste incine	0,16	0,001	1	30%		0,1576785
							0
							0
							0
							0
							0
							0
							0
							0
							0
							0
							0
							0
total end-of-life							0

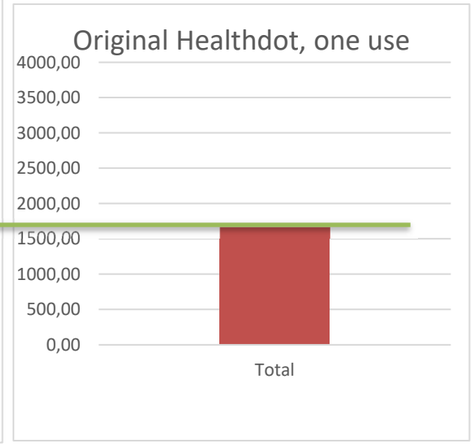




Healthdot

Item	Impact		Uncertainty range +-
Materials & Mfg.		1648,30	494,49
Transport		0,14	0,04
Use		0,00	0,00
End of Life		16,88	16,77
Total		1665,32	511,30





Resuable Healthdot - Total Emissions

Item	Impact		Uncertainty range +-
Materials & Mfg.		2860,50	858,15
Transport		0,28	0,08
Use		3226,47	967,94
End of Life		3,22	3,11
Total		6090,48	1829,29

Reusable Healthdot	1	2	3	4	5	6	7	8	9	10
Materials & Mfg.	2860,50	1430,25	953,50	715,13	572,10	476,75	408,64	357,56	317,83	286,05
Transport	0,28	0,14	0,09	0,07	0,06	0,05	0,04	0,04	0,03	0,03
End of Life	3,22	1,61	1,07	0,81	0,64	0,54	0,46	0,40	0,36	0,32
Use	322,65	322,65	322,65	322,65	322,65	322,65	322,65	322,65	322,65	322,65
Emissions Per Use	3186,66	1754,65	1277,32	1038,65	895,45	799,98	731,79	680,65	640,87	609,05
Percentage relative to	191%	105%	77%	62%	54%	48%	44%	41%	38%	37%
Percentage reduction	-91%	-5%	23%	38%	46%	52%	56%	59%	62%	63%

Detailed Healthdot vs. Resuable, component Level

		Healthdot	Reusable	2	3	4	5	6	7	8	9	10
Production	Housing	17,212	24,097	12,049	8,032	6,024	4,819	4,016	3,442	3,012	2,677	2,410
	PCB	1425,049	1995,068	997,534	665,023	498,767	399,014	332,511	285,010	249,384	221,674	199,507
	Battery	205,031	841,340	420,670	280,447	210,335	168,268	140,223	120,191	105,168	93,482	84,134
	Transport	0,141	0,282	0,141	0,094	0,071	0,056	0,047	0,040	0,035	0,031	0,028
	Skin Adhesive	1,005										
End of life	Incineration	16,879	3,223	1,612	1,074	0,806	0,645	0,537	0,460	0,403	0,358	0,322
Use	Patient - Hosptial Transport		0,001	0,001	0,001	0,001	0,001	0,001	0,001	0,001	0,001	0,001
	Cleaning		36,387	36,387	36,387	36,387	36,387	36,387	36,387	36,387	36,387	36,387
	Share in the casing		285,254	285,254	285,254	285,254	285,254	285,254	285,254	285,254	285,254	285,254
	Skin Adhesive		1,005	1,005	1,005	1,005	1,005	1,005	1,005	1,005	1,005	1,005
			3186,659	1754,653	1277,318	1038,650	895,450	799,983	731,792	680,649	640,871	609,048

G • System Concepts

G.1 Concepts Iteration 1

G.1.1 Reuse at the factory

At first, the Healthdot is used as normal. It is applied to the patient, who then goes home with it for 30 days. When the patient no longer needs the Healthdot, he separates the skin patch from the Healthdot. The skin patch gets thrown away in the local waste. The Healthdot is placed in the provided box with a return sticker and sent back to the factory.

In this concept, the factory can both be Philips or a 3rd party. This depends on the location of the hospital. When the Healthdot arrives at the factory, it gets checked for any damages, cleaned and prepared for another use. It is placed in a box with new adhesive patches and sent off to the hospital again. Any Healthdots which don't make the safety check get taken apart and get recycled into new Healthdots.

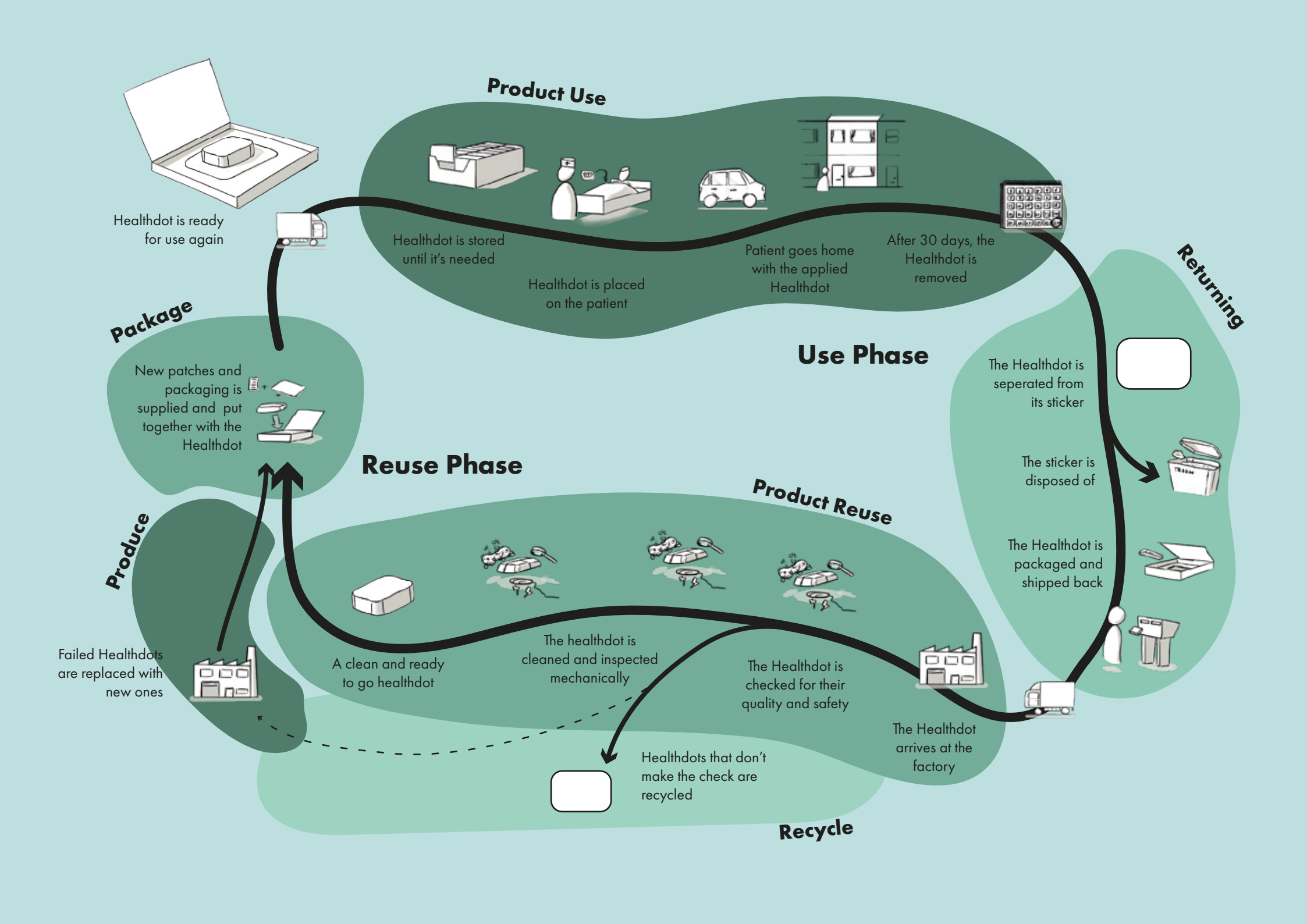
Business Model

The business model behind this concept is a pay-per-use model. Philips will stay the owner of the product, which means that the longer their product lasts the more they earn on it – an incentive to design sustainable.

The hospital just buys Healthdots as normal. They will pay an extra deposit, and if the patient doesn't return the Healthdot they would be in charge of billing the patient for this.

Stakeholders

The hospital doesn't need to change the activities that they do significantly. They would need to hand out an extra box to the patient, so the Healthdot can be sent back, but that would be it. Philips would be responsible for the cleaning and safety of the device. While this is the easiest for the hospital, a downside of this is that Philips's production is centred, so the product might need to travel far away increasing its impact.


Product Use
Healthdot is ready for use again
Healthdot is stored until it's needed
Healthdot is placed on the patient
Patient goes home with the applied Healthdot
After 30 days, the Healthdot is removed
Use Phase
Returning
The Healthdot is seperated from its sticker
The sticker is disposed of
The Healthdot is packaged and shipped back
Package
New patches and packaging is supplied and put together with the Healthdot
Reuse Phase
Product Reuse
Produce
Failed Healthdots are replaced with new ones
A clean and ready to go healthdot
The healthdot is cleaned and inspected mechanically
The Healthdot is checked for their quality and safety
The Healthdot arrives at the factory
Healthdots that don't make the check are recycled
Recycle

G.1.2 Reuse at the Hospital

Here the Healthdot is also used as normal. When the patient no langers needs the Healthdot, he separates the Healthdot from the patch and sends it back to the hospital. The skin patch gets thrown away in the local waste. The Healthdot is placed in the provided box with a return sticker and sent back to the hospital

In the hospital, it gets checked for any damages, cleaned and prepared for another use. This would differ per hospital, but I could mean that it is placed together with other cleaned Healthdot, new patches and return boxes. When a Healthdot is needed, the right combination of items is grabbed and given to the patient. Any Healthdots which don't make the safety check get sent back to Philips, where they are taken apart and get recycled into new Healthdots.

Business Model

The business model behind this concept is also a pay-per-use model. Philips will stay the owner of the product, which means that the longer their product lasts the more they earn on it – an incentive to design sustainable.

When the hospital activates a Healthdot, they will be billed for the use. The hospital can then bill this on the patient. Per Healthdot, the hospital pays a deposit. If the patient doesn't return the Healthdot they would be in charge of billing the patient for this.

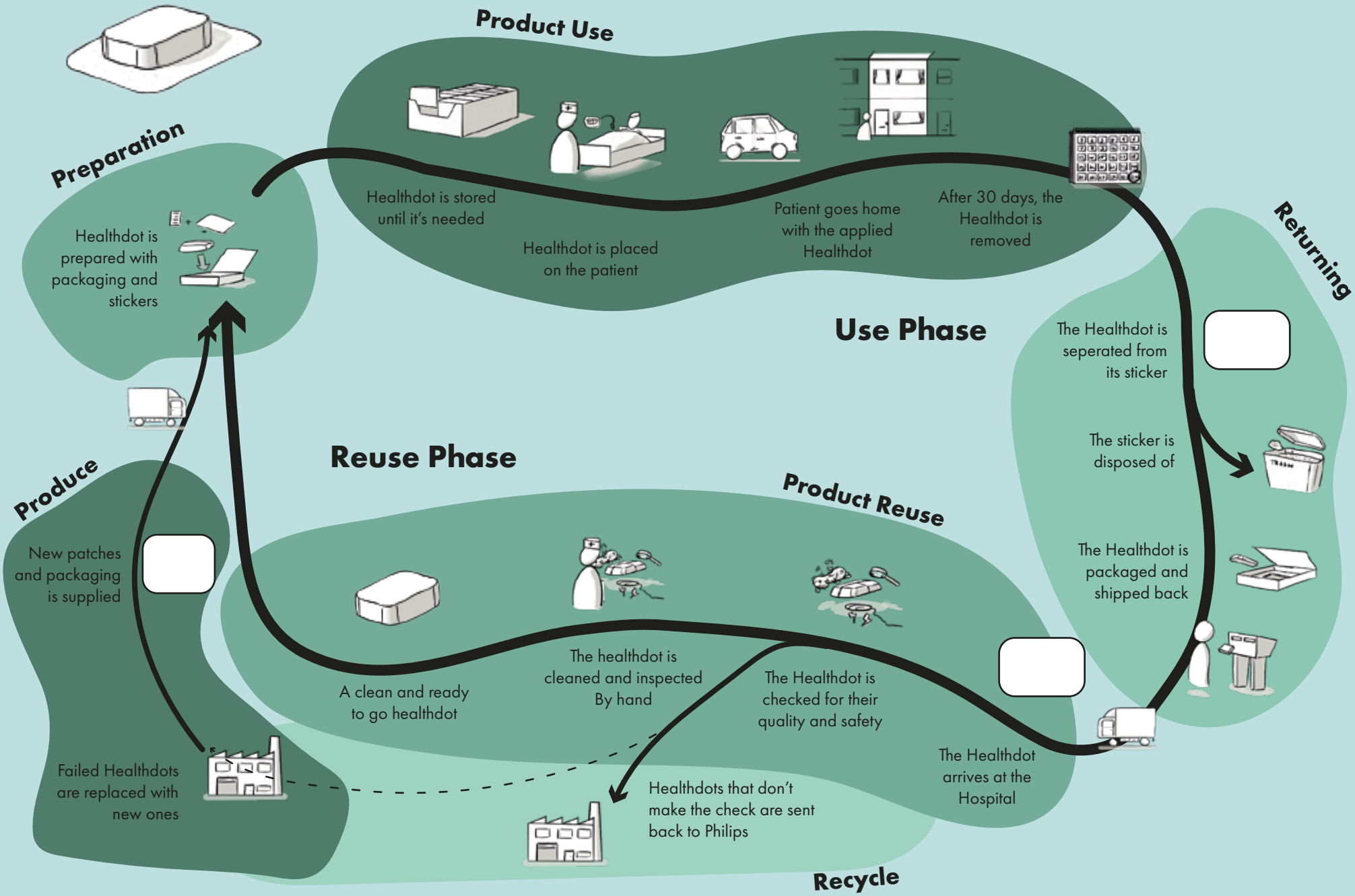
Stakeholders

The hospital will need to change the activities that they do significantly. They are now also responsible for the sorting and cleaning of the sensor. In this scenario, they would need to hand out an extra box to the patient, so the Healthdot can be sent back. When it comes back, they need to assess the Healthdot, clean it and prepare it again. Any failed products would need to be sent back.

G.1.3 Evaluation of C1 and C2

C1 and C2 were assessed in a meeting with Philips (personal communication, 21-6-2023). From this evaluation, it became clear that some context settings had to change. These concepts were developed with only the out-of-hospital scenario, however, Philips indicated that in-hospital use is also very common.

With this information, a brainstorm was done with a peer student. This resulted in two new concepts, which are split up between internal reuse and external reuse.


Product Use
Preparation
Healthdot is prepared with packaging and stickers
Healthdot is stored until it's needed
Healthdot is placed on the patient
Patient goes home with the applied Healthdot
After 30 days, the Healthdot is removed
Use Phase
Returning
The Healthdot is seperated from its sticker
The sticker is disposed of
The Healthdot is packaged and shipped back
Reuse Phase
Product Reuse
Produce
New patches and packaging is supplied
A clean and ready to go healthdot
The healthdot is cleaned and inspected By hand
The Healthdot is checked for their quality and safety
The Healthdot arrives at the Hospital
Failed Healthdots are replaced with new ones
Healthdots that don't make the check are sent back to Philips
Recycle

G.2 Concept Iteration 2

G.2.1 Internal Reuse

In this concept, the Healthdot is reused internally in the hospital. After its use cycle, and before the patient leaves the hospital, the Healthdot is removed from the patient. It is then sorted internally into a new department: the Central Disinfection Service.

The CDS is a central place in the hospital where reusable devices like the Healthdot are collected and prepared for reuse. When the Healthdot comes in, it gets scanned by personnel. At this moment, the computer checks how many times the device has been used. Once it reaches its maximum amount of uses, the device gets blocked and sent back to the OEM for reuse. Devices that are still good to go are cleaned, charged and get packaged with new skin patches – according to hospital protocol.

Devices that are sent back to the OEM get taken apart, the PCB goes through a check to see whether it could last another life cycle and the casing gets recycled into new casings.

Business Model

The business model behind this concept is a pay-per-use model. Philips will stay the owner of the product, which means that the longer their product lasts the more they earn on it – an incentive to design sustainable.

When the hospital activates a Healthdot, they will be billed for the use. The hospital can then bill this on the patient. Per Healthdot, the hospital pays a deposit. If the patient doesn't return the Healthdot they would be in charge of billing the patient for this.

Internal reuse flow

Product Use

Healthdot is stored until it's needed

Healthdot is placed on the patient

Healthdot is scanned when placed to activate it

After XX days, the Healthdot is removed

Use Phase

The Healthdot is seperated from its sticker

The sticker is disposed of

Sorting

The Healthdot is sorted seperately and brought to the Central Disinfection Service

CDS

Preparation

The Healthdot is scanned so their arrival is documented

The Healthdot is checked for their quality and safety

The healthdot is cleaned and inspected together with other sensors in a universal machine?

The Healthdot is ready for reuse!

Reuse Phase

Packaging

Healthdot is prepared with packaging and stickers per hospital protocol

Factory

New patches and packaging is supplied

Failed Healthdots are replaced with new ones

Production

The PCB's are checked if they could go through another use cycle

Recycling

Returned Healthdots are dismanteld

Healthdots that don't make the check are sent back to Philips

Healthdots that have reached their maximum uses are sent back

The Healthdot is charged, updated and personal data is removed

G.2.2 External Reuse

In this concept, the Healthdot is reused externally. The patient goes home with the device, and when it's no longer needed the patient sends it back to one of three locations.

The first option is the hospital. In this scenario, the device will come in and is sent to the CDS. It goes through the same process as the previous concept, but it gets there in a different way

The second and third options are reuse at either Philips or a 3rd party. Here the device is sent to the factory, where the device is scanned, cleaned and prepared. A computer checks how many times the device has been used and once it reaches its maximum amount of uses, the device gets blocked. If Philips is in charge of reuse, the device is already in a place where it could be recycled and the PCB could be reused. If it is a 3rd party, extra transport movements are needed for the rejected devices and the new patches and packaging.

Business Model

The business model behind this concept is a pay-per-use model. Philips will stay the owner of the product, which means that the longer their product lasts the more they earn on it – an incentive to design sustainable.

The hospital buys Healthdots as normal. They will pay an extra deposit, and if the patient doesn't return the Healthdot they would be in charge of billing the patient for this.

A 3rd party would be rewarded with a cleaning fee every time they scan one of the devices.

G.3 Concept Evaluation A and B

After working on it for a bit, I spit the two concepts into Hospital Reprocessing and External Reprocessing.

In the meeting with the Erasmus MC, the idea of a Central Disinfection Service was found unnecessary, as the Central Sterilisation Service already has disinfecting procedures and could take on this task as well. Another option that was mentioned was cleaning the Healthdots at the polyclinic were they are used, which is currently done for Holter devices, for example. Both were fine as long as the cleaning procedure is optimized for the context.

External reuse flow

Product Use

Healthdot is stored until it's needed

Healthdot is placed on the patient

Healthdot is scanned when placed to activate it

Patient goes home with the applied Healthdot

After 30 days, the Healthdot is removed

Use Phase

The sticker is disposed of

Returning

The Healthdot is seperated from its sticker

The Healthdot is packaged and shipped back

Reuse Phase

Preparation

Hosptial

CDS

The Healthdot is sorted seperately and brought to the Central Disinfection Service

The healthdot is cleaned and inspected according to the internal reuse flow diagram

3rd Party / Philips

The Healthdot is scanned so their arrival is documented

The Healthdot is checked for their quality and safety

Healthdots that don't make the check are taken apart

The healthdot is cleaned and inspected together with other sensors in a universal machine

The Healthdot is charged, updated and personal data is removed

The Healthdot is ready for reuse!

Factory

Packaging

The Healthdot is packeged with new patches and packaging

New patches and packaging is supplied

Production

Failed Healthdots are replaced with new ones

Recycling

The PCB's are checked if they could go through another use cycle

Returned Healthdots are dismanteld

3rd Party

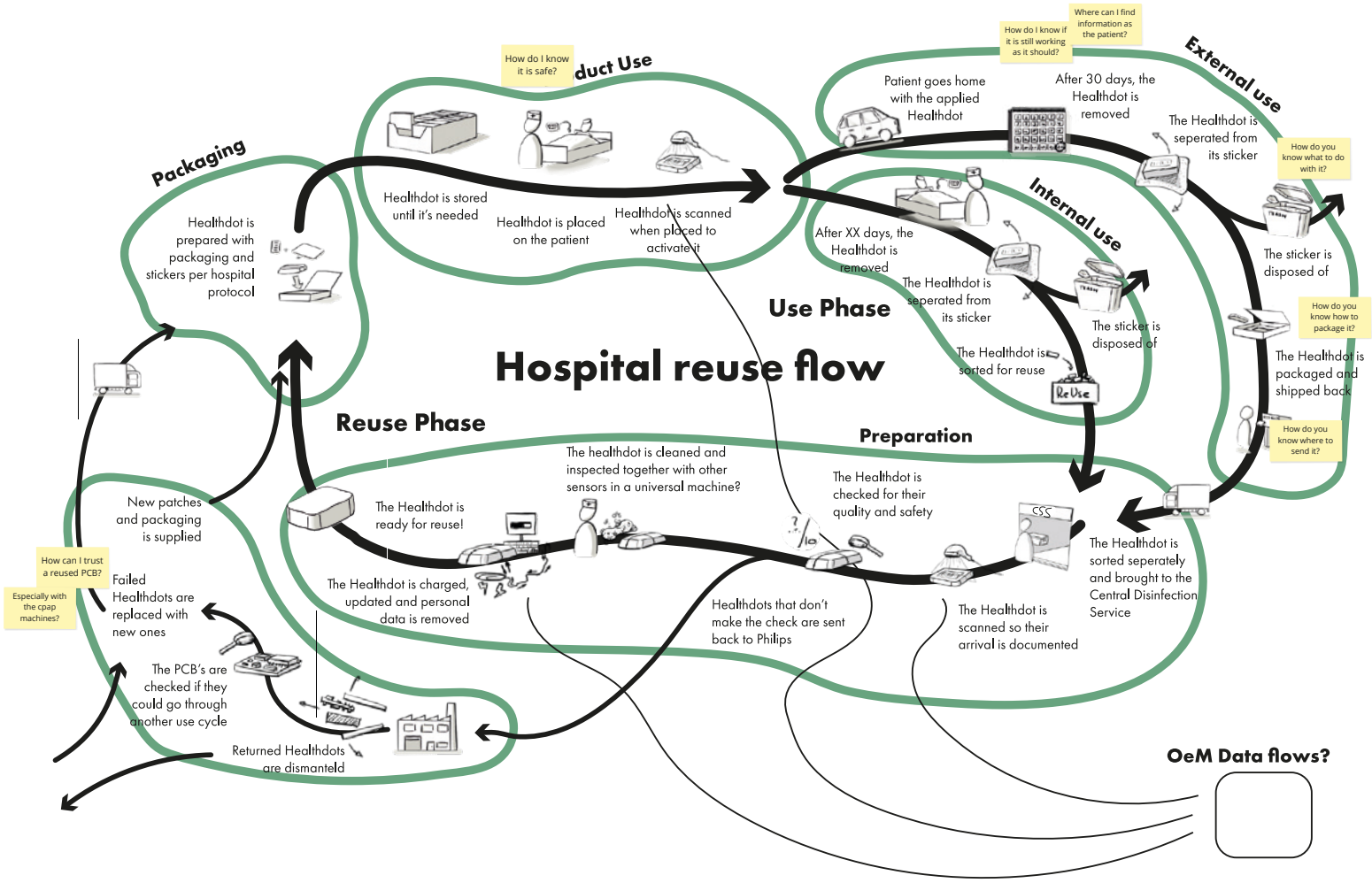
Philips

H • Challenges Map

	Challenge	Scope Check		Criticality	Reasoning
1	How do you guarantee supply of devices and supplements?	N	1		
2	How do you minimize downtime in storage?	N	1		
3	How does the patient know the device is safe?	M	3		
4	How do you know how to apply the sensor?	Y	5	2	Current product already has solutions for this, although there is always room for improvement
5	What does the patient need when they take the device home?	M	3		
6	How do you know where your devices are (in use)?	Y	5	2	Tracking systems already exist in hospitals
7	How does the device communicate that it is functioning normally?	Y/M	4		
8	How do you reduce the impact of the used disposables?	Y	5	4	Patches and packaging are the least circular components of the syste,
9	How do you make sure the patient returns the used device (quickly)?	N	1		
10	How do you ship the used device back?	M	3		
11	How do you sort the used device in the hospital?	M/N	2		
12	How to optimise the reprocessing of the device?	Y	5	4	Optimising the process will (assumed) result in a more efficient system
13	How do you know what to do with the device?	Y/M	4		
14	How do you know if the device is still safe for use?	Y	5	5	Trust is essential
15	How to separate / collect the rejected devices?	M/N	2		
16	How to (optimise) the cleaning process for multiple devices?	Y	5	4	Important, however there are already some good options
17	How do you reuse the cleaned device?	Y	5	5	If the system becomes to demanding it will fail
18	How do you prepare the cleaned device?	Y/M	4		
19	How to make sure you get rejected devices back?	M/N	2		
20	How do you disassemble/remanufacture rejected devices?	Y	5	3	There is already a lot of knowledge being done here
21	What do you do with components that can’t be remanufactured (e.g. waste)?	Y/M	4		
22	How can you produce your device with the least amount of impact?	Y	5	2	A lot of knowledge already exists here
23	How can you instil trust in remanufactured components?	M/N	2		

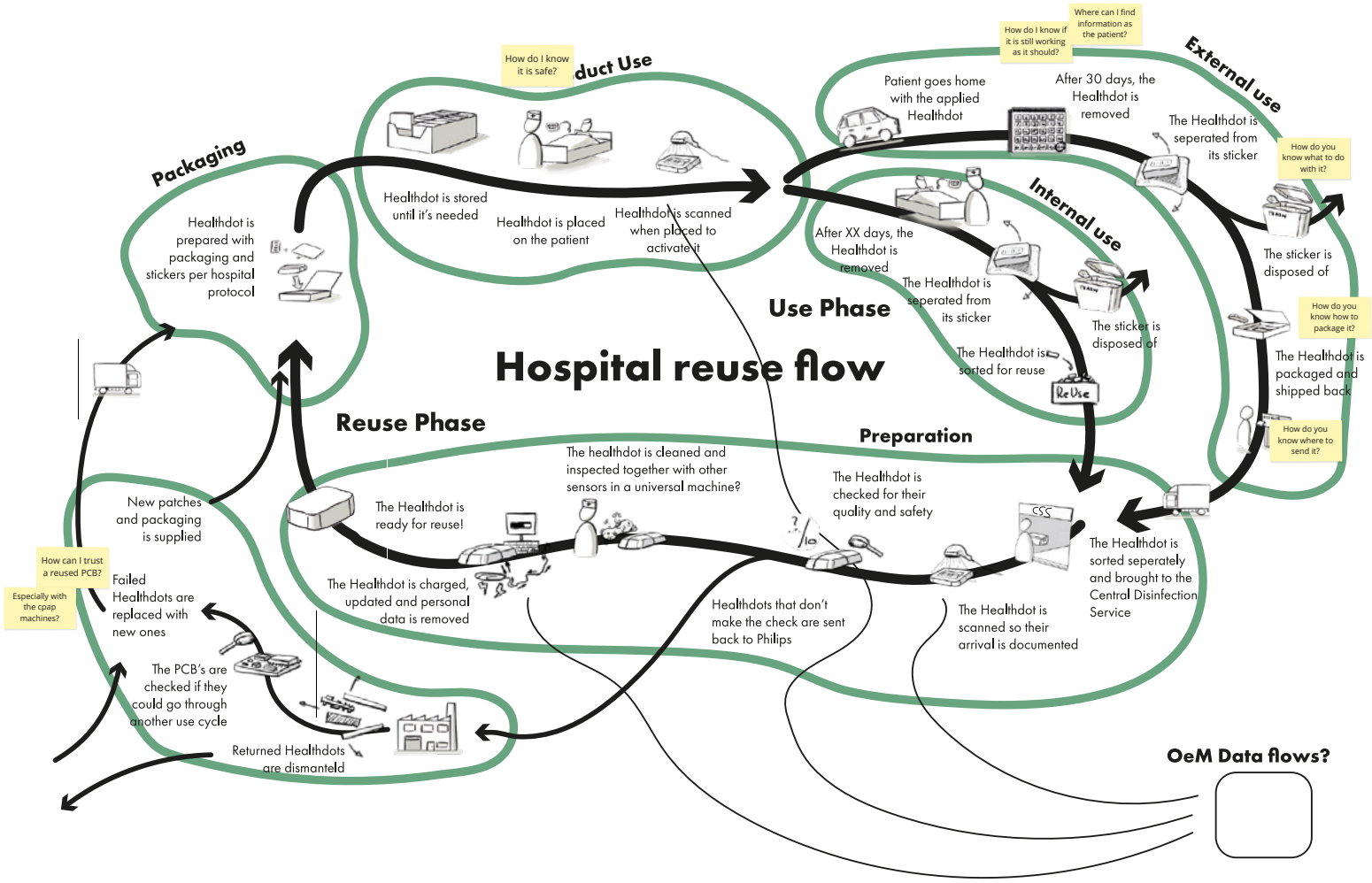
Patient Experience

Patient



Patient Experience

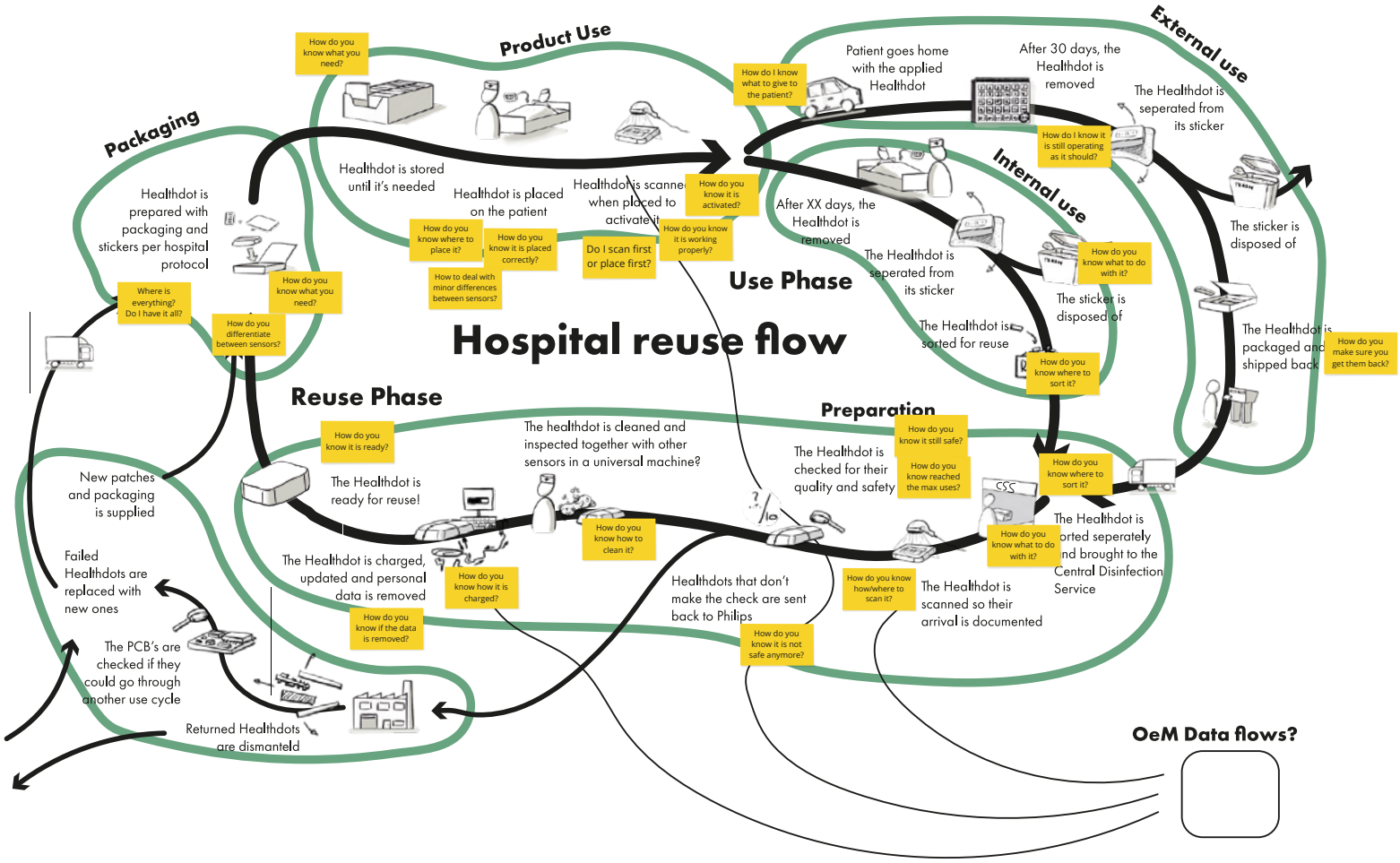
Patient



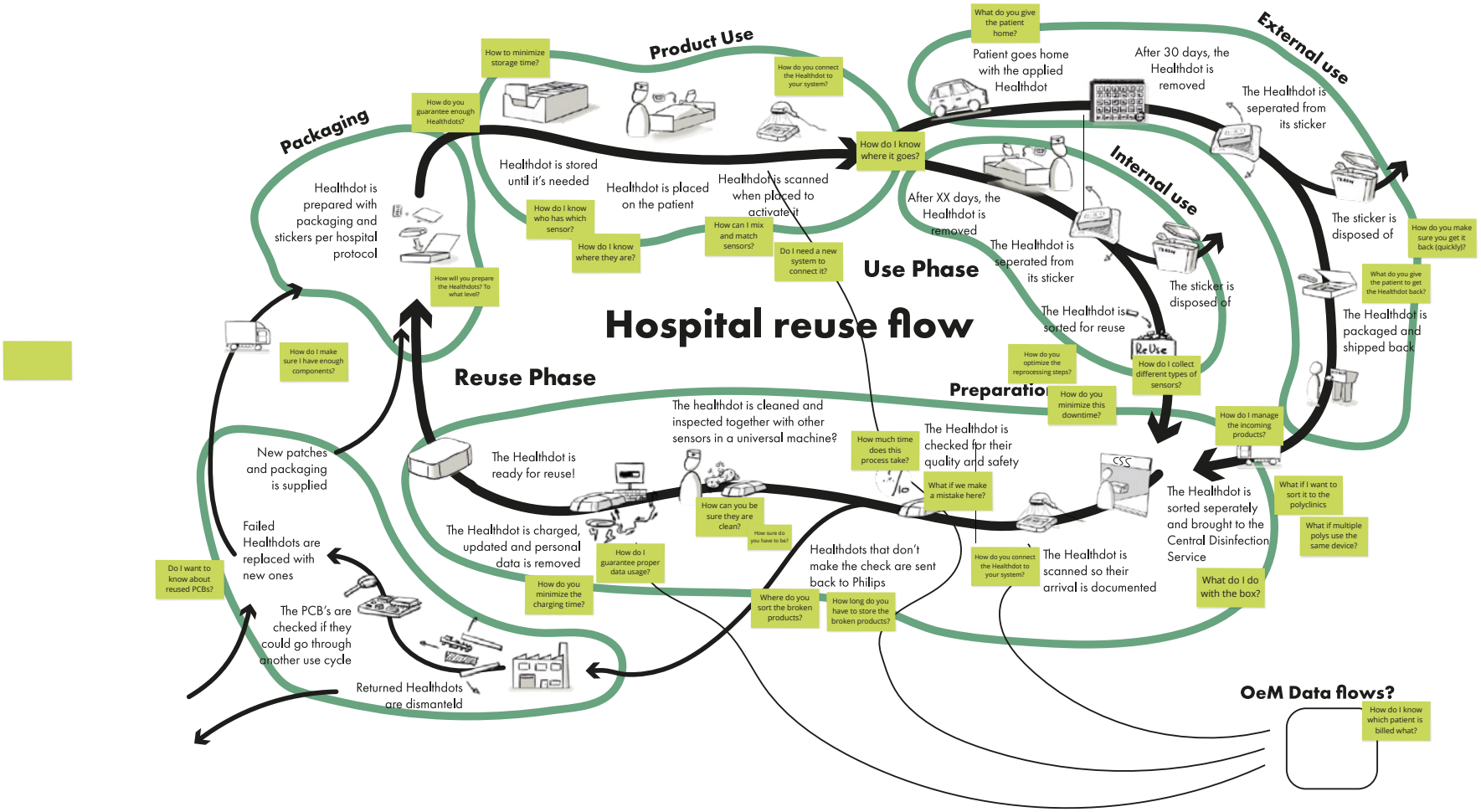
Doctor/Nurse experience

Nurse Doctor Patient

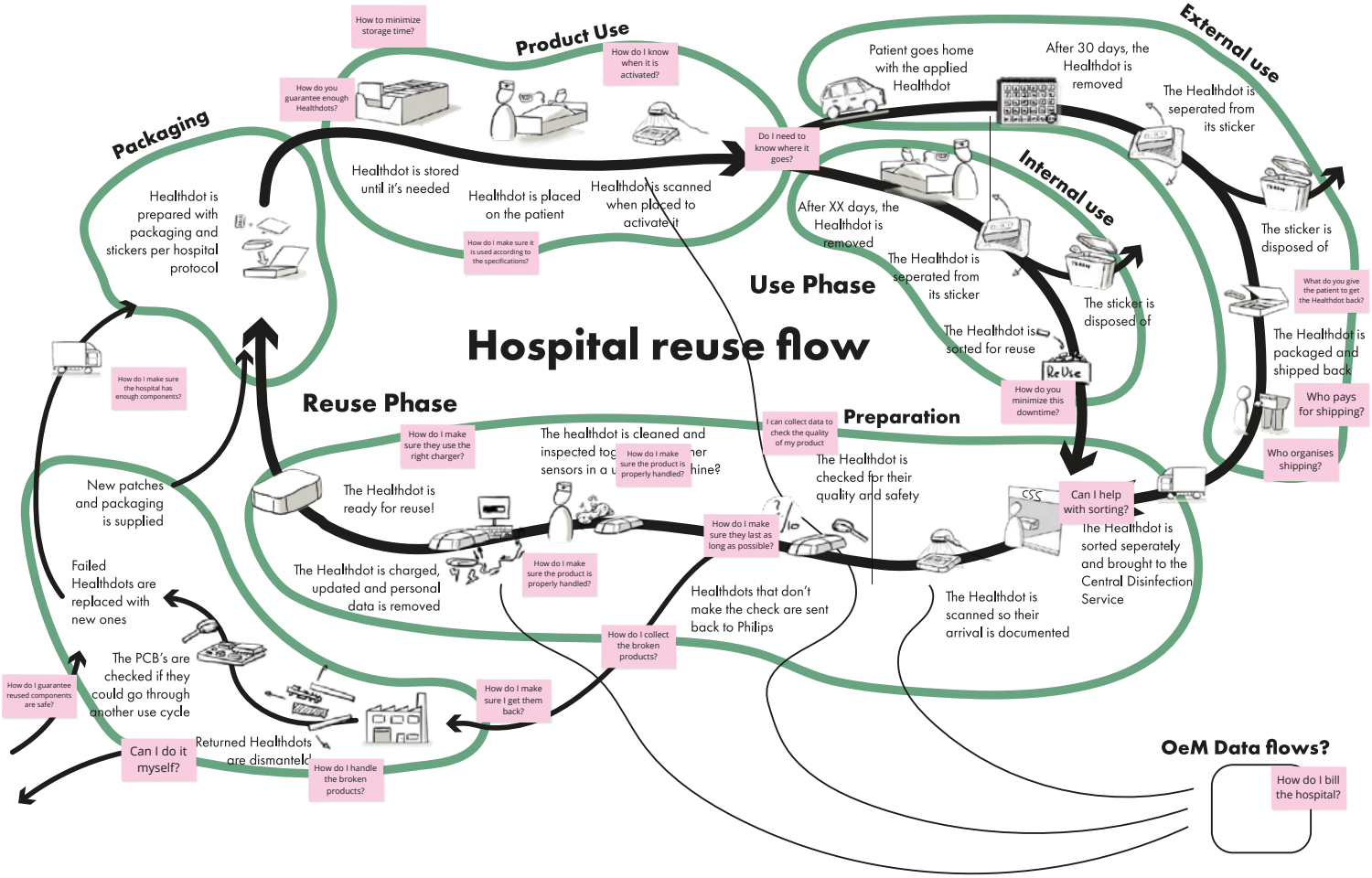
Nurse/Doctor



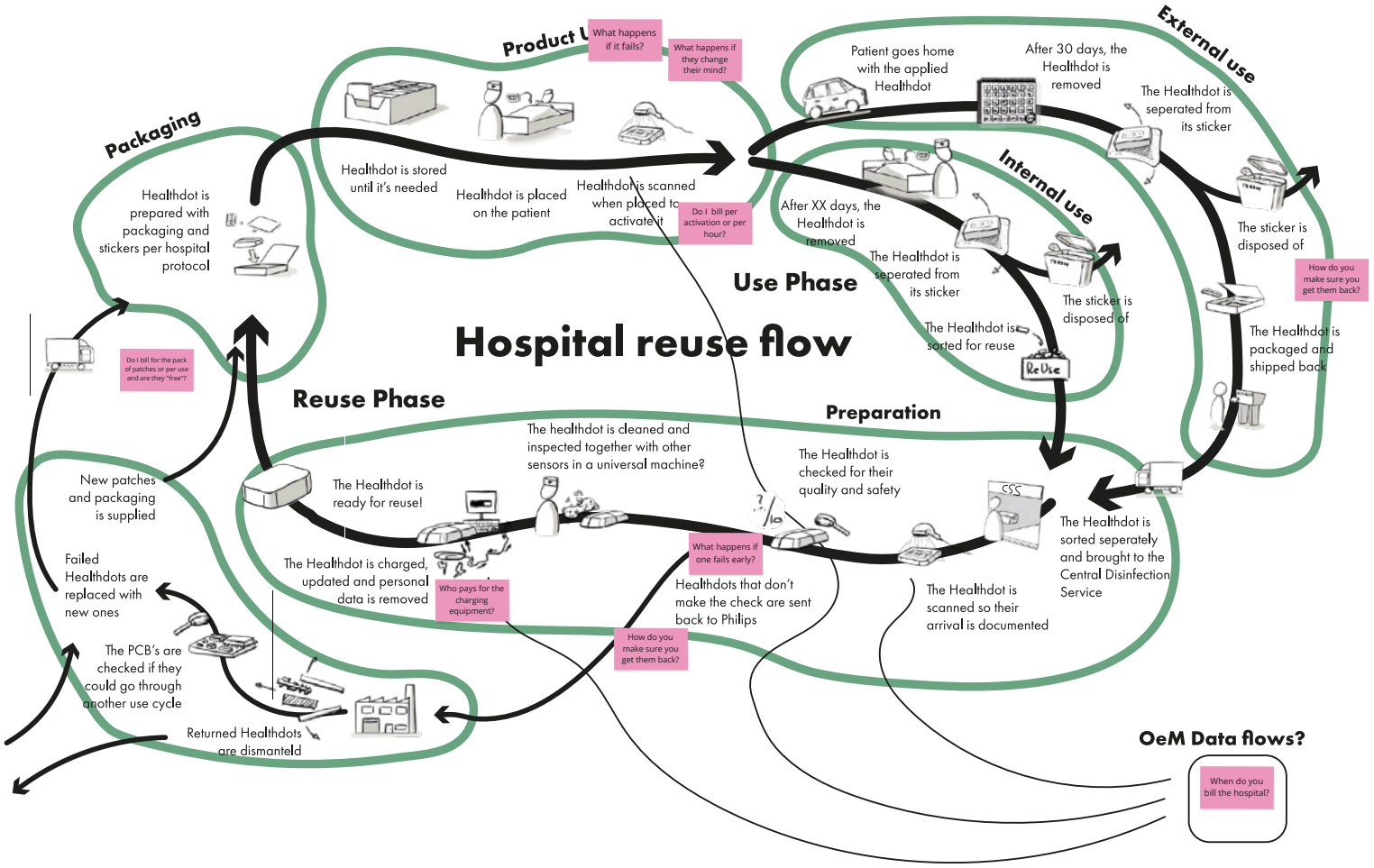
Hospital Experience



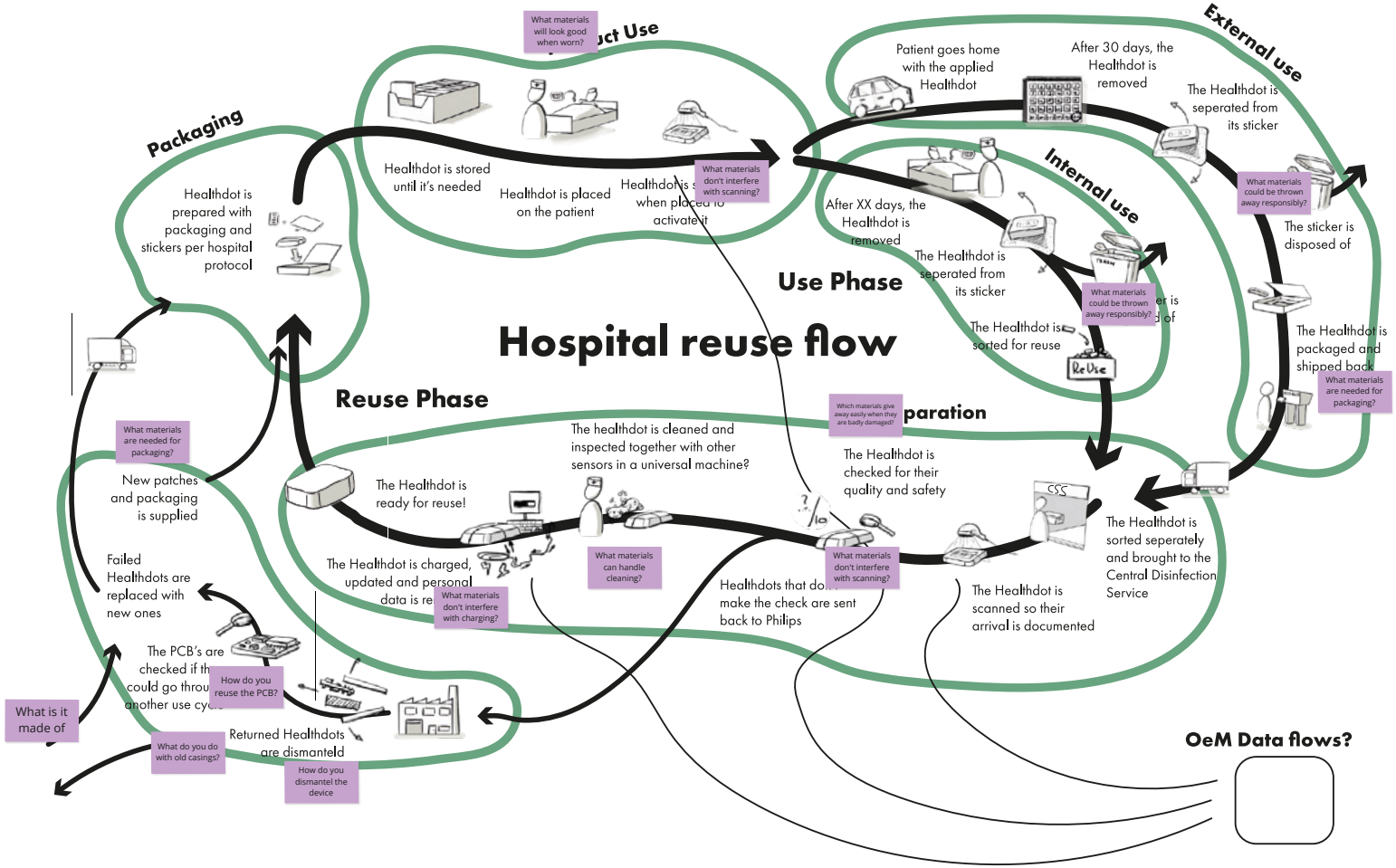
OeM Experience



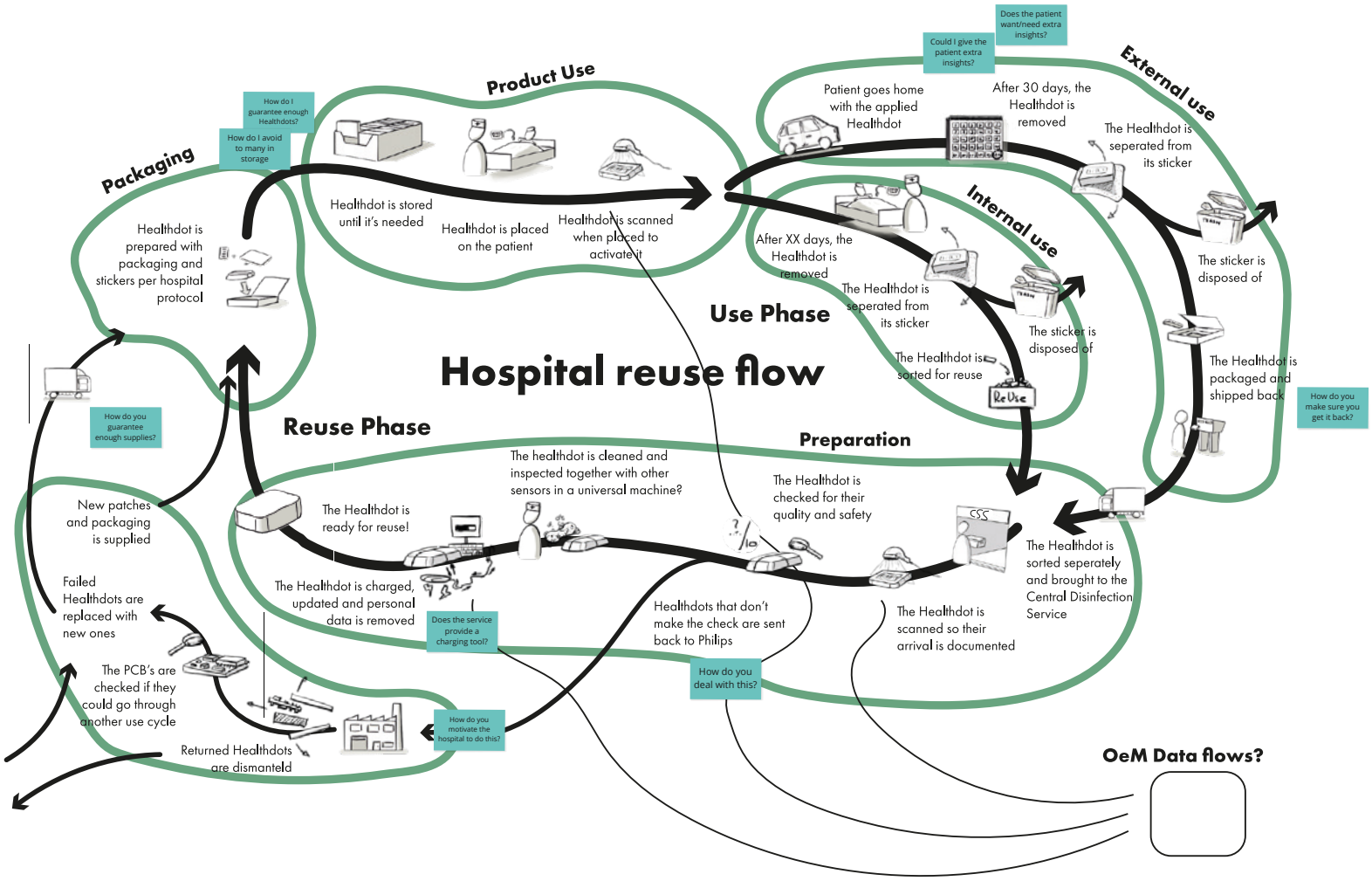
Financial


Hospital reuse flow
Packaging
Healthdot is prepared with packaging and stickers per hospital protocol
Do I bill for the pack of patches or per use and are they "free"?
New patches and packaging is supplied
Failed Healthdots are replaced with new ones
The PCB's are checked if they could go through another use cycle
Returned Healthdots are dismanteld
Reuse Phase
The Healthdot is ready for reuse!
The healthdot is cleaned and inspected together with other sensors in a universal machine?
The Healthdot is charged, updated and personal data is removed
Who pays for the charging equipment?
Preparation
The Healthdot is checked for their quality and safety
What happens if one fails early?
Healthdots that don't make the check are sent back to Philips
How do you make sure you get them back?
The Healthdot is scanned so their arrival is documented
The Healthdot is sorted seperately and brought to the Central Disinfection Service
Use Phase
Product U
What happens if it fails?
What happens if they change their mind?
Healthdot is stored until it's needed
Healthdot is placed on the patient
Healthdot is scanned when placed to activate it
Do I bill per activation or per hour?
External use
Patient goes home with the applied Healthdot
After 30 days, the Healthdot is removed
The Healthdot is seperated from its sticker
The sticker is disposed of
How do you make sure you get them back?
The Healthdot is packaged and shipped back
Internal use
After XX days, the Healthdot is removed
The Healthdot is seperated from its sticker
The sticker is disposed of
The Healthdot is sorted for reuse
ReUse
OeM Data flows?
When do you bill the hospital?

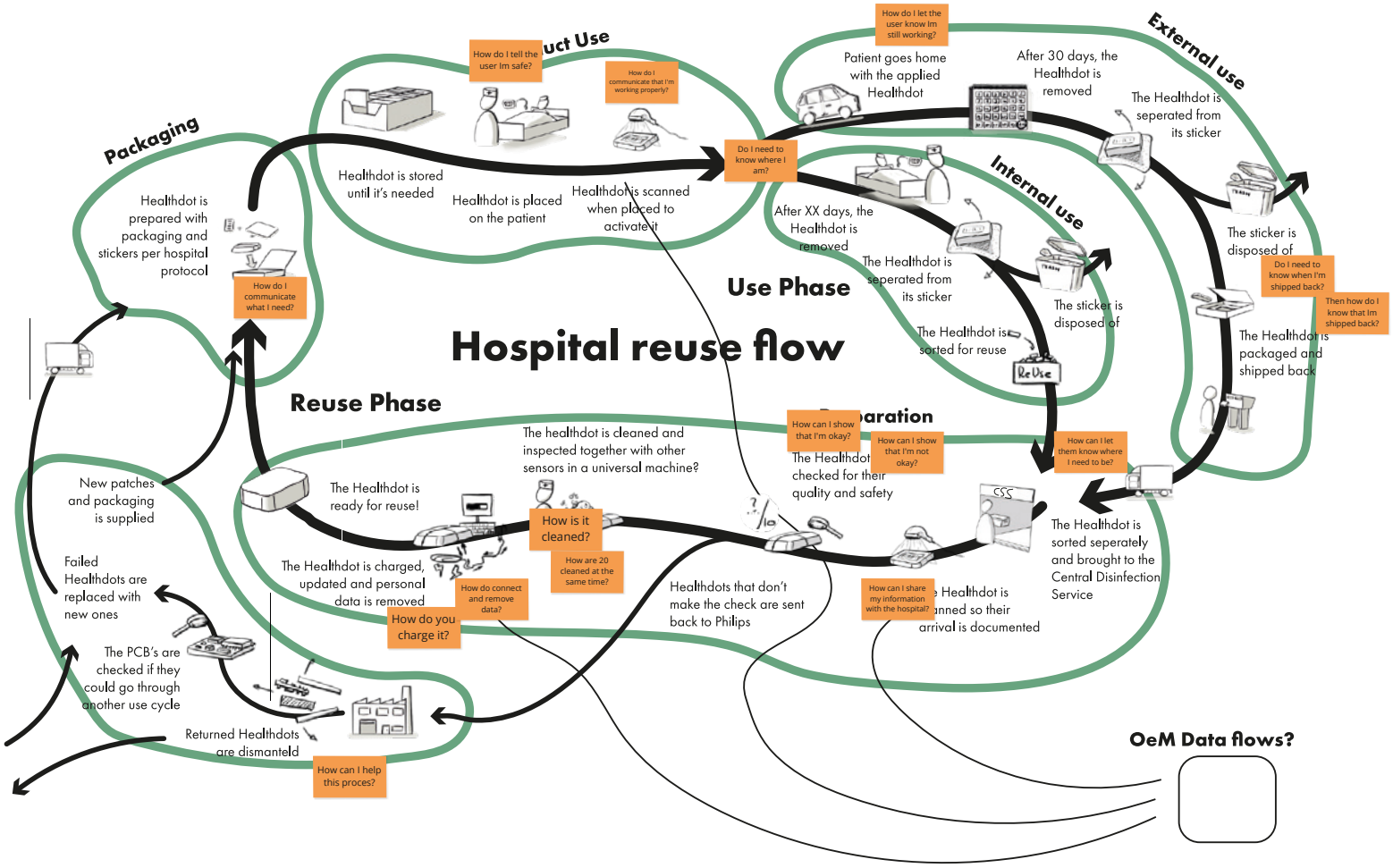
Materials and Manufacturing



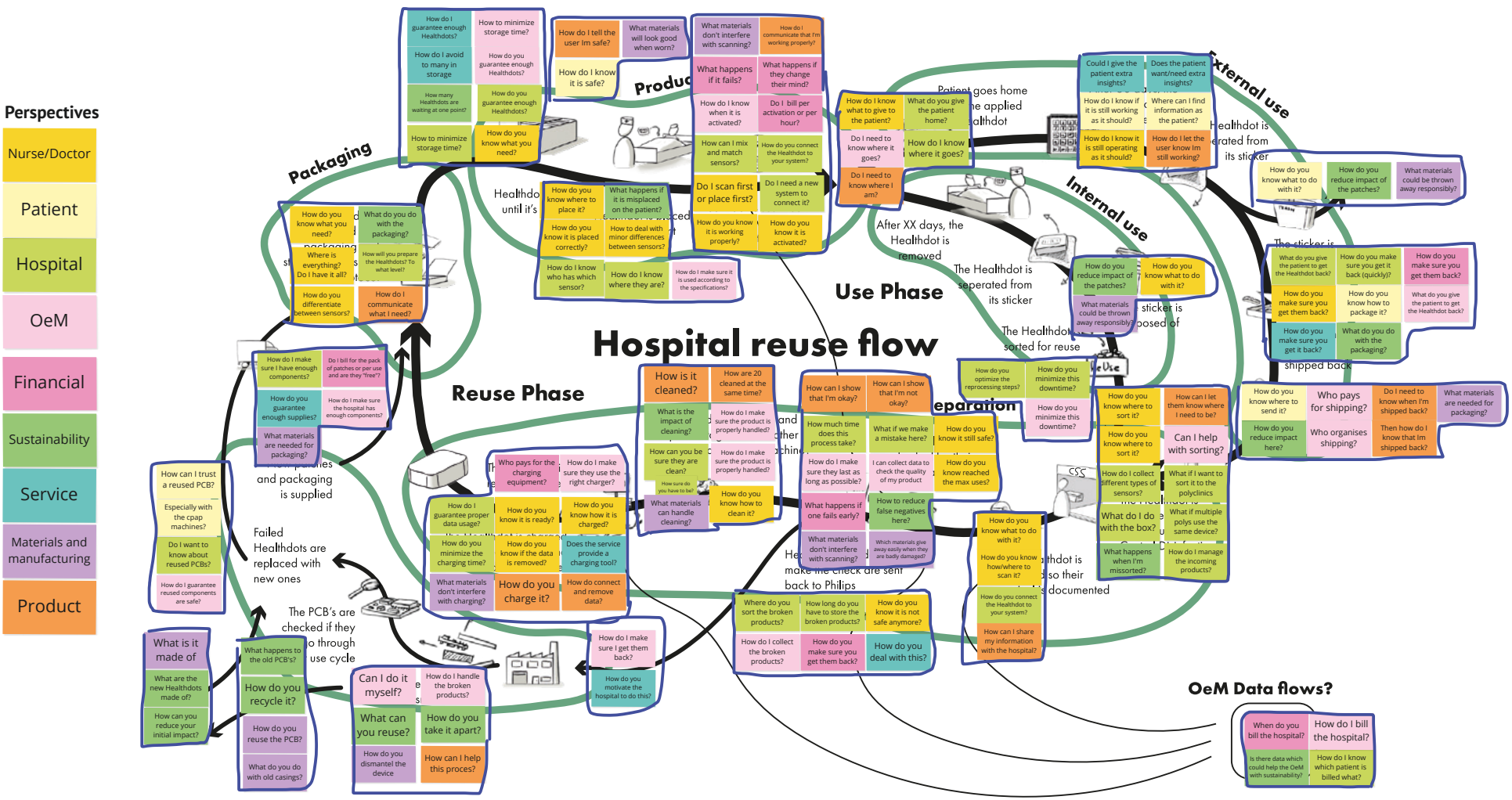
Service


Hospital reuse flow
Packaging
How do I guarantee enough Healthdots?
How do I avoid to many in storage
Healthdot is prepared with packaging and stickers per hospital protocol
Product Use
Healthdot is stored until it's needed
Healthdot is placed on the patient
Healthdot is scanned when placed to activate it
Use Phase
External use
Could I give the patient extra insights?
Does the patient want/need extra insights?
Patient goes home with the applied Healthdot
After 30 days, the Healthdot is removed
The Healthdot is seperated from its sticker
The sticker is disposed of
The Healthdot is packaged and shipped back
How do you make sure you get it back?
Internal use
After XX days, the Healthdot is removed
The Healthdot is seperated from its sticker
The sticker is disposed of
The Healthdot is sorted for reuse
Reuse Phase
How do you guarantee enough supplies?
New patches and packaging is supplied
Failed Healthdots are replaced with new ones
The PCB's are checked if they could go through another use cycle
Returned Healthdots are dismanteld
How do you motivate the hospital to do this?
Preparation
The Healthdot is ready for reuse!
The healthdot is cleaned and inspected together with other sensors in a universal machine?
The Healthdot is charged, updated and personal data is removed
Does the service provide a charging tool?
The Healthdot is checked for their quality and safety
Healthdots that don't make the check are sent back to Philips
How do you deal with this?
The Healthdot is scanned so their arrival is documented
The Healthdot is sorted seperately and brought to the Central Disinfection Service
OeM Data flows?

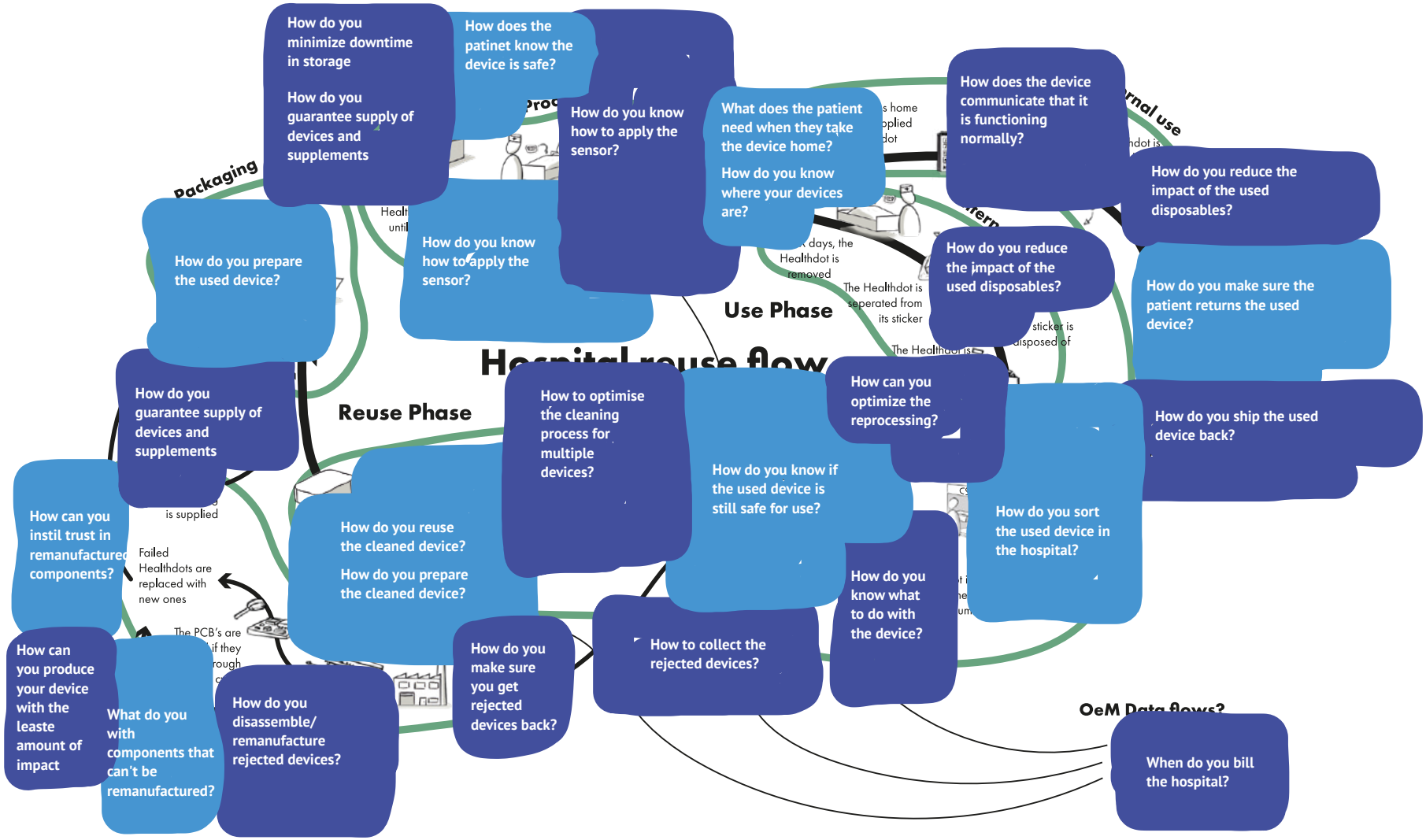
Product use


Hospital reuse flow
Packaging
Healthdot is prepared with packaging and stickers per hospital protocol
How do I communicate what I need?
Use Phase
uct Use
How do I tell the user Im safe?
How do I communicate that I'm working properly?
Healthdot is stored until it's needed
Healthdot is placed on the patient
Healthdot is scanned when placed to activate it
Do I need to know where I am?
External use
How do I let the user know Im still working?
Patient goes home with the applied Healthdot
After 30 days, the Healthdot is removed
The Healthdot is seperated from its sticker
The sticker is disposed of
Do I need to know when I'm shipped back?
Then how do I know that Im shipped back?
The Healthdot is packaged and shipped back
Internal use
After XX days, the Healthdot is removed
The Healthdot is seperated from its sticker
The sticker is disposed of
The Healthdot is sorted for reuse
ReUse
Reuse Phase
aration
How can I show that I'm okay?
How can I show that I'm not okay?
How can I let them know where I need to be?
The healthdot is cleaned and inspected together with other sensors in a universal machine?
The Healthdot is checked for their quality and safety
The Healthdot is ready for reuse!
How is it cleaned?
How are 20 cleaned at the same time?
The Healthdot is charged, updated and personal data is removed
How do connect and remove data?
How do you charge it?
Healthdots that don't make the check are sent back to Philips
How can I share my information with the hospital?
The Healthdot is sorted seperately and brought to the Central Disinfection Service
New patches and packaging is supplied
Failed Healthdots are replaced with new ones
The PCB's are checked if they could go through another use cycle
Returned Healthdots are dismanteld
How can I help this proces?
OeM Data flows?

Overview


Perspectives
Nurse/Doctor
Patient
Hospital
OeM
Financial
Sustainability
Service
Materials and manufacturing
Product
Hospital reuse flow
Use Phase
Reuse Phase
Packaging
Internal use
External use
OeM Data flows?
Failed Healthdots are replaced with new ones
The PCB's are checked if they
After XX days, the Healthdot is removed
The Healthdot is seperated from its sticker
shipped back
Patient goes home
How do I guarantee enough Healthdots?
How to minimize storage time?
How do I avoid to many in storage
How do you guarantee enough Healthdots?
How many Healthdots are waiting at one point?
How do you know what you need?
How do I tell the user Im safe?
What materials will look good when worn?
How do I know it is safe?
What materials don't interfere with scanning?
How do I communicate that I'm working properly?
What happens if it fails?
What happens if they change their mind?
How do I know when it is activated?
Do I bill per activation or per hour?
How can I mix and match sensors?
How do you connect the Healthdot to your system?
Do I scan first or place first?
Do I need a new system to connect it?
How do you know what it is working properly?
How do you know it is activated?
How do you know where to place it?
What happens if it is misplaced on the patient?
How do you know it is placed correctly?
How to deal with minor differences between sensors?
How do I know who has which sensor?
How do I know where they are?
How do I make sure it is used according to the specifications?
How do you know what you need?
What do you do with the packaging?
Where is everything? Do I have it all?
How will you prepare the Healthdots? To what level?
How do you differentiate between sensors?
How do I communicate what I need?
How do I make sure I have enough components?
Do I bill for the pack of patches or per use and are they "free"?
How do you guarantee enough supplies?
How do I make sure the hospital has enough components?
What materials are needed for packaging?
How can I trust a reused PCB?
Especially with the cpap machines?
Do I want to know about reused PCBs?
How do I guarantee reused components are safe?
What is it made of
What are the new Healthdots made of?
How can you reduce your initial impact?
What happens to the old PCB's?
How do you recycle it?
How do you reuse the PCB?
What do you do with old casings?
Can I do it myself?
How do I handle the broken products?
What can you reuse?
How do you take it apart?
How do you dismantel the device
How can I help this proces?
How do I make sure I get them back?
How do you motivate the hospital to do this?
Who pays for the charging equipment?
How do I make sure they use the right charger?
How do I guarantee proper data usage?
How do you know it is ready?
How do you know how it is charged?
How do you minimize the charging time?
How do you know if the data is removed?
Does the service provide a charging tool?
What materials don't interfere with charging?
How do you charge it?
How do connect and remove data?
How is it cleaned?
How are 20 cleaned at the same time?
What is the impact of cleaning?
How do I make sure the product is properly handled?
How can you be sure they are clean?
How do I make sure the product is properly handled?
How sure do you have to be?
What materials can handle cleaning?
How do you know how to clean it?
How can I show that I'm okay?
How can I show that I'm not okay?
How much time does this process take?
What if we make a mistake here?
How do you know it still safe?
How do I make sure they last as long as possible?
I can collect data to check the quality of my product
How do you know reached the max uses?
What happens if one fails early?
How to reduce false negatives here?
What materials don't interfere with scanning?
Which materials give away easily when they are badly damaged?
Where do you sort the broken products?
How long do you have to store the broken products?
How do you know it is not safe anymore?
How do I collect the broken products?
How do you make sure you get them back?
How do you deal with this?
How do you optimize the reprocessing steps?
How do you minimize this downtime?
How do you minimize this downtime?
How do you know what to do with it?
How do you know how/where to scan it?
How do you connect the Healthdot to your system?
How can I share my information with the hospital?
How do you know what to do with it?
How do you reduce impact of the patches?
What materials could be thrown away responsibly?
How do you know where to sort it?
How can I let them know where I need to be?
How do you know where to sort it?
Can I help with sorting?
How do I collect different types of sensors?
What if I want to sort it to the polyclinics
What do I do with the box?
What if multiple polys use the same device?
What happens when I'm missorted?
How do I manage the incoming products?
How do you know what to do with it?
How do you reduce impact of the patches?
What materials could be thrown away responsibly?
How do you know where to send it?
Who pays for shipping?
Do I need to know when I'm shipped back?
What materials are needed for packaging?
How do you reduce impact here?
Who organises shipping?
Then how do I know that Im shipped back?
How do you know what to do with it?
How do you reduce impact of the patches?
What materials could be thrown away responsibly?
What do you give the patient to get the Healthdot back?
How do you make sure you get it back (quickly)?
How do you make sure you get them back?
How do you make sure you get them back?
How do you know how to package it?
What do you give the patient to get the Healthdot back?
How do you make sure you get it back?
What do you do with the packaging?
Could I give the patient extra insights?
Does the patient want/need extra insights?
How do I know if it is still working as it should?
Where can I find information as the patient?
How do I know it is still operating as it should?
How do I let the user know Im still working?
How do you know what to do with it?
How do you reduce impact of the patches?
What materials could be thrown away responsibly?
How do I know what to give to the patient?
What do you give the patient home?
Do I need to know where it goes?
How do I know where it goes?
Do I need to know where I am?
When do you bill the hospital?
How do I bill the hospital?
Is there data which could help the OeM with sustainability?
How do I know which patient is billed what?

Overview


How do you minimize downtime in storage
How do you guarantee supply of devices and supplements
How does the patinet know the device is safe?
How do you know how to apply the sensor?
What does the patient need when they take the device home?
How do you know where your devices are?
How does the device communicate that it is functioning normally?
How do you reduce the impact of the used disposables?
How do you make sure the patient returns the used device?
How do you ship the used device back?
How do you sort the used device in the hospital?
How do you know what to do with the device?
How do you know if the used device is still safe for use?
How can you optimize the reprocessing?
How to optimise the cleaning process for multiple devices?
How to collect the rejected devices?
How do you make sure you get rejected devices back?
How do you disassemble/ remanufacture rejected devices?
What do you with components that can't be remanufactured?
How can you produce your device with the leaste amount of impact
How can you instil trust in remanufactured components?
How do you guarantee supply of devices and supplements
How do you prepare the used device?
How do you know how to apply the sensor?
How do you reduce the impact of the used disposables?
How do you reuse the cleaned device?
How do you prepare the cleaned device?
When do you bill the hospital?
Use Phase
Reuse Phase
Packaging
Failed Healthdots are replaced with new ones
The Healthdot is seperated from its sticker
is supplied

I • Design Brainstorm

Random Ideas

How might we store more?

How might different MHWs look like?

There is no max use, AI will check the performance and uses big data to see how long it lasts

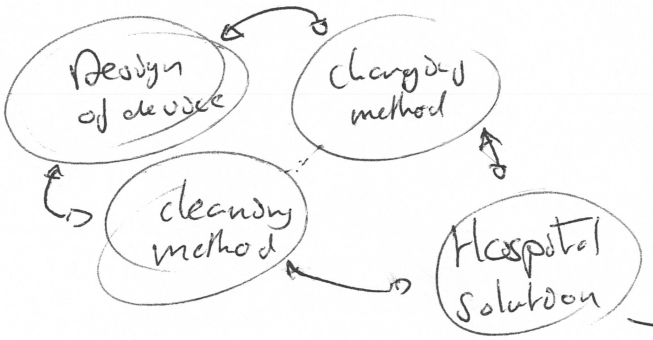
Two directions

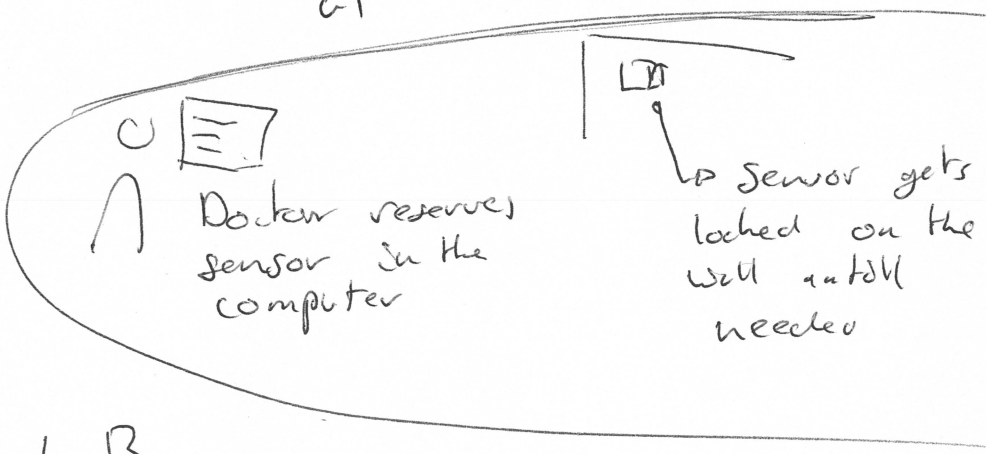
1
manual cleaning etc.

2
a machine does it

How might we lock a sensor?

Part A



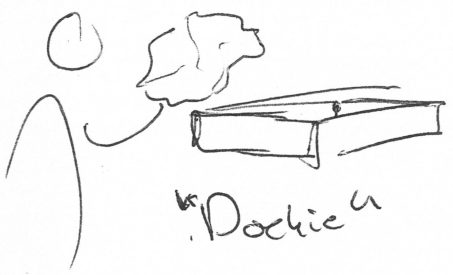


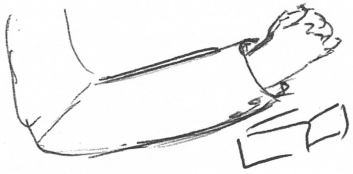
Part B

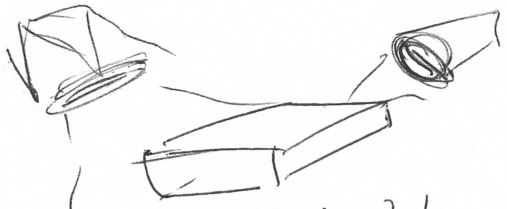
How might we clean mws? (multiple)

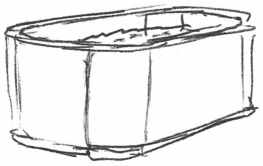
Cleaning time = 2o se
25 sec

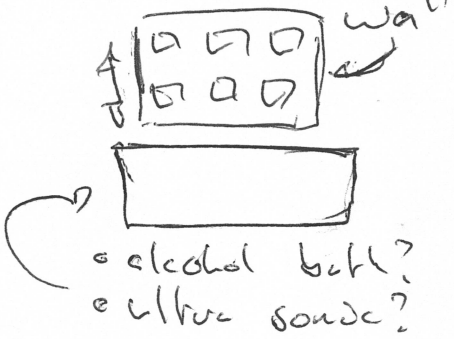
- assume 3
10 sensors
= 5 mi



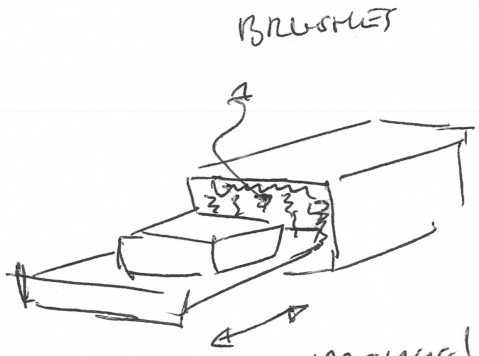








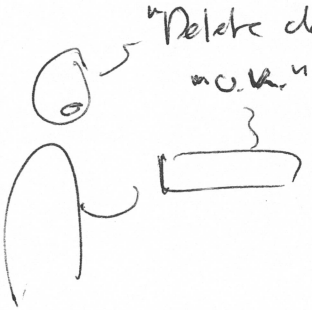
that ... submerge?

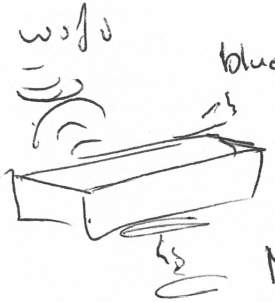


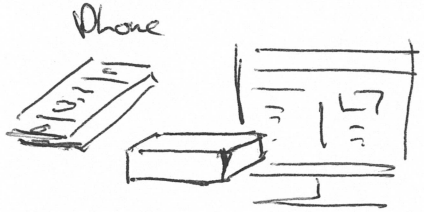
(with UV still manual cleaning for residue)

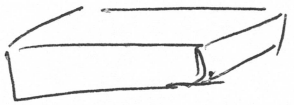
How might (multiple) we communicate with MWS ?

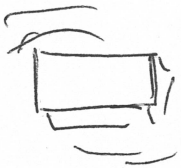
QR CODE + Internet







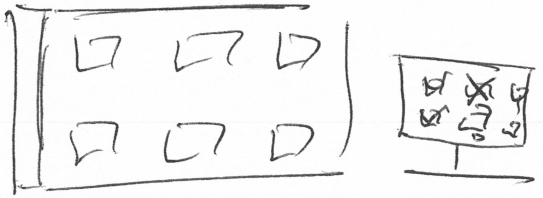




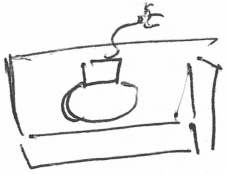
Bluetooth checkcode

Big magnet

Screen + buttons



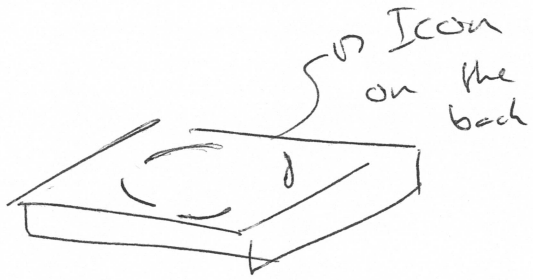
Wall + computer

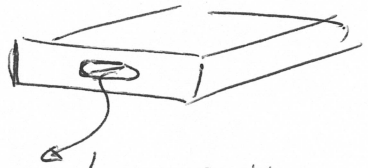


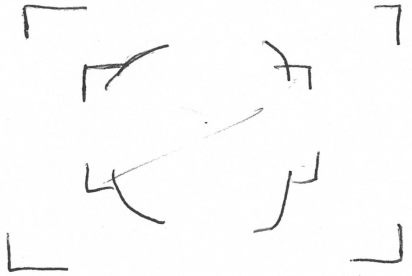
self destruct of data

USB-C

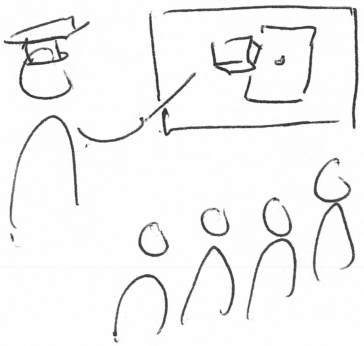
How might we know how to charge the MWS?



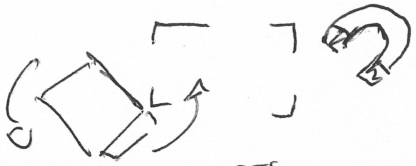


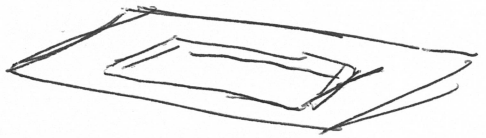


Icons on the charger

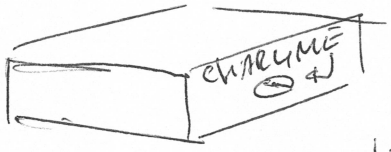


Teaching



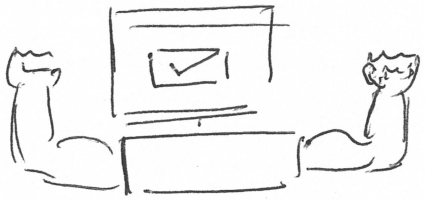


indented charger

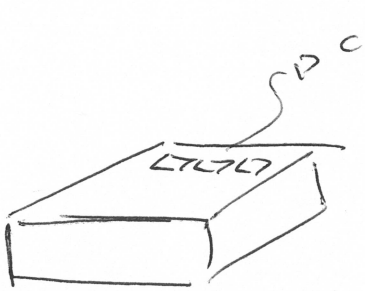


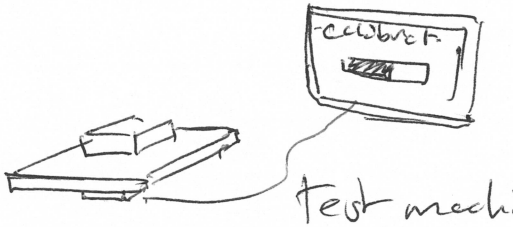
description
on the product

How might we verify that the mics still work good?

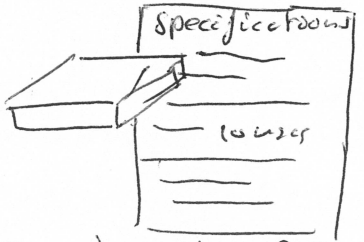


- self diagnosis
- computers says yes





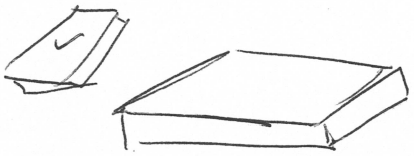
trust the use counter



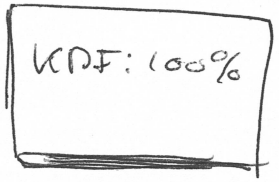
TRUST THE DEVICE

SHAKE TEST

No noise = ok

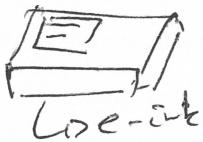


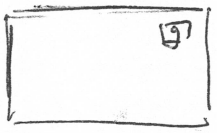
Device says nothing (green gekoor is rechtdoor)



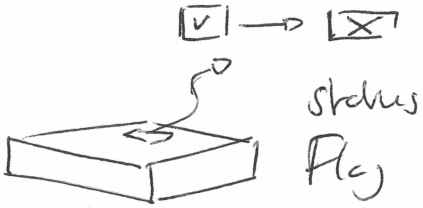
COMPUTER ALGORITHM
Detects proper operation

How might we avoid over-use of mws ?

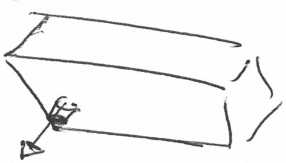




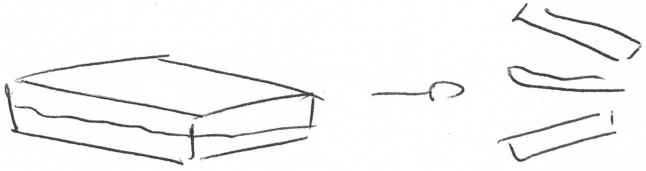
Use counter



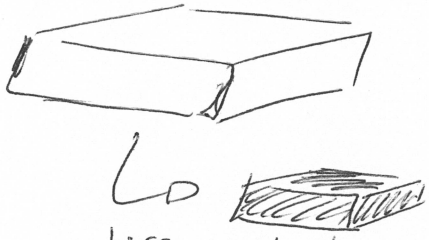
Status Flag



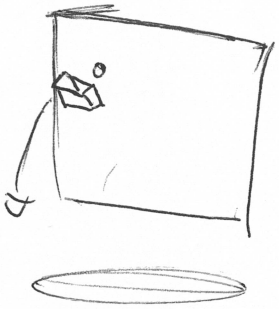
Button ext
Prevents
Patch to



self destructs



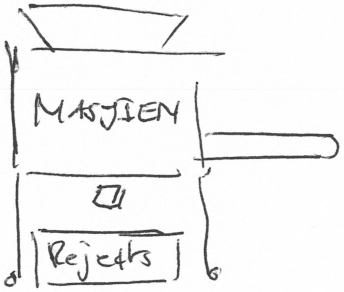
entire product colour change



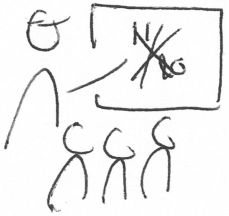
Falls of the wall
Wont charge

CHARGER GIVES WARNING

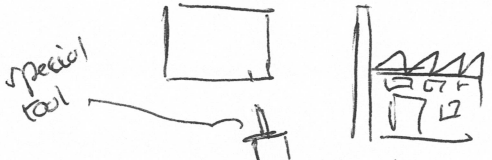
COMPUTER SAYS NO
Blocks digitally
COMPUTER NOTIFIES



Machine sorts rejects



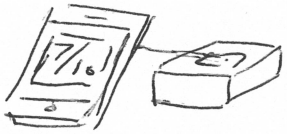
Teaching



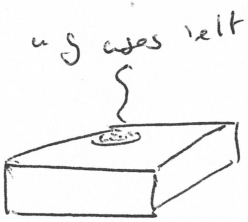
Only reset

Factory can

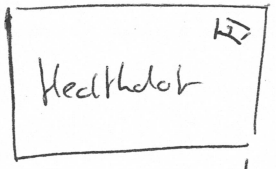
How might we check the amount of uses on multiple mws?



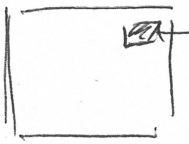
check digitally



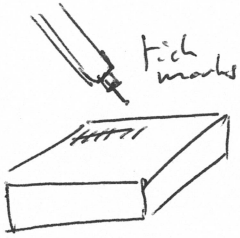
speaker

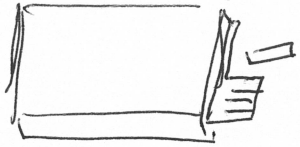


Use counter

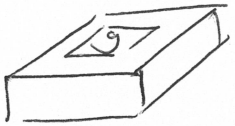


Coloured "flag"

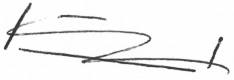


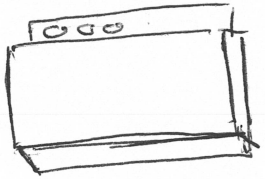


Tear-off strip



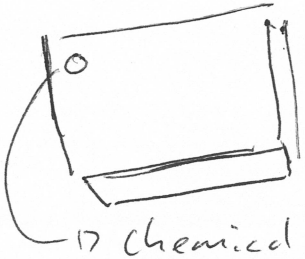
e-ink display



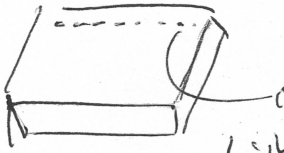


Hole Puncher

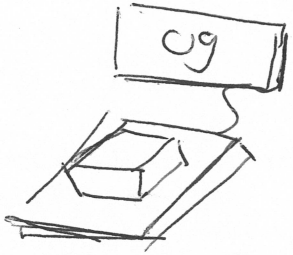
Button gets pressed/depressed by the patch



Chemical reactive marker

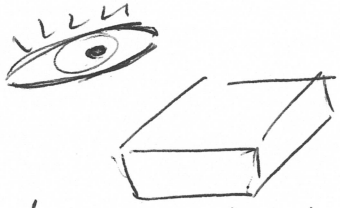


LED Lights

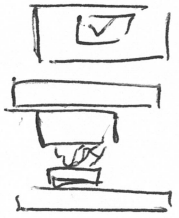


Charger has indicator

How might we check for damage on multiple mugs?

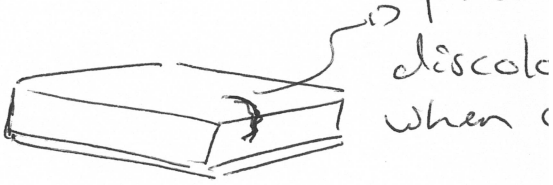


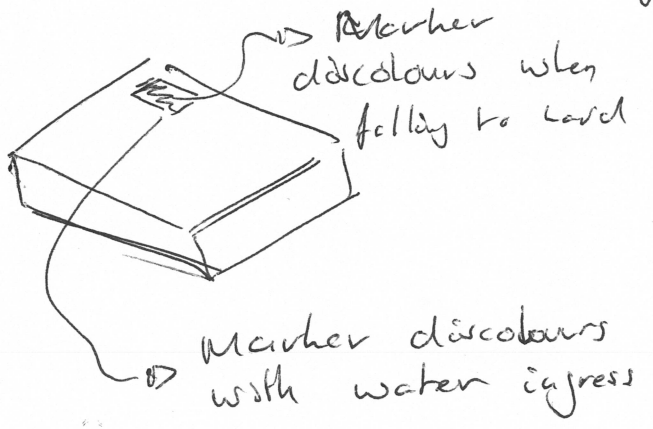
look at it

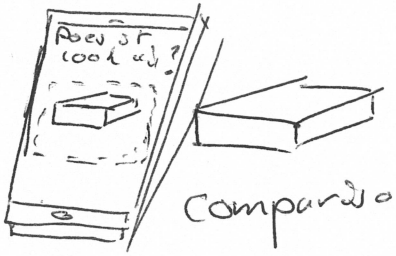


machine checks

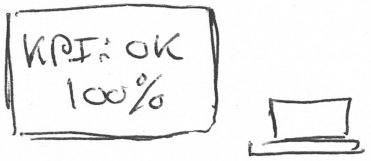
digital



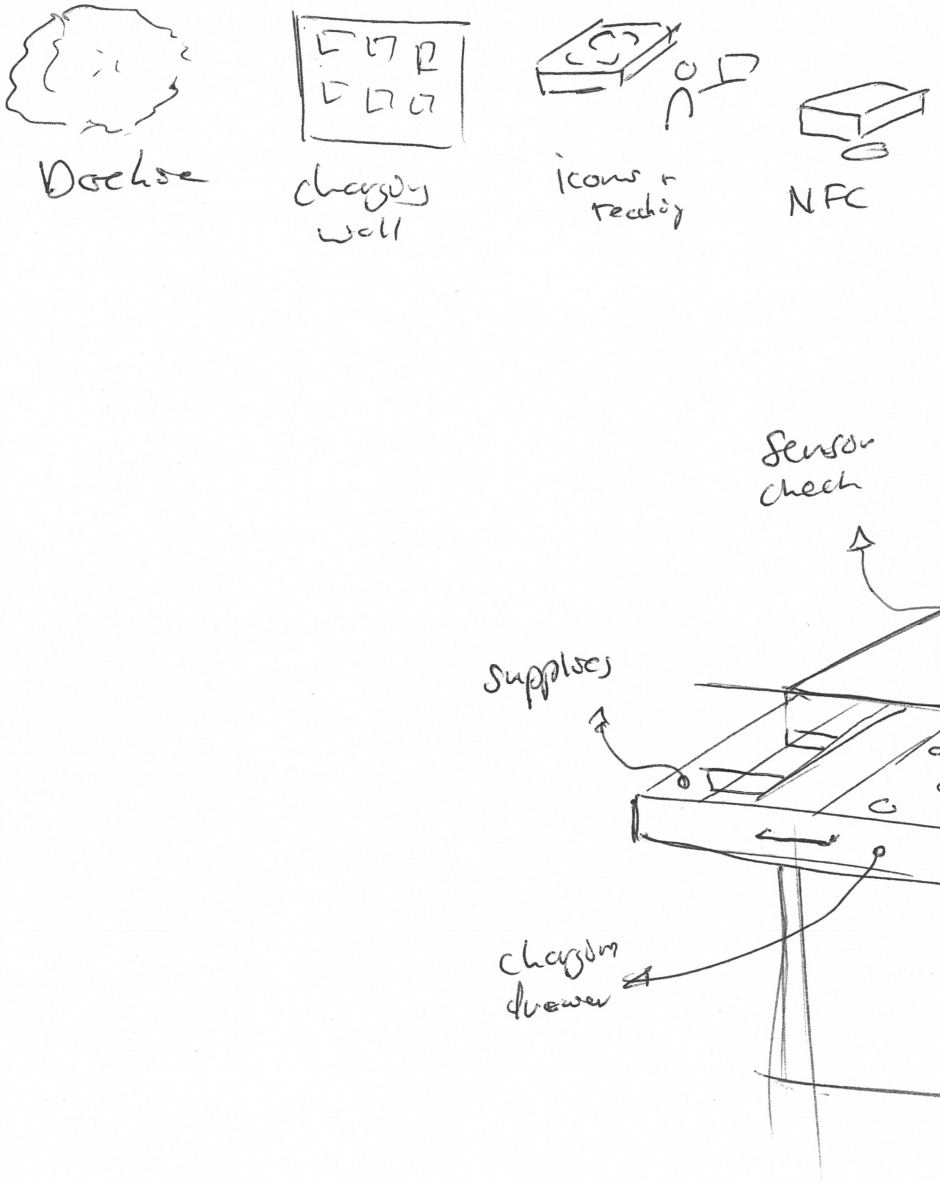


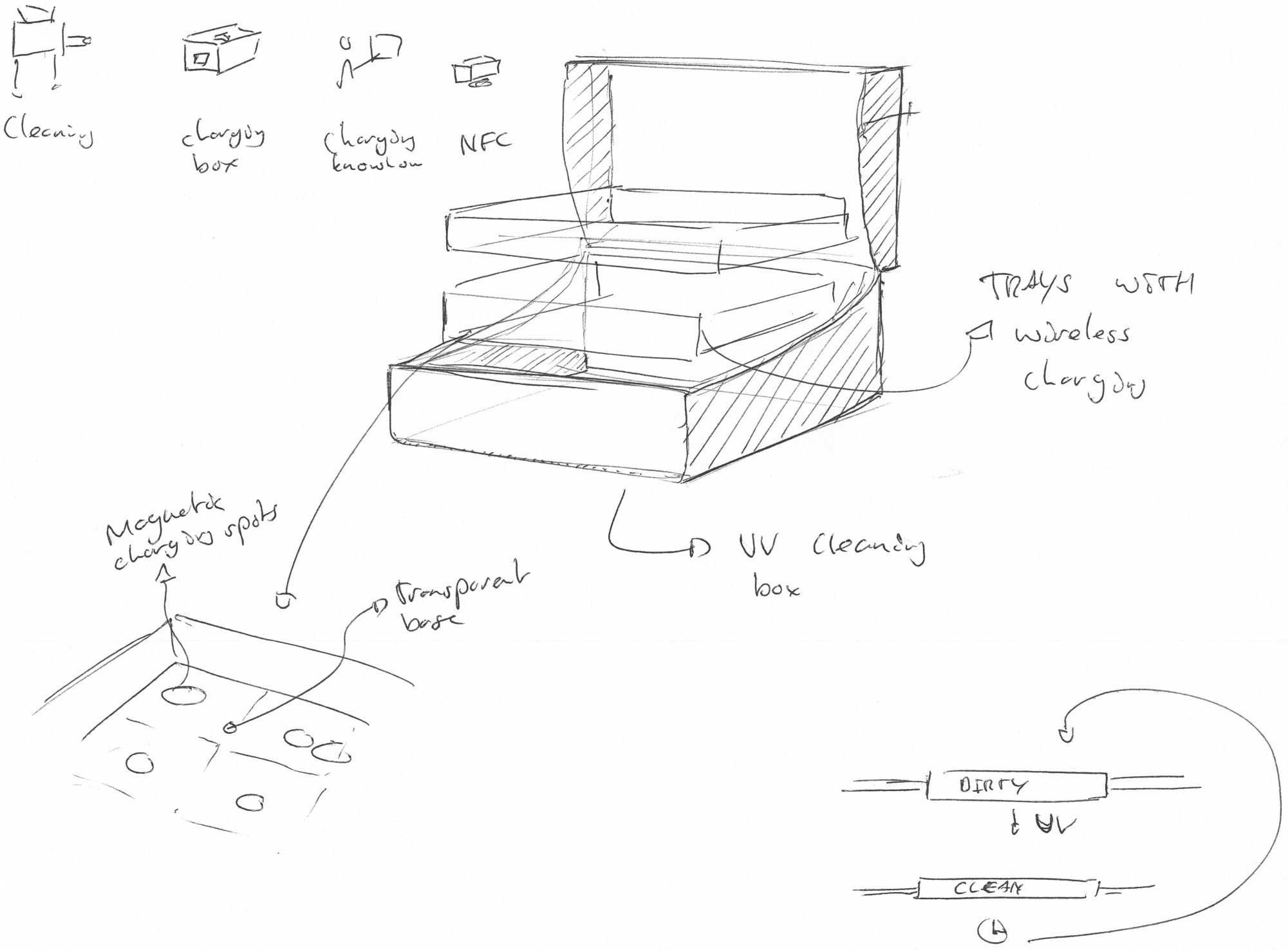


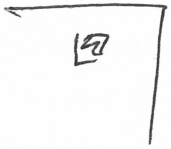
Comparison when scanning



computer uses big data to learn

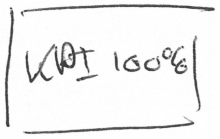

Docks
charging wall
icons + reading
NFC
Brand + model name
Amount of users
Is it still safe
digital lock
Unlock from patient
Sensor check
Sensor
Unlock
Supplies
UV lights for extra disinfection
charging drawer


Cleaning
charging box
charging known
NFC
TRAYS WITH wireless charging
Magnetic charging spots
transparent base
UV cleaning box
DIRTY
UV
CLEAN



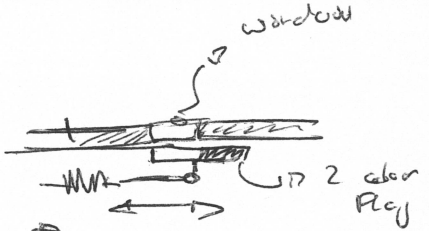
colored Flag

Maximum/over use



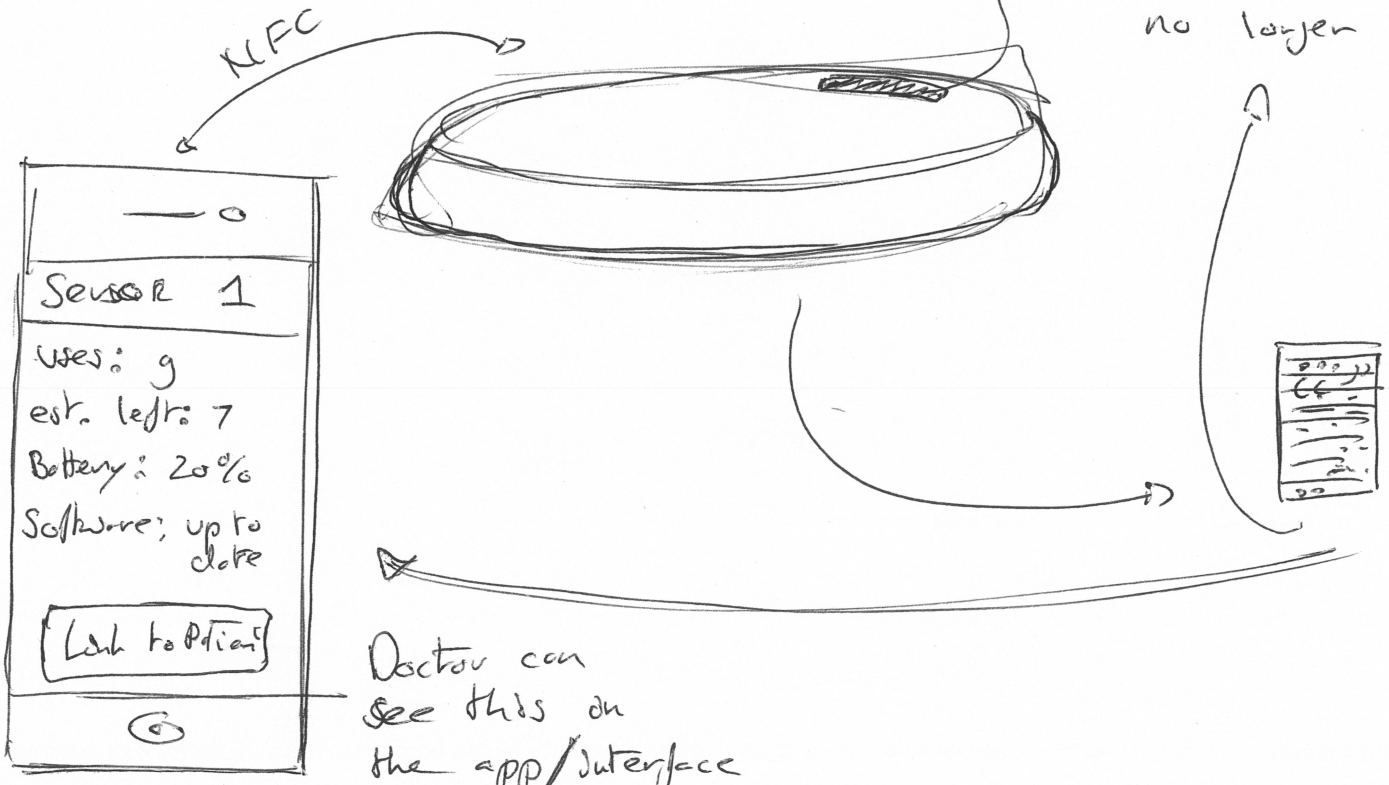
AI Jou data

NFC Scanning



electro mechanical marker

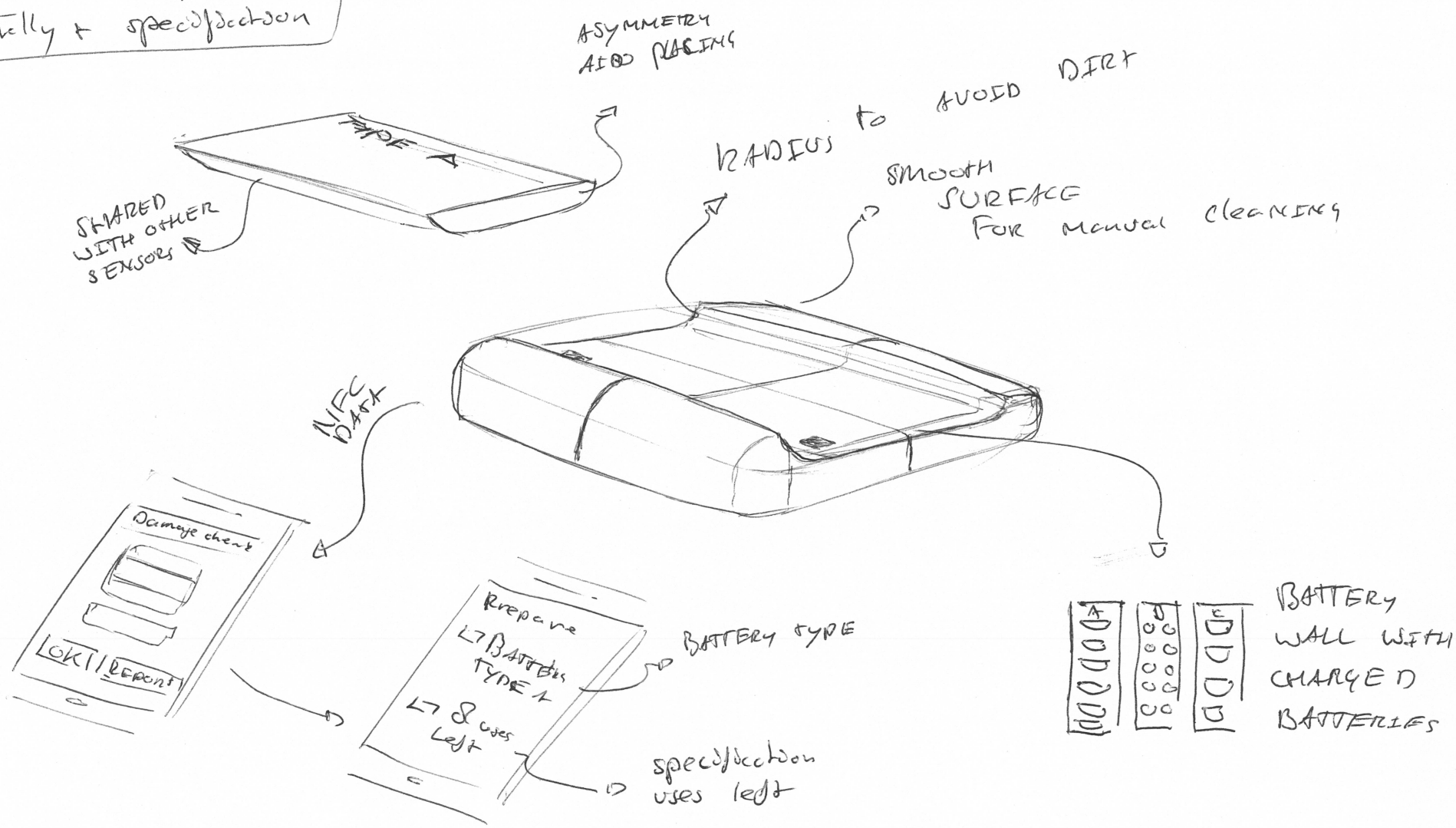
actuates, when the device is no longer 99.9% safe



Doctor can see this on the app/interface

AI on servers use data to Predict How many uses the device has left with 99 Safety rating

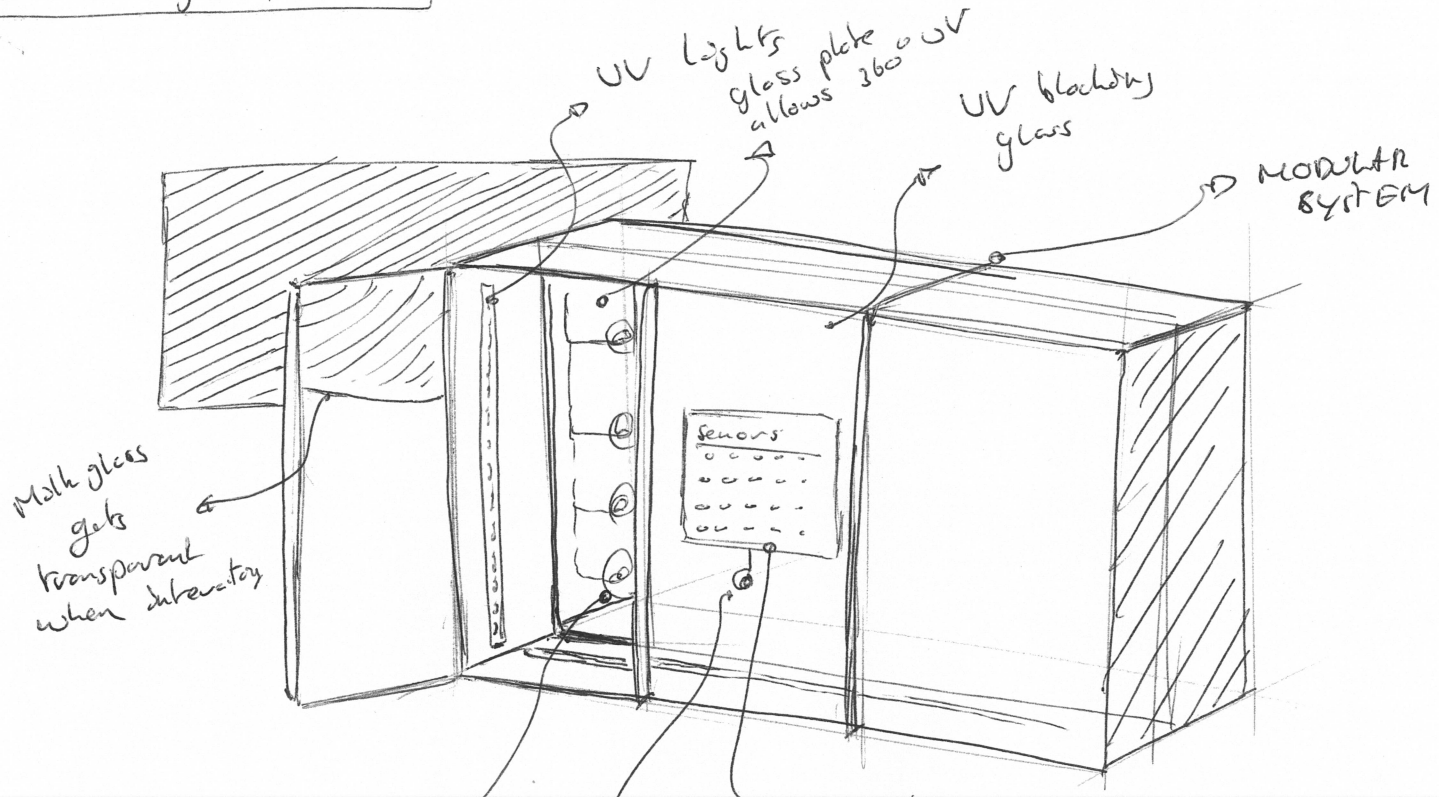
NFC + Batteries
+ Docks + comparison
+ digitally + specification



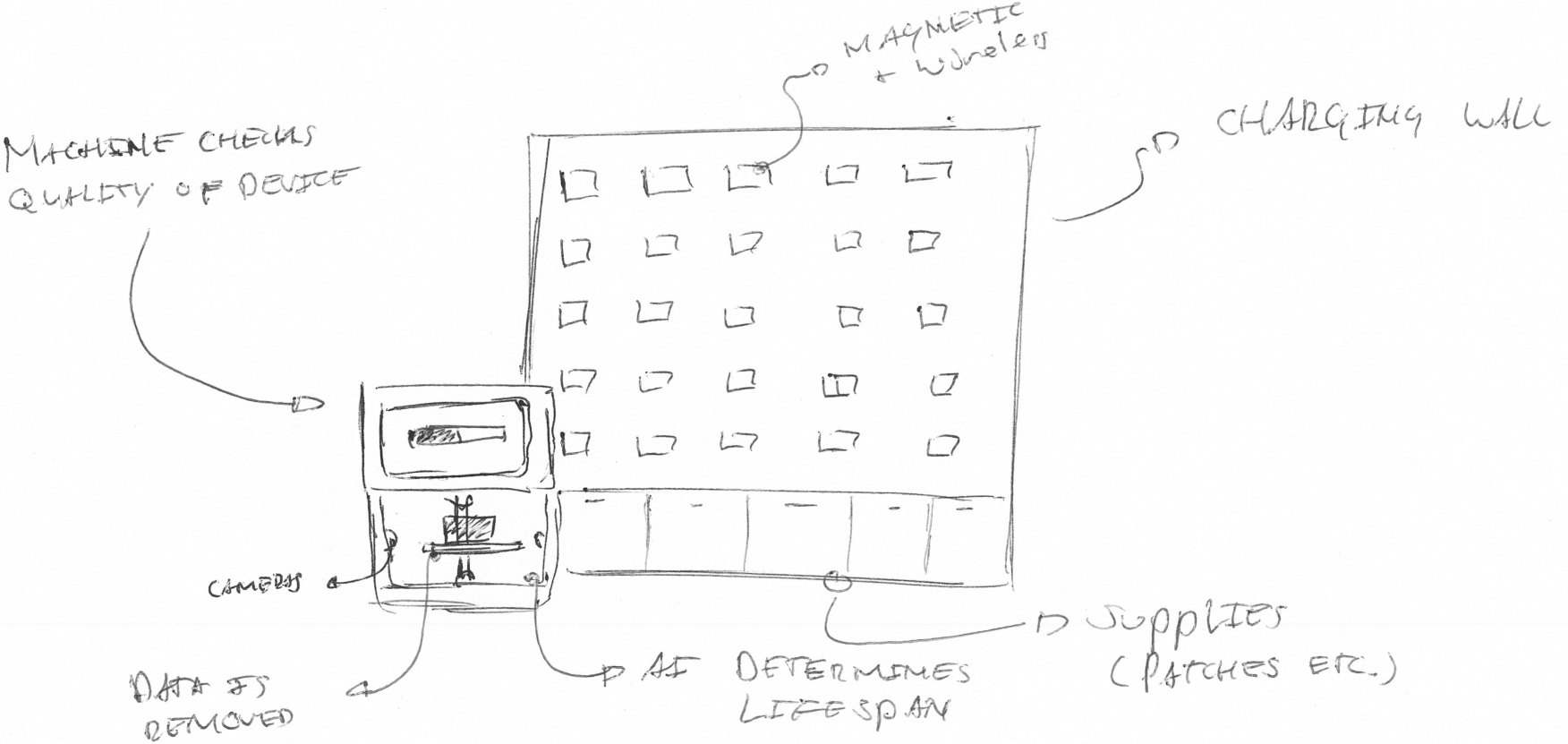
Battery also needs tracking

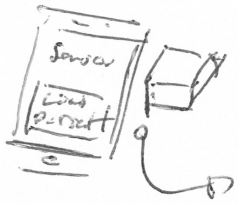
UV disinfection + charging box

Wall compr wall charge + machine clean + visual + digitally + AI



MFC + charge wall +
Doehde + machine +
digitally + AI

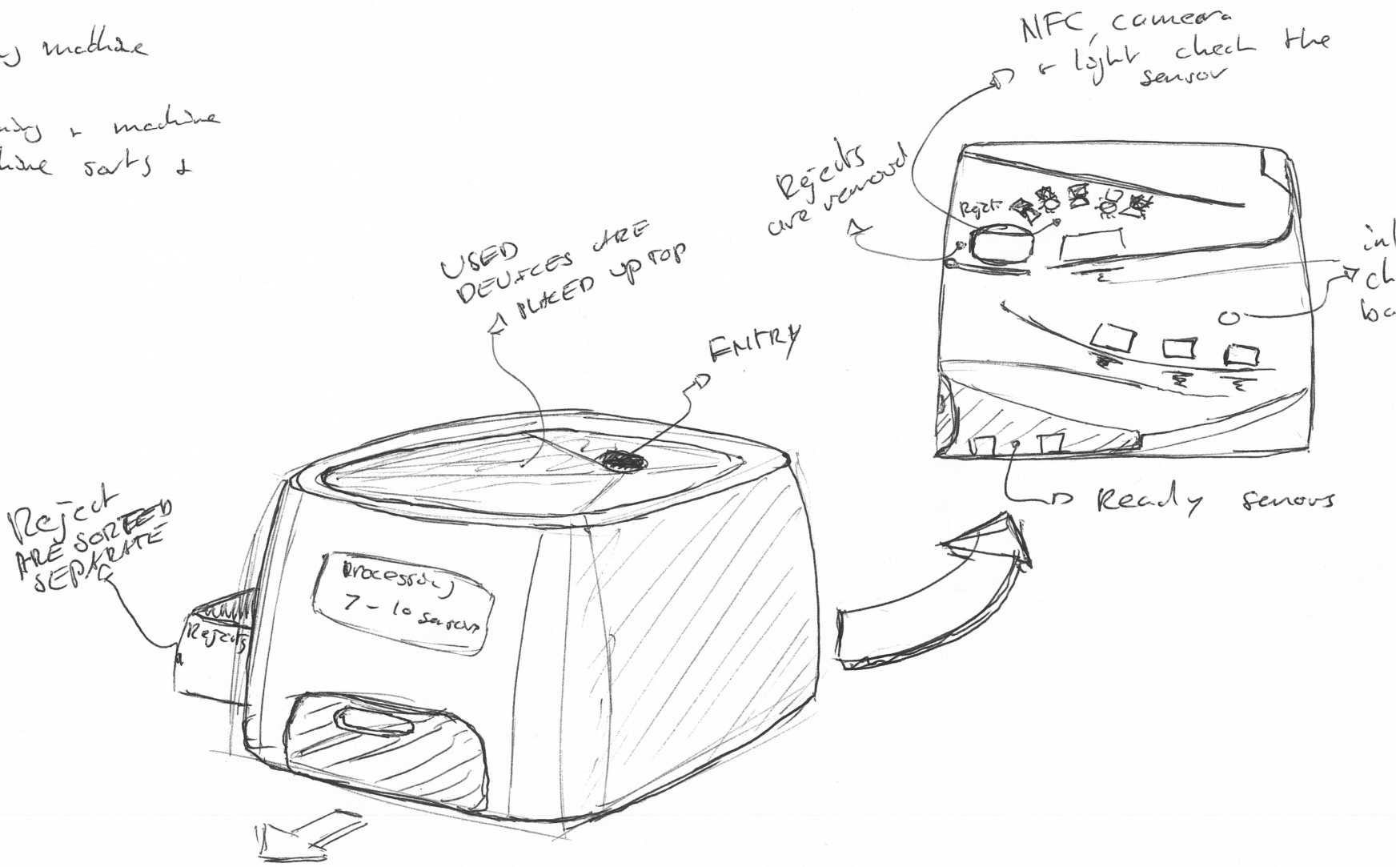




SMARTPHONE
LINKS DEVI

NFC + charging machine

+ ~~Device~~ machine cleaning + machine checks + machine starts + ~~task machine~~



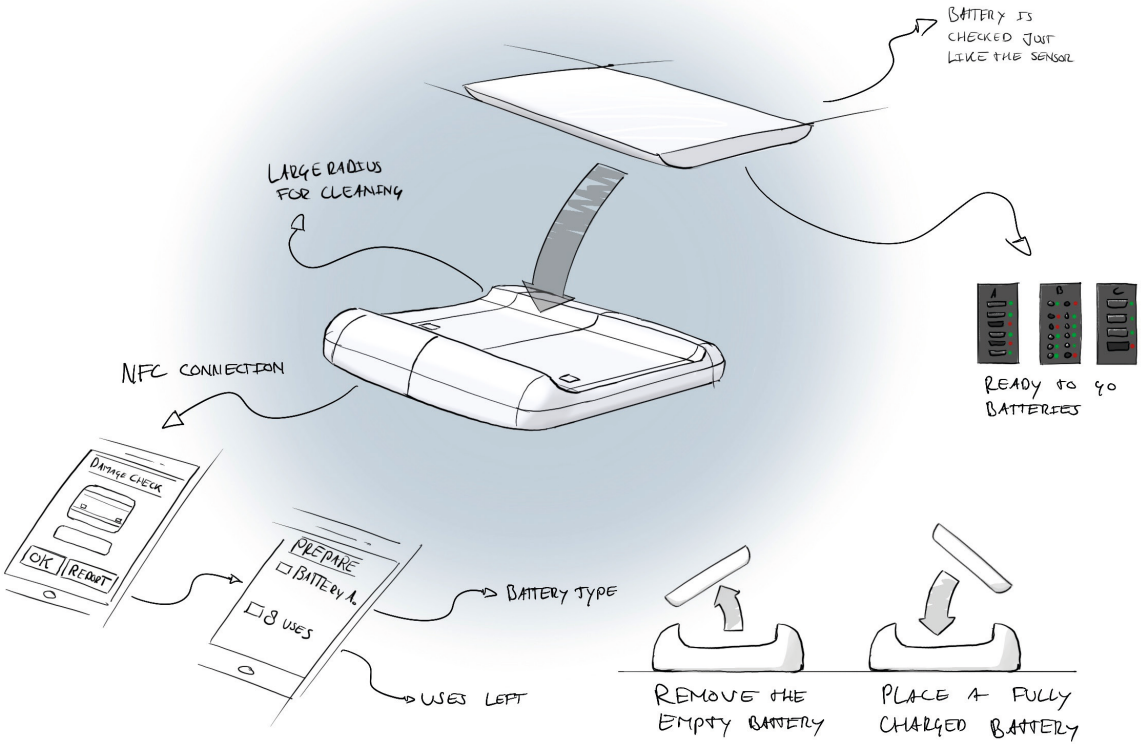
J • Detailed Concepts

J.1 Standardised Batteries

In this concept, the batteries of the MWS are replaceable and standardized – thus interchangeable. They come in several standard sizes which are charged separately in a charging wall. This allows the sensors to be reused quicker, as there is no more waiting on its battery to charge, you simply swap it. However, because the batteries are now separate these also need to be tracked for their amount of uses.

Use

When a sensor returns, the nurse removes the used battery from the sensor. Both items are cleaned and scanned manually, after which the empty battery is placed in the charger. A full battery is inserted into the sensor, which can immediately be reused. When the sensors are scanned with the phone, a notification shows how many uses both the battery and the device have left.



J.2 Smart Scan + Charging wall

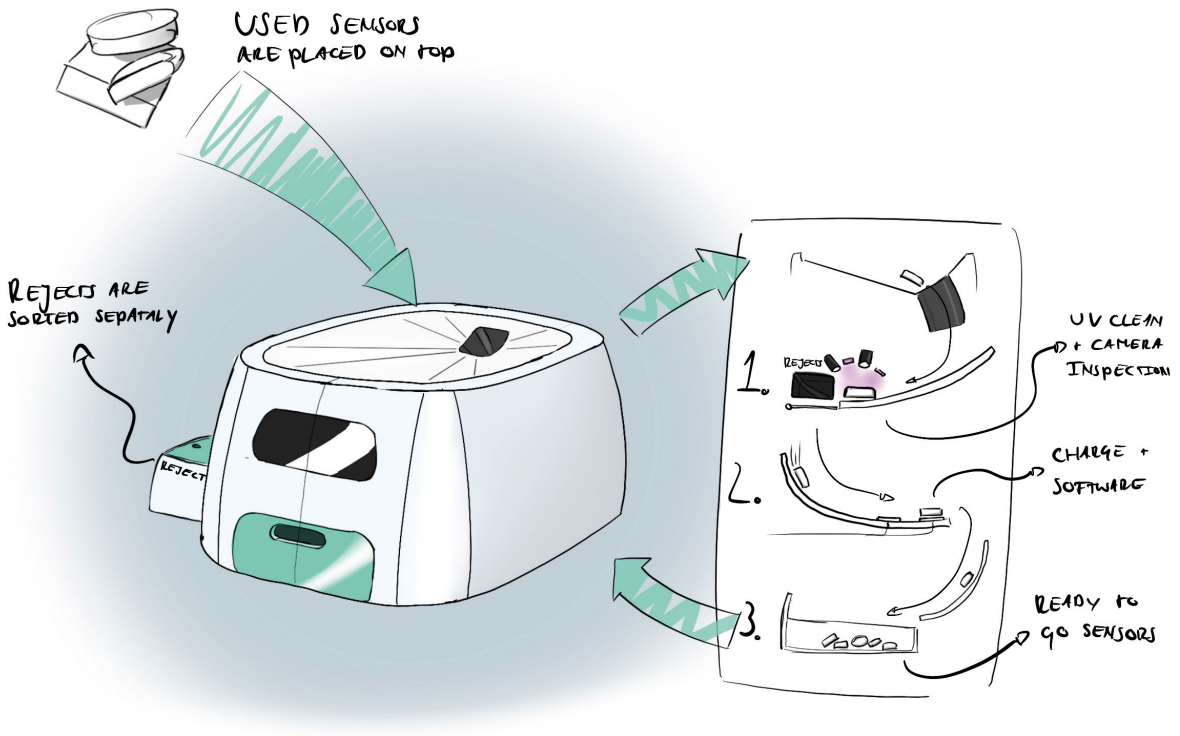
The Smart Scan + Charging Wall consists of two parts, which can be bought and used separately.

The Smart Scan is an automatic scanner for the sensors. A sensor is placed inside, where cameras and software will inspect the sensors to see if it is still safe for use. Using AI, sensors no longer have a maximum amount of uses; instead, they will get a minimum amount. Using AI – which is trained using data from these internet-connected sensors – sensors can be checked to see if they can last additional uses, further reducing the number of new sensors needed and thus reducing emissions even further.

The Charging Wall consists of a bunch of magnetic wireless charges, similar to the UV Cabinet, which then charge the controlled sensors. Lights indicate the charge status of the sensors.

Use

When a sensor returns, the nurse places it in the smart scan. The machine inspects the sensor for damages and uses AI to asses if the sensor can handle another use. If the answer is no, the sensor is blocked and then the nurse sorts it with other rejects. If the answer is yes, the device is placed on the charging wall where it is wirelessly charged for another use.

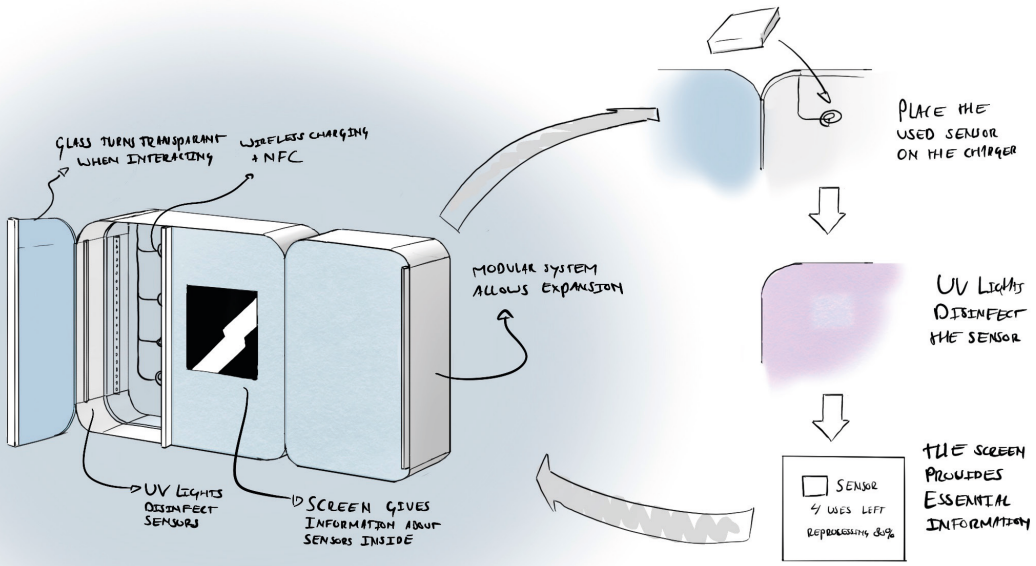


J.3 AutoPro

The AutoPro (Automatic + reprocessing) takes this to the next level. Used sensors are placed in the hopper on top, after which they are fed one by one into the machine. Here they are checked with a similar AI model as the Smart Scan, and UV disinfected. Sensors that make the check move on to the charging bay, were they are charged internally in the machine. Sensors that don't make the check are rejected and placed in a separate container.

Use

When a sensor returns, all the nurse has to do is place it on top of the AutoPro, which takes care of the rest. Sensors that are charged and ready to go are placed in a collection box in the machine, while rejected devices are sorted separately.

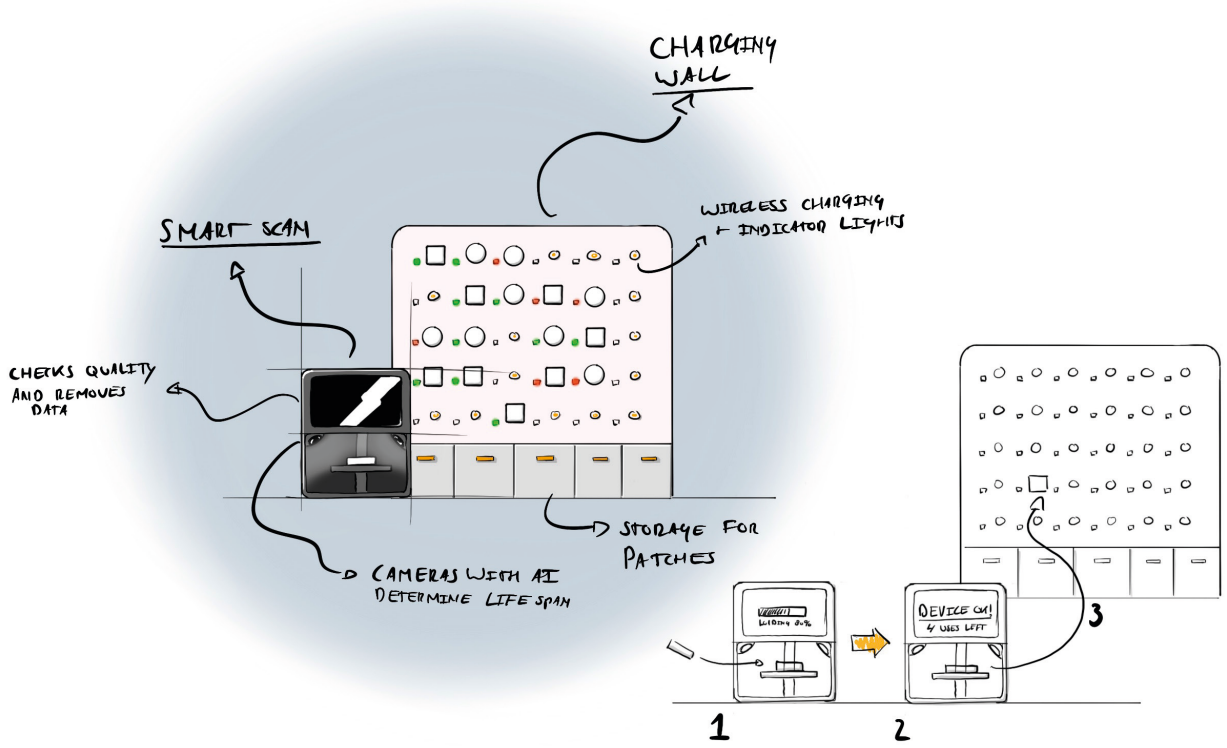


J.4 UV Cabinet

The UV-cabinet is an all-in-one solution. The MWS can be placed inside the cabinet on a magnetic charging plate, where they are charged, personal data is removed and software is updated. The cabinet emits UV light which disinfects the sensors during their charge. A touch screen on the front allows the staff to see the status of the sensors inside without opening the cabinet. When a cabinet is opened, the UV light automatically turns off to avoid injury to the staff.

Use

When a sensor returns, the nurse wipes the sensor clean and places it on a charging spot. The cabinet detects the sensor and removes personal data. A wireless charger recharges the sensor. A screen on the cabinet shows the status of each sensor placed inside.



K • Datum Method Concepts

	Criteria	Reference	Datum 1 Battery	Datum 1 UV Cab	Datum 1 Smart Scan	Datum 1 AutoPro	Datum 2 Battery	Datum 2 UV Cab	Datum 2 Smart Scan	Datum 2 AutoPro
1	The solution should create as little CO2 impact as possible	Chapter 2	3	2	1	1	4	3	2	1
2	The solution should create as little e-waste as possible	Chapter 2	3	2	2	2	3	3	2	2
3	The solution should work as an example for other MWS	Chapter 2	3	5	4	4	2	3	3	2
4	The device should be as easily reusable as possible	Chapter 6	3	4	4	5	2	3	2	5
5	Machines that the hospital has to purchase should be as cheap as possible	Chapter 11	3	2	1	1	4	3	2	1
6	The solution should be as maintainence-free as possible	Chapter 11	3	3	3	1	4	3	2	1
7	The solution should be as simple as possible	Chapter 11	3	4	4	5	2	3	4	5
8	The device should minimize cycle times	Chapter 6	3	2	2	1	4	3	3	2
9	The device has to be checked for its quality as quickly as possible	Chapter 11	3	3	4	4	3	3	2	4
10	The solution should instil the maximum amount of trust in the hospital staff	Chapter 11	3	4	5	4	2	3	4	3
11	The solution should take up as little space as possible	Chapter 11	3	3	3	3	3	3	3	3
12	The solution should be as time efficient as possible	Chapter 11	3	4	3	5	4	3	2	5
13	The solution should have a minimal chance of failing	Chapter 11	3	4	2	1	2	3	2	1
14	The solution should resist tampering from the patient	Chapter 11	3	4	4	4	1	3	3	3
15	The solution gives the maximum form-freedom to the OeM's design team	Chapter 11	3	5	4	3	1	3	2	1
			100%	113%	102%	98%	91%	100%	84%	87%

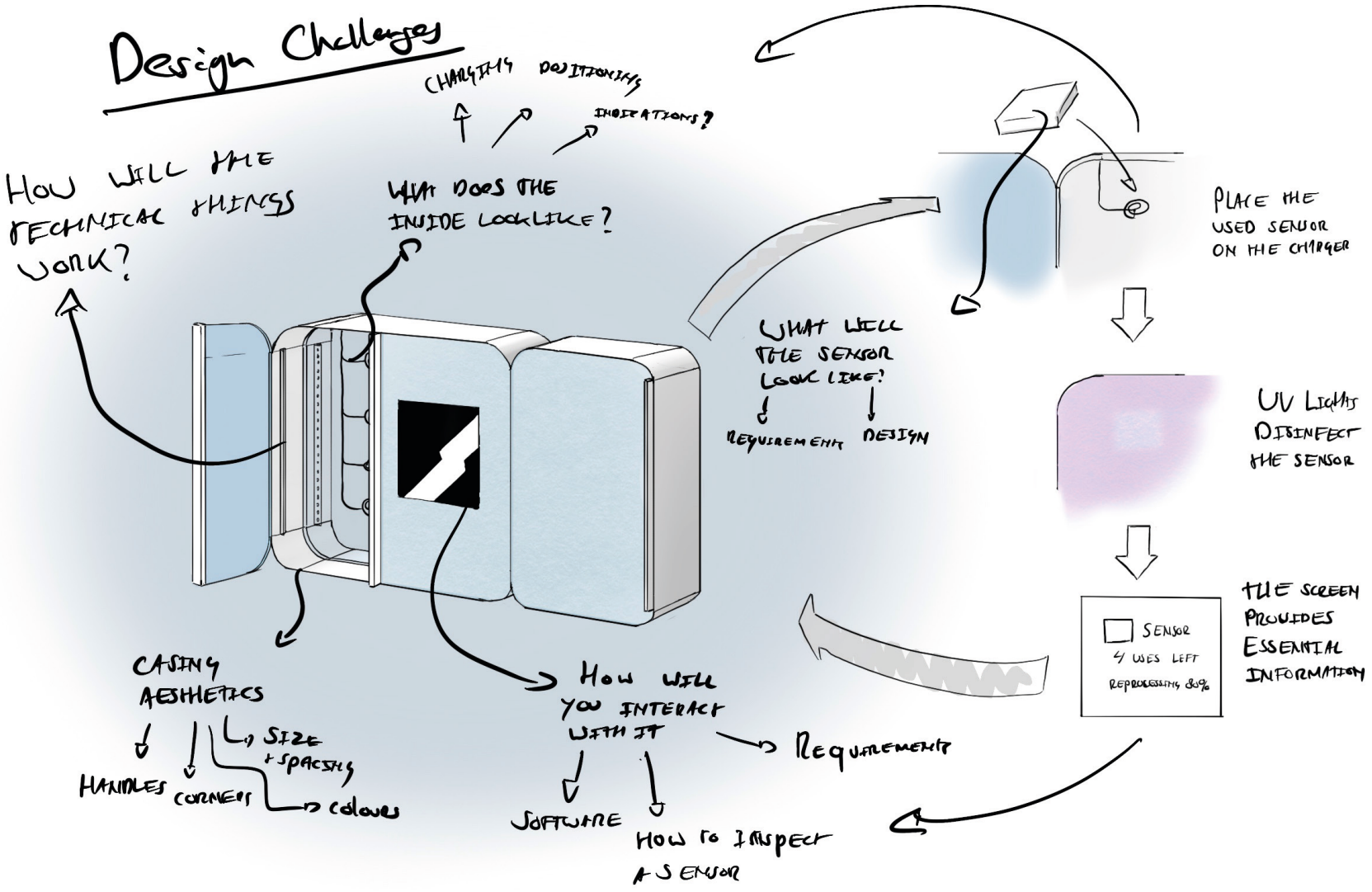
Datum 1 - Weighted

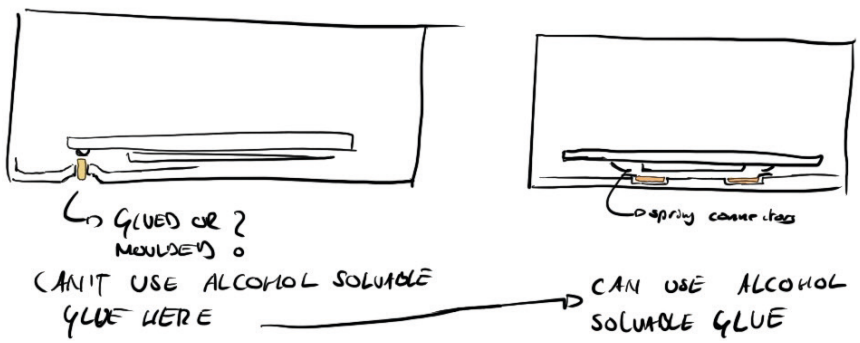
Weight	Battery	UV Cab	Smart Scan	AutoPro
2	3	2	1	1
2	3	2	2	2
2	3	5	4	4
2	3	4	4	5
2	3	2	1	1
1	3	3	3	1
1	3	4	4	5
1	3	2	2	1
1	3	3	4	4
1	3	4	5	4
1	3	3	3	3
1	3	4	3	5
1	3	4	2	1
1	3	4	4	4
1	3	5	4	3
	100%	110%	97%	95%

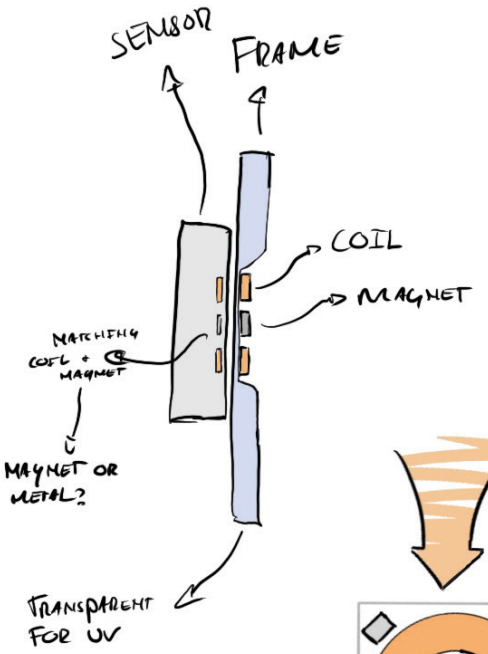
Datum 2 - Weighted

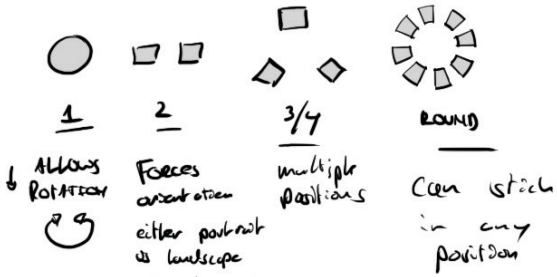
Weight	Battery	UV Cab	Smart Scan	AutoPro
2	4	3	2	1
2	3	3	2	2
2	2	3	3	2
2	2	3	2	5
2	4	3	2	1
1	4	3	2	1
1	2	3	4	5
1	4	3	3	2
1	3	3	2	4
1	2	3	4	3
1	3	3	3	3
1	4	3	2	5
1	2	3	2	1
1	1	3	3	3
1	1	3	2	1
	93%	100%	82%	83%

L • Final Iteration

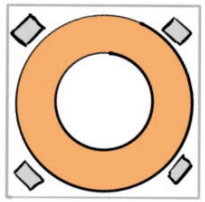


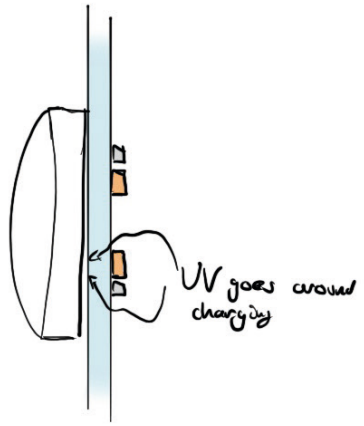






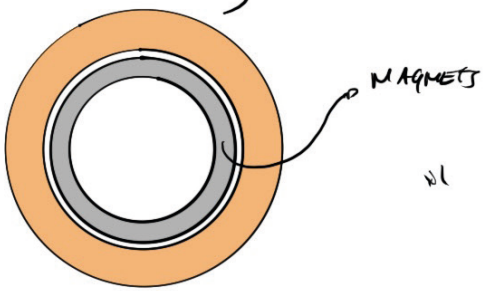
Does orientation matter?

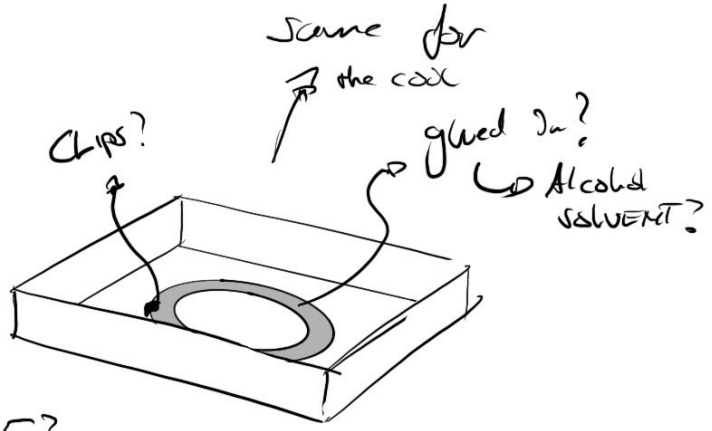


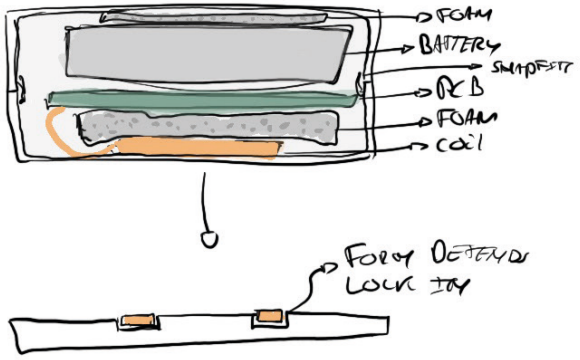


Magnet
- Position
- Side? → only on the cab?

Coils





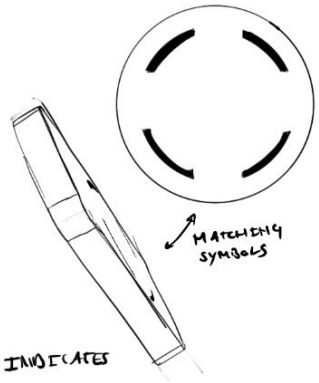


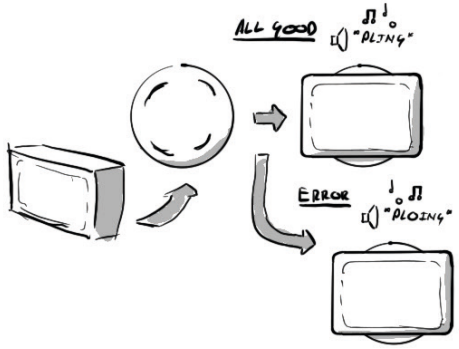
INTERACTION

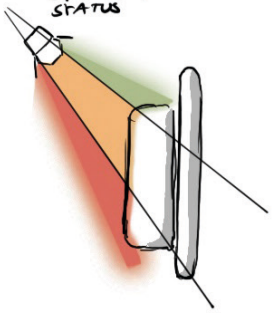
Positioning, knowing sth placed Properly

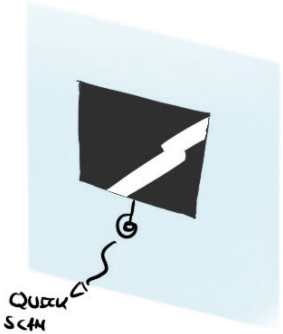
↑

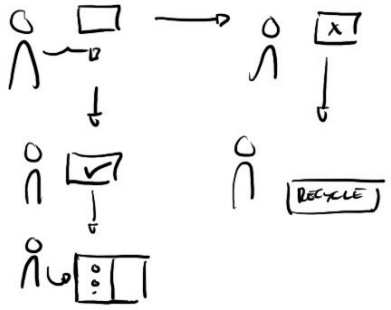
CHARGING



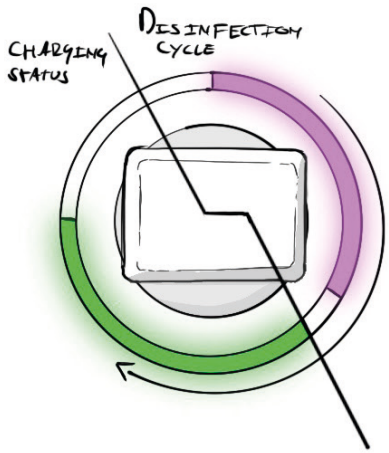


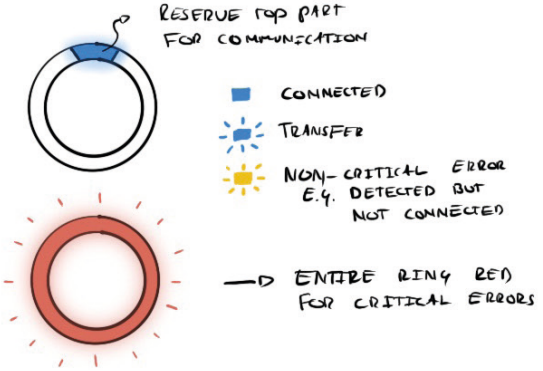


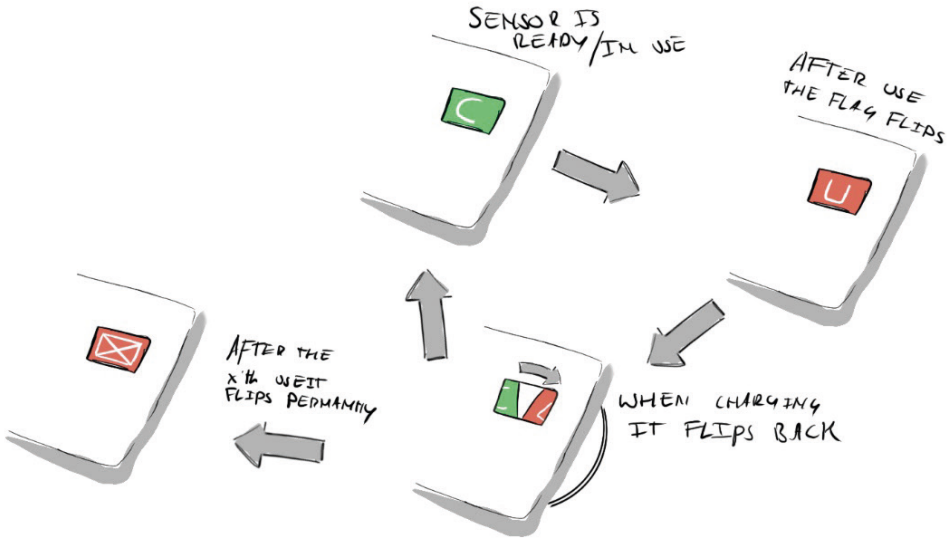




SENSOR STATUS







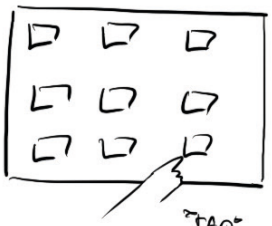
INTERFACE

WHAT DOES IT NEED TO SHOW?

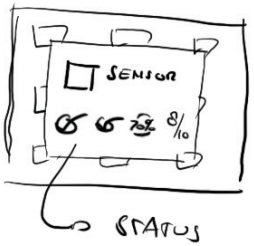
- Connected sensors
  - ERRORS
  - USES LEFT
  - charging status
  - Data status

e-ink vs. LCD?
Do you NEED colour?

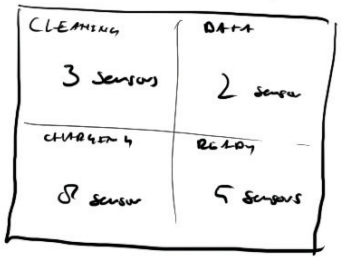
OVERVIEW



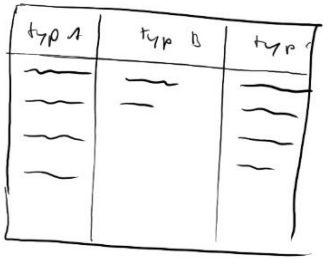
DETAILED VIEW



QUICK ACCESS / STANDBY

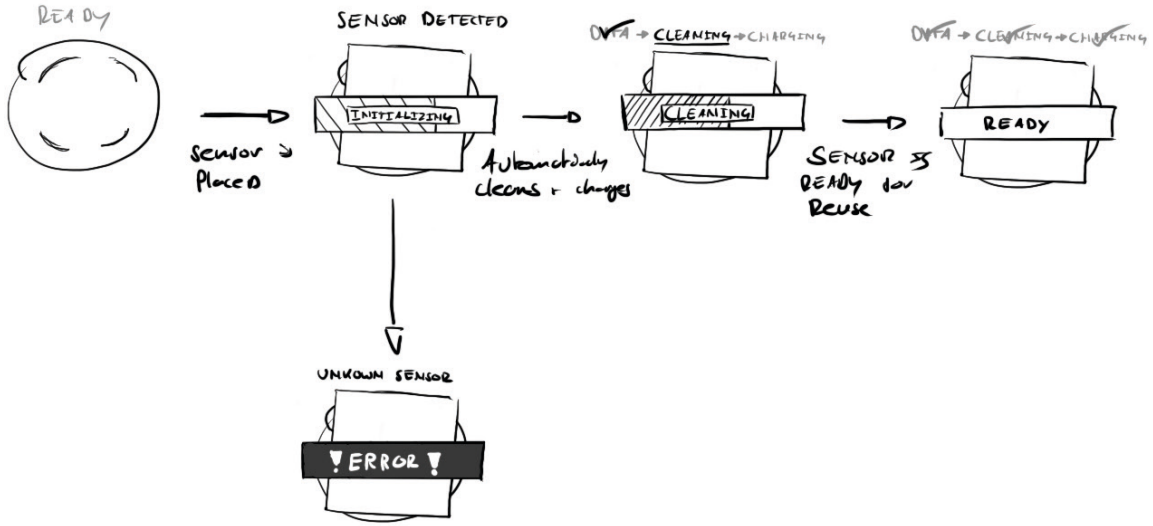


List overview



Colour SCREEN

e-INK INTERFACE



M • Design Brief

DESIGN FOR our future

TU Delft

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT

Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy".
Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name: Bult
initials: _____ given name: Matthijs
student number: _____
street & no.: _____
zipcode & city: _____
country: _____
phone: _____
email: _____

Your master programme (only select the options that apply to you):

IDE master(s): ★ IPD ☐ DfI ☐ SPD
2nd non-IDE master: _____
individual programme: - - (give date of approval)
honours programme: ☐ Honours Programme Master
specialisation / annotation: ☐ Medisign
☐ Tech. in Sustainable Design
☐ Entrepeneurship

SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair: Ruud van Heur — dept. / section: HCD
** mentor: Tamara Hoveling — dept. / section: SDE
2nd mentor: _____
organisation: _____
city: _____ country: _____

comments (optional)

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

APPROVAL PROJECT BRIEF

To be filled in by the chair of the supervisory team.

chair _____ date 23 - 02 - 2023 signature _____

CHECK STUDY PROGRESS

To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair.
The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: _____ EC

Of which, taking the conditional requirements into account, can be part of the exam programme _____ EC

List of electives obtained before the third semester without approval of the BoE

YES all 1st year master courses passed

NO missing 1st year master courses are:

name _____ date - - signature _____

FORMAL APPROVAL GRADUATION PROJECT

To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **.
Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: APPROVED NOT APPROVED

Procedure: APPROVED NOT APPROVED

comments

name _____ date - - signature _____

Initials & Name Bult Student number _____

Title of Project Developing circular solutions for small medical electronic patches

Developing circular solutions for small medical electronic patches — project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 24 - 01 - 2023 — 14 - 07 - 2023 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

Currently, there is a major need to work towards a greener and more sustainable future. This also applies to the healthcare sector, however they are still lagging behind. In 2019 they were responsible for 4,4% of global net emissions [1], and in the Netherlands the healthcare was responsible for 7% of the Dutch national net emissions [2].

This is why we need initiatives such as the DiCE program. The Digital health in Circular Economy is an EU wide program that aims to create more sustainable digital health solutions. In this program, the TU Delft and Philips are collaborating to develop a sustainable version of the Philips Healthdot.

The Philips Healthdot is a medical patch that is placed on the lower rib and collects vital signs from the patient, both inside and outside the care facility [3]. The device uploads the data and transmits this straight to the hospital. After two weeks, the device is disposed of. According to Philips, the average hospital places one Healthdot per day.

Disposing of the Healthdot is not a good practice. Although small, it contains electronics, a battery and plastics, which are currently not recycled. It is right of Philips to want to make this consumable more sustainable. That is why this graduation project is focused on developing a sustainable concept of the Philips Healthdot and to create a set of design guidelines to help improve the sustainability of similar medical electronics.

Both Philips and other competitors offer similar products to the Healthdot (figure 1). Because the Healthdot is not unique, developing a sustainable concept and guidelines is crucial as it can drive sustainability for similar devices as well.

Stakeholders
A circular solution for the Healthdot has a complex web of stakeholders. In the current situation, the Healthdot is sold to the Hospital that places the device on the patient. The patient then wears it for up to 14 days. In cases where the patient leaves the hospital with the device, the patient also disposes of it. It's a linear economy with three main stakeholders: Philips, the hospital and the patient.

In a circular solution, the activities that have to be done will most likely change. For example, the Healthdot might be collected, cleaned, possibly repaired or prepared for its next use. If it is re-used, it has to be re-distributed to or in the hospital. The big question that comes up is: who is going to do what? Is the hospital going to take care of collection and cleaning? Or is Philips going to be responsible for this? Or is Philips only going to do the preparing and is the hospital going to be responsible for the collection? Is there a third party that is going to be involved somehow? Answering this question will be a major part of the research done in this graduation.

For the recollection of the Healthdot from the patient's home, a cooperation with Games for Health is in place. Games for Health is part of the DiCE project and will work on the recollection method for the patient. I plan to collaborate with Games for Health on this matter.

[1] Health Care Without Harm & Arup, (2019). "Health care's climate footprint" from [https://www.arup.com/perspectives/publications/research/section/healthcares-climate-footprint]

space available for images / figures on next page

introduction (continued): space for images

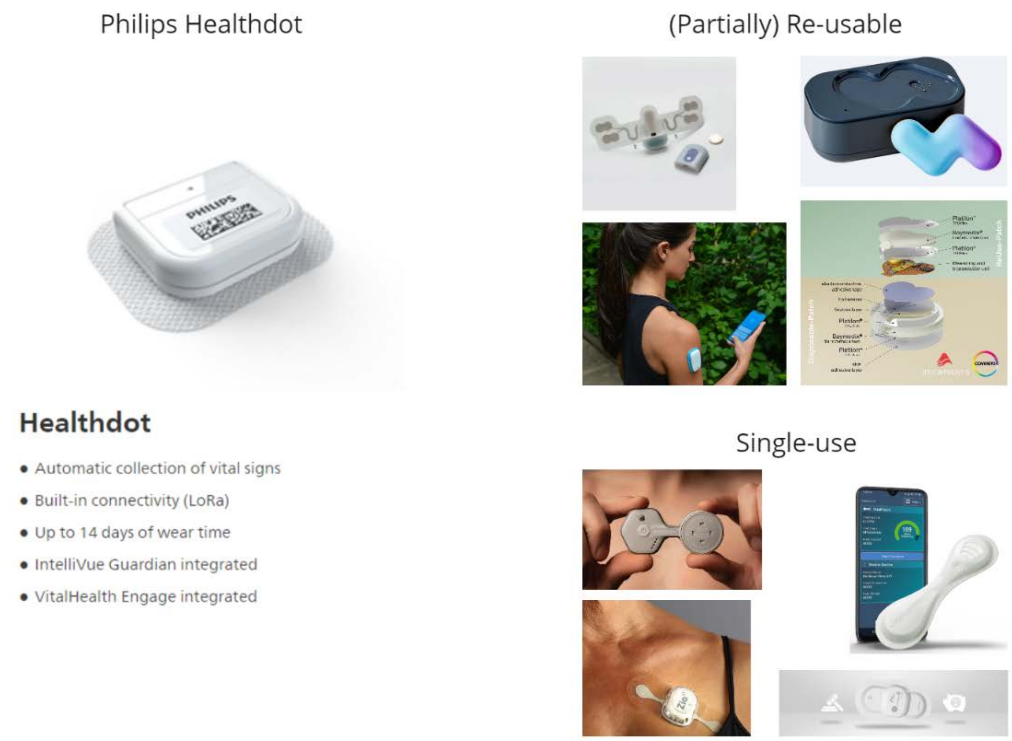


image / figure 1: Philips Healthdot (left) and Comparable alternatives categorised on single-use/re-usable (right)

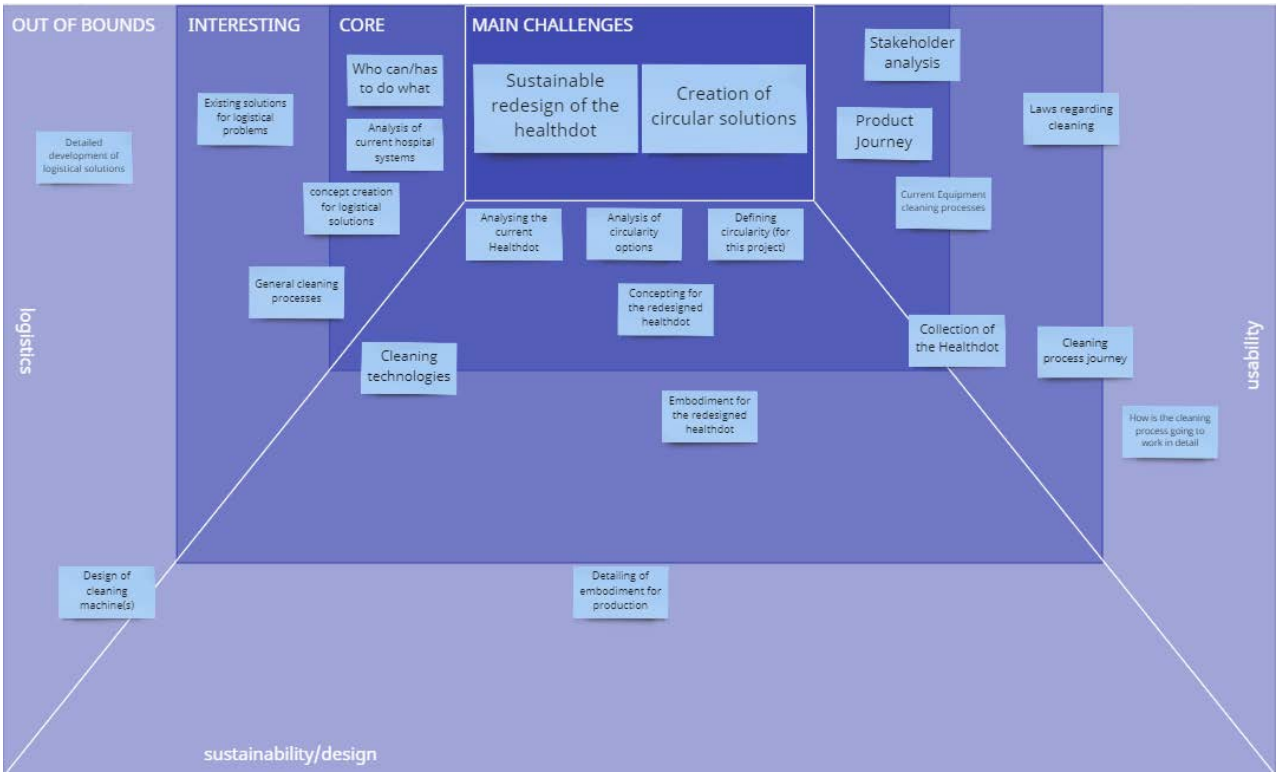


image / figure 2: Project scope

Initials & Name _____ Student number _____

Title of Project _____

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

Currently, the Healthdot is non-reusable. While some similar devices exist that are (partially) reusable, see figure 1, no circular alternatives have been found. Furthermore, most of these alternatives seem to be consumer or prosumer devices or are focused on use on one patient and not for mass use in a hospital. Their disposable parts often contain electronics and other harmful materials.

The main focus of this project is to create a solutions space, for example a framework or guidelines, to aid sustainable and/or circular redesigns of products like the Healthdot and their supporting systems in order to reduce the ecological impact of modern day medical products. The core of the project, see figure 2, contains the creation of solutions based on a case study of the Healthdot. In scope is, among others, generation concepts for new product/logistical flows, analysing the current situation and future alternatives. Out of scope is, among others, detailing of cleaning processes (if any) and detailed embodiment of designs.

It is expected that creation of new systems and logistic flows will be an important part of the project. However, it is in my master's and personal interest to focus more on the embodiment of products, which is why the design of solutions will be prioritized and the development of the logistical system will be kept to a more conceptual level.

[2] Grupta Strategist (2019). "Een stuur voor de transitie naar duurzame gezondheidszorg" from [https://gupta-strategists.nl/storage/files/1920_Studie_Duurzame_Gezondheidszorg_DIGITAL_DEF.pdf]

[3] "Healthdot Wearable Biosensor" (n.d.). Philips. https://www.philips.nl/healthcare/product/00884838103719/philips-healthdot-wearable-biosensor

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

This project aims to develop circular solutions for small medical electronic patches, like the healthdot, in the form of a framework or guidelines by doing case studies.

The goal is to create a solution space which can aid future development of circular small medical electronic patches. The solution space could have the form of a framework, guidelines or a set of solutions which can be adapted and implemented. This is to be determined during the project.

This will be done by first analysing the current Healthdot situation to set a benchmark. A literature study finding relevant information and existing solutions will be done as well. In the next phase it is expected that a case study will be done to determine the solution-space and its contents. The case study might be to improve the Healthdot's circularity. Multiple concepts for circular solutions can be compared, for example a situation where the product is re-used with a logistics system versus a biodegradable product. These concepts will include eco-impact, but will also include the changes in operation required for both producers like Philips and users like Hospitals and doctors. The aim is to consult and interview field experts on proposed solutions and their viability, feasibility and desirability to aid in the concept selection.

Based on the outcome of this case study the solution-space will be created. Finally, the goal is to evaluate the usefulness of the solution-space by doing a second case study in a design sprint form. This could be a one week design sprint where a similar, but different product will be taken as the subject, possibly including stakeholders as well.

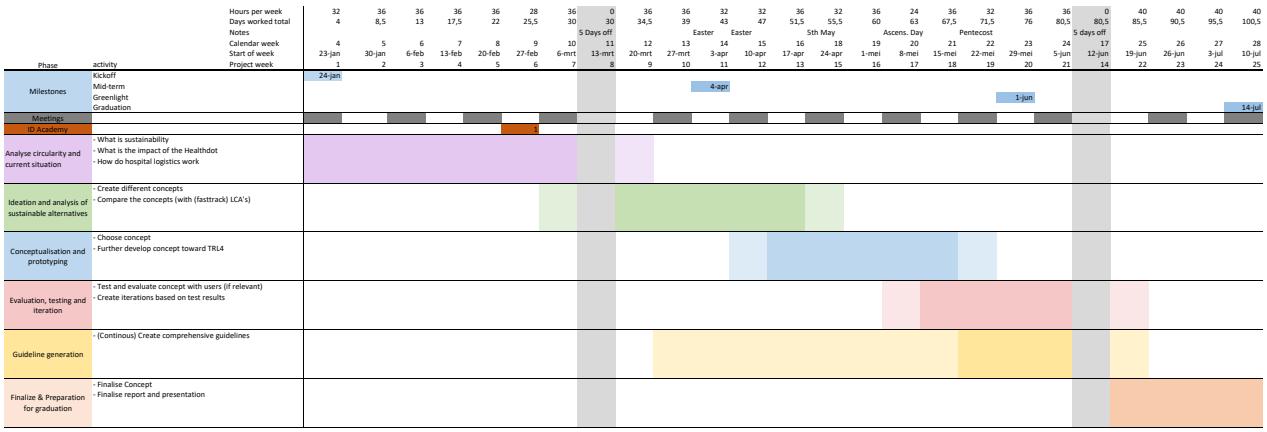
Initials & Name _____ Student number _____

Title of Project _____

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 24 - 1 - 2023 14 - 7 - 2023 end date



Expected Milestones:
Kickoff: 24th January
Midterm: 4th April
Greenlight: 1th June
Presentation & Graduation: 14th July

The project kick off is on the 24th of January. The plan is to work 36h at first to provide space for personal reasons, the last 4 weeks will be 40h a week, and I have scheduled 10 days of holidays to relax. Additionally, all official TU Delft holidays (e.g. Liberation day and others) are scheduled as non-working days. As I have yet to finish the ID Academy course, one day is scheduled for completion of the course. The greenlight meeting is pushed forward as that better suited the supervisory team. All-in-all, the projected graduation date is the 14th of July.

The project can be roughly divided in four phases. The first phase is focused around gaining knowledge of the circular economy and the current situation. Analysis of the Healthdot's impact will be made, and knowledge about how hospitals and large companies operate will be gained. In the second phase the case study will be done, where guidelines and solutions will be created that will be compared. This phase is all about solution creation and validating these ideas with experts. The third phase is focused on reflecting on and refining the solutions. The fourth and final phase is focused around validation with a second case study in the form a design sprint, if time permits.

Initials & Name _____ Student number _____

Title of Project _____

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

With the current state of the world rapidly declining and seeing how much we consume on a daily basis, I want to use my design skills to make a difference. It is my personal ambition to leave the world in a better way then that I found it. I don't want to add to the pile of waste with the next best plastic thing, I want to design for a change.

The past few years I've realised that sustainable design is not a given. It is a very complex topic that I want to know more about and get better at. This is why I was excited to connect with Conny Bakker and Tamara Hoveling about doing the Philips Healthdot case as a graduation project. This project allows me to create a product with a reduced, hopefully zero, impact in a field where there is massive amounts of waste: the medical industry. With my work I hope to inspire other designers to design more sustainable products in the medical industry, and with the guidelines I want to give them some tools to get started with.

Like I mentioned before, a major reason for me to take on this graduation project is because I want to learn more about sustainability and improve my sustainable design skills. During my studies and experiences I've had so far I realised that sustainability is not a given yet, but its changing for the better. I expect sustainable designing to be a very important skill in the future. This graduation project is probably my last chance to gain knowledge on sustainable design at an academic level, which is why improving my sustainable design skills is the core learning goal for this project.

Combined with other motivations not mentioned here, these are the four learning goals of this project:

1. Sustainable knowledge and design - I want to improve my knowledge of sustainable design and improve at its implementation for the reasons mentioned above.
2. Concepting skills - I want to improve the creativity and quality of my ideation, using methods as a basis.
3. Visualisation skills - I want to improve the quality of my visualisations, both in ideation sketching, concept renders or communication.
4. Prototyping skills - I want to improve the amount and relevance of prototypes in all phases of the project, and use different methods of prototyping and fabrication if possible.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

Initials & Name _____ Student number _____

Title of Project _____