Reuse of intubation devices as a catalyser for systemic change

Towards Circular ICUs

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Integrated Product Design | Delft University of Technology

Master thesis
Towards Circular ICUs. Reuse of intubation devices as catalyser for systemic change.

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Climate change is a major crisis for healthcare. Chronic and infectious diseases increase as air quality declines and temperatures shift to extremes. All this increases the pressure on health services. Current healthcare saves lives by making extensive use of energy and material resources, injuring an environment we are entangled in, thus jeopardising other lives and adding to climate change.

We can envision healthcare that heals without generating waste, provides care keeping all resources in use, and nurtures human lives and the whole ecosystem we are part of. Transitioning to a circular economy could lead us to such a future by designing waste and pollution, keeping products and materials in use, and regenerating natural systems.

How can Erasmus Medical Center (EMC) initiate its path towards circularity? Can we create a solution for the 50.000kg of waste they generate every year? Finding a solution to a problem of such scale is out of this master's graduation scope.

The following report aims to provide a better understanding of which entangled circumstances have led current unsustainable behaviours to be ingrained in hospitals and propose two pilot projects for Erasmus MC ICU to gain resilience by avoiding disposable and practicing safe reuse of medical supplies instead.

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Executive summary

This project aims to reduce the environmental impact of the ICU, the department which provides constant care to critical patients. One of the most common and wasteful ICU procedures is intubation. Intubation is needed when patients cannot breathe by themselves. Can we design a circular intubation procedure as a catalyzer for systemic change towards circular ICUs? This project aims to design a pilot system to initiate the transition towards circular intubations.

Research was done to understand better the current waste created by the ICU. Literature review, interviews and observation were performed to gather information about:

- Healthcare context
- EMC procurement
- ICU intubation procedures
- Devices used for intubation

A set of challenges derived from the research were used to ideate on different systems which could improve the ICU sustainability. It was decided to further detail a system that allows reuse (reprocessing) of intubation devices, articulating the first pilot around a specific product, the video laryngoscope. This video laryngoscope is used to intubate patients. It is composed of various plastics and electronics, and has a relatively high procurement cost.. Nevertheless, it is a single-use device, disposed of and incinerated after a few minutes of use.

Ideation on a system enabling a safe and hassle-free reuse of the video laryngoscope at the ICU with a lower environmental impact was done. The ideation and pilot were done at three levels: Product, Reprocessing and procedures.

Two pilot systems were proposed:

Product

The first proposal, **reduce**, enables Erasmus MC to reuse the current video laryngoscope in use at the ICU. Adding a removeable polyethylene plastic cover to the device enables reuse of the device. By not binging the device in direct contact with the patient, fewer reprocessing steps will be required since fewer microorganisms will get in contact with the video laryngoscope.
The second proposal, **reuse**, offers the complete reuse of a modular video laryngoscope. The main body would be, likewise the first proposal, reprocessed after not having been in contact with the patient. A polycarbonate hardcover would surround the product and would redesign to allow reuse and traceability of the number of reprocessing cycles it has gone through.

Procedure

Reprocessing in both proposals could be done at the ICU. Not relying on the sterilization department allows the ICU to be resilient and to increase devices availability.

Reprocessing

The use of a novel reprocessing technique, UV-C radiations, is proposed. Compared to current reprocessing techniques, it consumes less water, electricity, and space. In addition, UV-C reprocessing allows a high level of automation of the process, increasing its safety and reducing the hassle for ICU workers.

Outcomes

A better understanding of the healthcare complexity and impact has been achieved. A pilot system is proposed, with which CO2 emissions, amount of waste and costs for the hospital would be reduced compared to the current single-use system. Future scale-up of the reuse system to other devices is envisioned, as well as replicating it into other Erasmus MC departments. Next to this pilot focusing on reuse, a set of complementary opportunities areas to introduce circularity to the ICU are summarized in a booklet.

Abbreviations

CE	Circular Economy
EMC	Erasmus Medical Center
EOL	End of life
ICU	Intensive Care Unit
PPE	Personal Protective Equipment
TCO	Total Cost of Ownership
SD	Sterilization department
VL	Video Laryngoscope

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Part 1
Context research

Spotting the sustainable challenges affecting healthcare and ErasmusMC Intensive Care Unit.

Chapter 1
Project Introduction

This chapter elaborates on the lack of circular medical practices in developed countries and the urgency to consider a less wasteful future healthcare system. It introduces the project, involved stakeholders, aim and approach.

1·1 · Future healthcare challenges

The healthcare sector presents the paradox of being responsible for saving lives while simlutaneously contributing to climate change. Climate change iteslf has been referred to as the greatest health threat of the 21st century (Karliner, Slotterback et al. 2020). The need for sustainable health practices is increasingly considered across the sector, resulting in a challenge that implies changes at multiple scales, involving multiple stakeholders in a highly regulated environment.

Double-edged healthcare

The health sector is one of the major contributors to climate change. It is responsible for 4,4% of global net greenhouse gas emissions, as well as toxic air pollutants, jeopardizing its mission of protecting and promoting health (Karliner, Slotterback et al. 2020).

There are numerous reasons for the increasing use of disposable products in the health sector such as contagion risks prevention, logistic ease or cost reduction (Sjöberg and Olsson Stjernberg 2020), increasing the sector's carbon-intensive activity, as shown in Figure 1.1

Can we afford to sustain a system that, while saving some lives, might jepordize global health at scale?

The linear use of resources negatively impacts health due to the intense carbon emissions it implies (World Health Organization, 2018). The first world medical sector cannot be linear if we are to consider the importance of global health. A change is needed. Transitioning from a linear to circular economy is necessary to prevent the intensive depletion of finite natural resources and fossil energy reserves, and the associated negative environmental and social impacts.

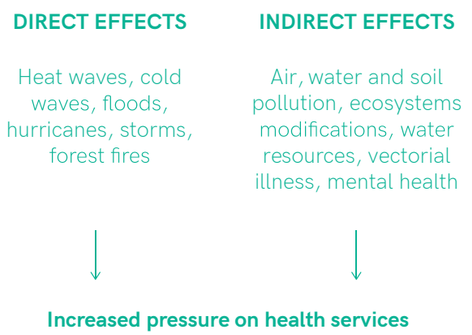


Figure 1.1 Climate change influence on the healthcare system (Shift, 2021)

Need of circular ICUs

The circular economy (CE) is regenerative and restorative by design and is based on the following three principles: designing out waste and pollution, keeping products and materials in use and regenerating natural systems (Ellen MacArthur Foundation, 2021). This would enable hospitals to capture and retain value for longer and thus be less harmful to the environment.

An ICU is a special facility within a hospital that provides intensive medicine, medical specialty dedicated to critically ill patients which require intensive supervision, monitoring and life support. Due to the constant and critical care they provide to patients suffering from severe illnesses and injuries, ICUs produce high amounts of waste.

They make use of large amounts of disposables which are strictly regulated to minimize the risk of potential infectiousness, resulting in a striking waste stream (Browne-Wilkinson et al., 2021).

The EMC ICU produces 50.000kg of waste yearly. From a carbon standpoint, one day at the EMC is equivalent to driving 2000 km or deforesting a 200 square meter area (Rijnmond, 2021).

The waste stream generated by ICU contains of a wide range of products, as illustrated in Figure 1.2: Electronic waste, sophisticated invasive devices, and potentially infected single-use devices (Guzzo, Carvalho et al. 2020). The ICU is one of the areas of the hospitals where a relatively high amount of waste per patient is produced, and where consequently a transition towards a circular economy is highly necessary.

The value hill model (Figure 1.3) outlines R-strategies that can be used to improve the circularity of a product system.

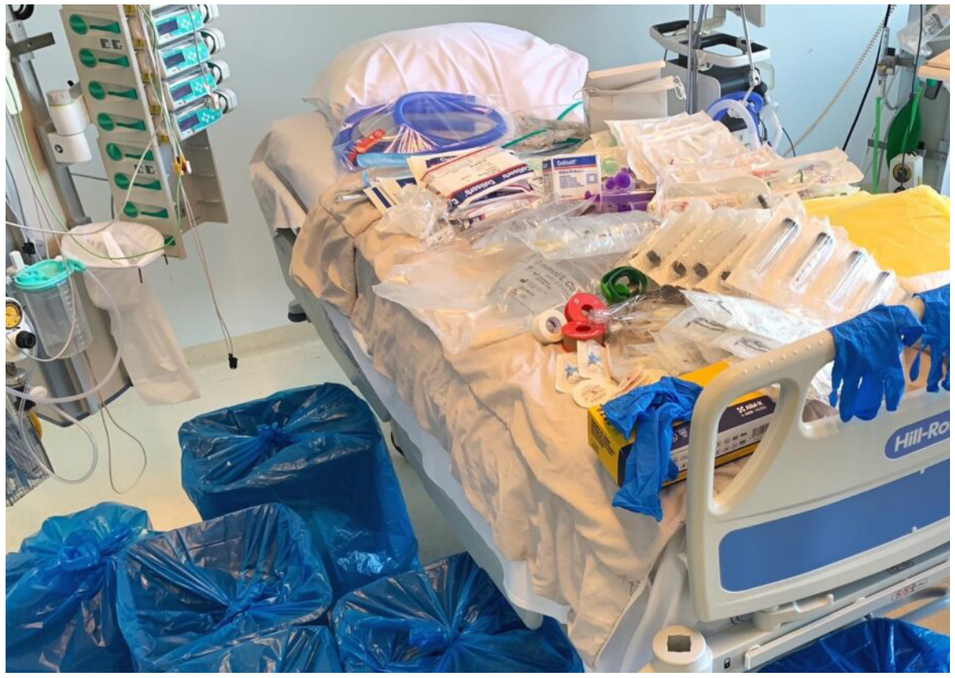


Figure 1.2 Waste generated per patient in one day at Erasmus MC ICU (Erasmus, 2021)

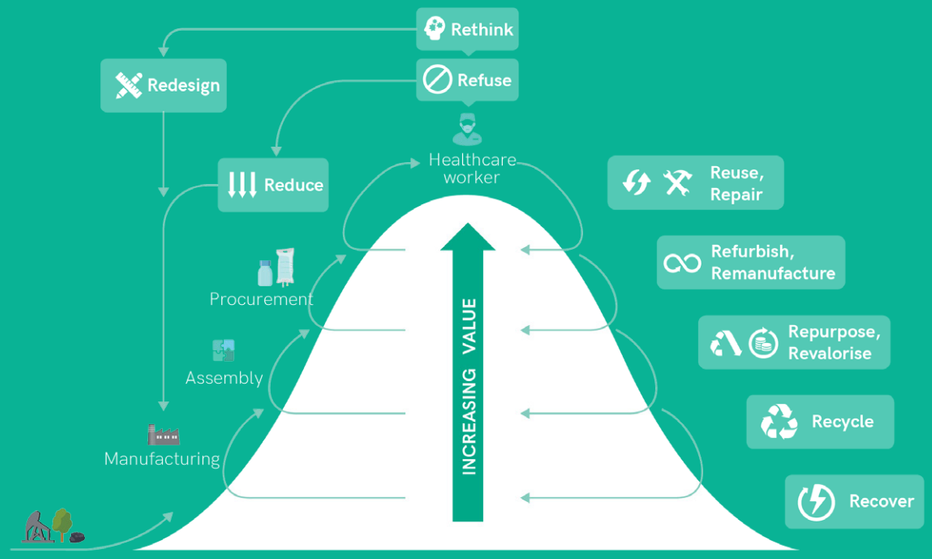


Figure 1.3 Value hill, adapted from Metabolic visuals, 2021.

Higher R Strategies, preserving the value of products in use

- **Refuse:** Abandoning the function of redundant products (EIB, n.d.).
- **Rethink:** Design towards a more inteligently used product (EIB, n.d.).
- **Reduce**: Increase efficiency in product manufacture or use by consuming fewer materials and energy (EIB, n.d.).
- **Reuse:** Use a product again for the same purpose in its original form or with minor enhancement or change (Ellen MacArthur Foundation, 2013). *Healthcare reprocessing: When used, reusable devices are contaminated with microorganisms. Reusable devices undergo "reprocessing," a process to clean and then disinfect or sterilize them (Food and drugs administration, 2018)*
- **Repair:** Ability to bring a product back to working condition after failure in a reasonable amount of time and for a reasonable price (Flipsen et al., 2016).
- **Refurbish**: Restore a used product to an original as-new condition.
- **Remanufacture:** Standardized industrial process in which cores are restored to original as-new condition and performance or better. (International Resource Panel, 2018).

Lower R Strategies, based on reintegrating materials

- **Repurpose**: Use of products or parts that have been discarded in a new product with a different function than the initial one (Browne-Wilkinson et al., 2021).
- **Recycling:** Process of material recovery for use in new, potentially different products.
- **Recover**: Incineration of material with energy recovery.

Tackling complexity

Applying circularity to healthcare is challenging due to stringent regulations and emphasis on patient safety and risk reduction.

The medical environment is highly regulated and thus resistant to sustainable innovations. These regulations lead most hospitals to incinerate nearly all the waste they produce. Patient safety is prioritized, often leaving innovations in other areas such as sustainability to be undervalued. Most stakeholders are fixated on avoiding risks, thus perpetuating and intensifying a linear economy, generating an extremely high amount of waste (Leissner and Ryan-Fogarty 2019).

It also results in a complex challenge involving changes at different scales.

Changes can be done to the disposable products themselves and at an organizational level within hospitals, for example with waste management logistics. Solutions scopes are also broad, and circular solutions could range from energy efficiency to waste management (Shepley, Song et al., 2016). Even focusing only on disposable products used, the complete product lifecycle of these health devices needs to be changed to successfully create a circular healthcare system. The entire healthcare ecosystem, from manufacturers to policymakers, must be considered together.

This led us to a third challenge faced: the lack of dialogue between all stakeholders involved in the healthcare ecosystem.

Current communication and collaboration between healthcare stakeholders are far from fluent. Waste processors refuse waste coming from health care, afraid of a possible risk of infections (Nederland circulair, 2018). Resistance to sustainability is present in hospitals themselves, where most stakeholders consider circular solutions more costly or less safe. Suppliers are reluctant to keep ownership of the disposable they sell, and manufacturers do not consider more sustainable solutions as hospitals tend to ask for lower costs. Hospitals are still sometimes reluctant make economic investments in sustainability. Manufacturers are not engaged in changes, and hospitals continue on their current course.

Stakeholders in isolation cannot achieve disruptive changes in the medical products supply chain (Browne-Wilkinson et al., 2021)

1·2 · Project background

Transitioning towards circular healthcare must involve collaborations between health sector stakeholders, and Erasmus MC aims to be the pioneer next to TUDelft.

The Erasmus University Medical Center (EMC), based in Rotterdam and affiliated with Erasmus University, is one of the largest hospitals in the Netherlands and a research and innovation hub. They define their core tasks as patient care, research, education and valorization (Erasmus MC, 2021). This project is focused on the ICU department of EMC.

EMC ICUs aim to be circular by 2030 Rijnmond 2021

A transition towards circularity starts by first understanding the current impact of linear healthcare. EMC has initiated this transition by assessing the wastefulness of its Intensive Care Unit (ICU). A material flow analysis of EMC ICU quantified more than 50.000 kg of waste yearly (Browne-Wilkinson et al., 2021), mostly incinerated.
Collaboration is needed to achieve systemic circular innovation (Brown et al., 2019). EMC and the Industrial Design Engineering (IDE) Faculty from the Technical University of Delft (TUDelft) have decided to collaborate towards greener ICUs.

A set of three master theses have been initiated in the scope of this collaboration. This report presents the result of one of these projects. It was developed under the mentorship of VanBerlo, a design consultancy with previous valuable practical knowledge both on circular product design and medical design.

1·3 · The project

The project focuses on the intubation to detubation of a patient at Erasmus MC ICU. It aims to understand the current system wastefulness and propose a set of opportunity areas and pilot towards reducing its environmental impact. The project is approached using systemic design.

1.3.1 Scope

Focus on intubation procedure

This project focuses patient intubation and its associated waste. Patients get intubated if they cannot maintain their airway or breathe independently without assistance (Figure 1.4). As it entails a critical condition with constant observation and care, patients are usually placed in the ICU. As a result, intubation is a frequent procedure amongst most hospital ICUs. It is estimated that approximately 50 million intubation procedures are performed each year globally (Guide In Medical, 2015).

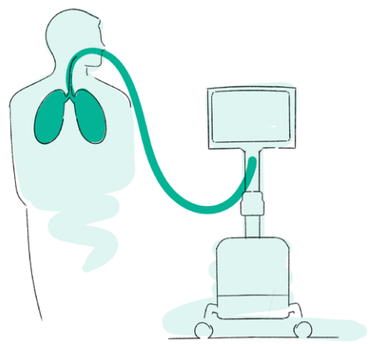


Figure 1.4 Illustration of an intubated patient which lungs are connected to a ventilator, equipment assisting the patient breathing

Around 70% of patients who enter the EMC ICU are intubated during their stay at the hospital (Goomers D., 2021), resulting in 1800 intubations in a year (Stichting Nice, 2020). A third of these intubations will be done at the ICU itself (Appendix C).

An intubation consist in inserting a tube into the patient's trachea to get air into their lungs with an external machine, a ventilator (Figure 1.5). As the patient cannot breathe during the tube insertion, intubations are quick operations of a maximum duration of 2 to 3 minutes, a highly demanding procedure for the doctors performing it.

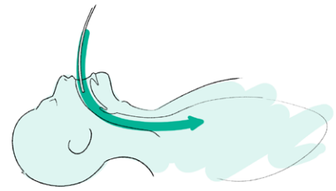


Figure 1.5 Illustration of a patient getting intubated.

Patients stay intubated on average for 3 to 4 days (Stichting Nice, 2020), during which nurses will provide periodic caregiving. Doctors will periodically assess the patient's capacity to breathe back by themselves and eventually remove the tubes placed into the patient's lung.

Research scope

The scope of the research conducted during this project is to investigate the current wastefulness of the system. Specifically, the causes and associated challenges that exist in reducing such waste are considered through observation of practices undertaken at the ICU.

The research will focus on waste generated by devices, and how this relates to the protocol, habits and practices of both procurement and ICU users (doctors and nurses). The medicine administred to the patient throughout an intubation, as well as the water or energy used throughout the process will be considered out of scope.

From such research, ideation on one of the identified challenges has been, and a system solution is proposed for the specific EMC ICU scenario. Next to this tangible solution - articulated as an action plan - a booklet was made presenting other opportunities areas for circular practices discovered throughout the research.

1.3.2 Aim

Aim

Can we make the intubation to extubation process more circular? The aim of this project is to clarify why and how intubations are wasteful processes. From here, a range of opportunity areas detail high-level strategies that could lead towards more circular ICUs. Finally, a pilot proposal is designed for a circular intubation-detubation process, to demonstrate concretely what first steps might look like, and to inituate the transition towards circularity in the ICU.

Overall questions

Throughout this report, answer to the following question will be given at the end of the indicated chapters:

Chapter 2 — **Q1**

What are the main **challenges** that the current healthcare and intubation to detubation system presents from a sustainability perspective?

Chapter 3 — **Q2**

Which are the different **design opportunities** that could be explored at the Erasmus MC ICU?

Chapter 5 — **Q3**

What are the first **action points** and potential redesign that could be implemented at the ICU in upcoming years?

Chapter 6 — **Q4**

Based on the project research and outcomes, what other **recommendations** could be given to Erasmus MC in their journey towards more sustainable healthcare?

The answer to these questions will be presented in a booklet as a summary of the main outcomes of this project.

Relevance

This project aims to provide methods and approaches that could used in other systems present at the ICU or hospital more broadly. Thus, a focus is placed on scalability and transferability to different medical contexts.

Design goal

Design of a pilot system which initiates the ICU transition towards fully circular intubations to detubation system.

1.3.3 Method

Systemic design

This project was approached from a systemic design perspective as the system within which a product is manufactured, used and disposed of (Browne-Wilkinson et al., 2021) needs to be taken into account to create impactful change. Design thinking, and more precisely systemic design, aims to offer tools to tackle system complexity.

First, a research around the system context was done. Methods used were:

- Literature review on the healthcare holistic context
- Observation and interviews on the ICU practices

The key takeaways of this research are summarised in a system map. This approach visually clarifies the system complexity, and can be used as a tool to hotspot the challenges the ICU faces from a sustainable perspective.

From the detected challenges, a set of proposed system directions were generated, one of which was chosen and taken forward.

From system to product design

Next to the selection of a system direction, a specific product used throughout patients intubation was chosen. Ideation around the specific product and system was then done.

The scope of was ultimately reduced to a single product. This approach aims to first generate systemic insights, apply them at the product level through an investigative design process, and then generate product-level insights that can then further be scaled up at a system level. This iteration from product to system level are visualized Figure 1.6 and steps followed in Figure 1.7.

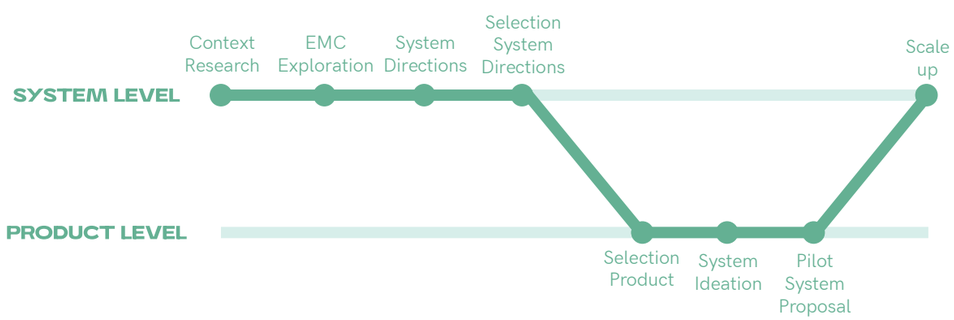


Figure 1.6: Design method product system levels overview

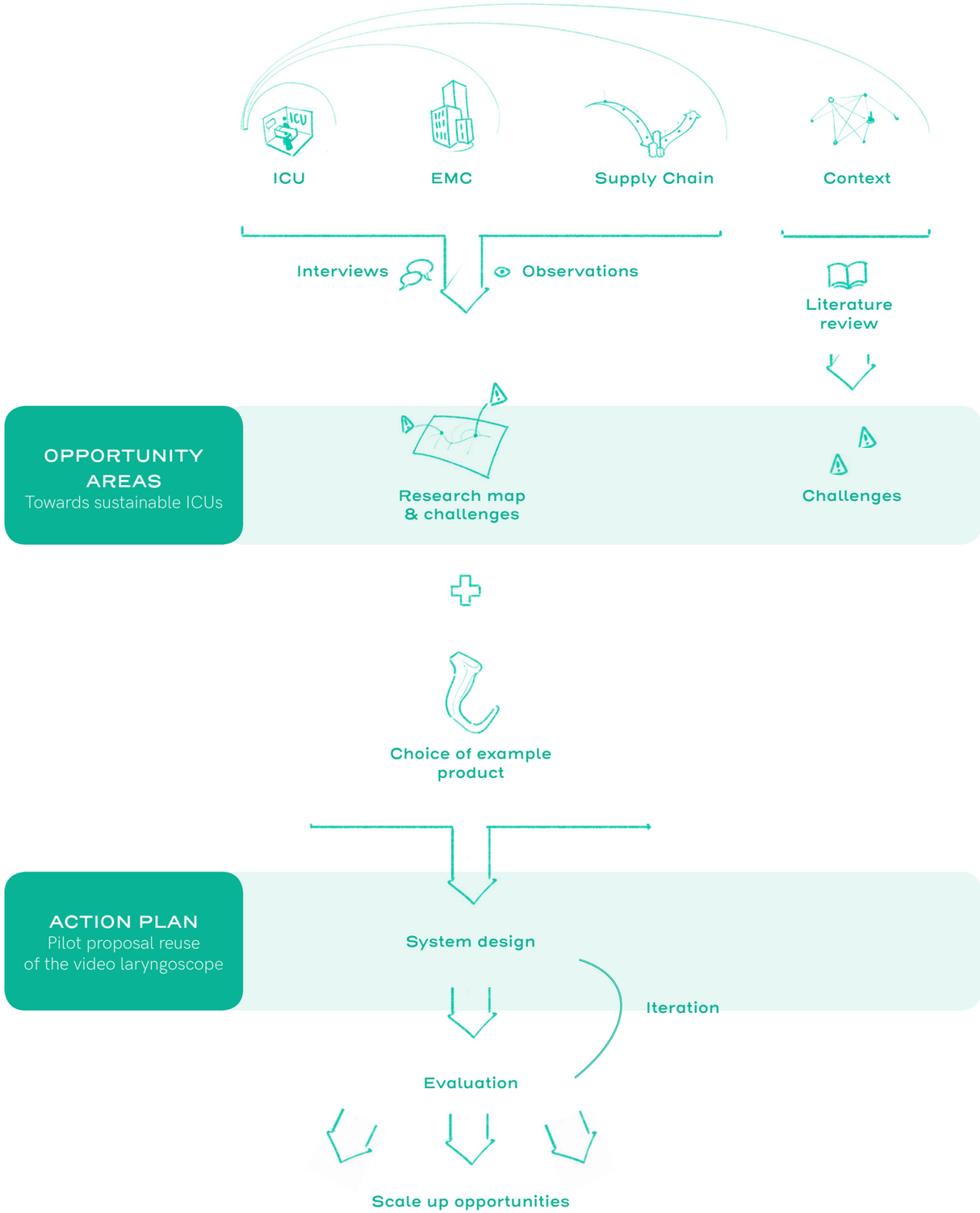


Figure 1.7: Project design steps overview

Chapter 2
Literature review

Healthcare practices, context and regulation. A literature review

This chapter aims to answer the following question: What are the main challenges that the current system of intubation to detubation presents from a sustainability perspective? Outcomes from the literature research will be presented and key takeaways concluded.

2.1 · Research approach

First, a literature review was undertaken. Base literature concerning the current wastefulness stage of ICUs was provided by both the client and the mentoring team of this graduation project.
At the same time, databases such as the TUDelft repository (TUDelft, 2022) and Elsevier Journals (Science Direct, 2017) were consulted to gather the information that was still needed to answer the research questions mentioned previously.

To be able to answer the main overarching question, a set of four research questions were identified before conducting literature review:

RQ1
What are the laws, regulations and policies guiding procurement and waste management in EU hospitals?

RQ2
Which current practices make ICUs a non-circular environment and their consequent impact?

RQ3
Are there already some pilot projects showing potential areas where circular strategies could be applied in ICUs and hospitals?

RQ4
What are the effects of climate change and COVID on healthcare systems?

2.2 · Literature review

Regulations & their consequences on hospital procedures

The medical environment is highly regulated to ensure that all patients receive safe and high-quality care (AHA, 2017). The European Union also intends to unify European countries' caregiving through policies like the (EU) 2017/745 regulation. These policies target medical devices development regulation and define the European obligations of each stakeholder, reprocessing, product traceability, safety and clinical performance, confidentiality etc.

On top of these European regulations, national ones must be considered as well (EUR-Lex, 2017). In the Netherlands, the Royal Netherlands Standardization Institute Foundation adds another layer on top of European regulations. The NEN-EN-ISO 13485:2016 specifies quality management requirements for an organization involved in one or more steps of the life cycle of a medical device, including design and development, production, storage and distribution, installation, service, final decommissioning, disposal, etc.

Manufacturers define guidelines for each device based on the regulations mentioned above. In their turn, hospitals must follow product use guidelines stated by manufacturers. **Therefore, applying R-strategies at a hospital depends on a particular device and can vary based on a manufacturer of that device.**

Waste Framework Directive and hospital waste management

The European Waste Framework Directive applies to hospitals' waste management. McGain et al. estimate that almost 60% of intensive care unit general waste could be recycled, specifically plastic, cardboard and paper waste(McGain et al., 2009).

However, impediments are plentiful. Hazardous waste, also known as infectious waste, refers to waste contaminated with substances known to have pathogenic properties. If exposed to such waste, humans and animals can get infected (Padmanabhan, K.K. et al. 2019). Thus, infectious waste cannot be recycled.
Even for non-hazardous waste, high variability of materials used to produce medical equipment creates difficulties in identifying each material for later-stage recycling (Leissner & Ryan-Fogarty, 2019).

Most hospitals mix non-hazardous and hazardous waste types, reducing possibilities of end-of-life others than incineration. **The lack of waste separation yields greater amounts of hazardous waste, which implies higher environmental impact and financial cost of disposal methods (HDWR, 2020).**

Regulations that shape a potential circular future of healthcare

The healthcare sector's tendency to save short-term costs through disposables destroys our planet. However, some European policies like the Green Deal (European Green Deal, 2022) aim to fight against this hurtful tendency.

Regulation to reduce waste is happening and will continue getting stronger. Suppliers will have to take responsibility for the end of life of their products. (Moses, Bachman, & Prusty, 2021).

Reuse and disposability practices in hospitals

To reuse a device in the healthcare environment, it has to go through a reprocessing procedure. Manufacturers can establish reprocessing requirements for the devices they produce, while hospitals carry out reprocessing themselves.

Hospitals tend to acquire medical devices and supplies based on their quality and purchase costs. On the other hand, manufacturers increase their competitiveness by reducing their prices, which often means designing and selling cheaper disposable devices as opposed to more expensive reusable ones. **As a result, currently all stakeholders prefer disposability as it creates stable income for manufacturers and lower prices and risks for hospitals.**

But at which cost? Disposables generate higher amounts of waste, and their total cost of ownership is, most of the time, higher than that of the reusable devices (Moses et al., 2021).

Figure 2.1 Picture of the ICU corridor with two nurses, two doctors and a care assistant.

Unsustainable ICU practices and their impact

Most of the hospitals' CO2 footprint comes from medications and devices. Medical devices generate 21% of the French healthcare sector's footprint, as Figure 2.2 shows (The Shift Project, 2021).

Although theoretically recyclability percentages at hospitals could be high, currently there are no effective ways of separating general waste from infectious one following all safety regulations. For example, medical devices are sometimes too small or contain multiple materials, challenging separation for later recycling (Leissner & Ryan-Fogarty, 2019). In addition, while in use, devices get contaminated with body liquids or have stickers attached to them, further obstructing recyclability (Nederland circulair, 2018). Finally, insufficient labeling of recyclability makes it challenging to distinguish materials and thus reduces the possibility of choosing the appropriate method even if a recycling option exists (Leissner & Ryan-Fogarty, 2019). All these increases the footprint of ICU and hospitals practices.

Pilot projects and circular strategies towards circular ICUs

Nevertheless, a more environmentally friendly healthcare can be envisioned. Multiple proposals and pilot projects are already exploring such transition.

Figure 2.6 explores some of the cost benefits of sustainable practices in hospital operating rooms. The Shift project (2021) envisions various initiatives to reduce environmental impact within a hospital setting, from purchasing to equipment to waste management changes. The actions for systemic change related to medical devices and consumables are stated below:

REUSE: Limiting the use of single-use devices through reusing.

Medical device reprocessing keeps the device's resources longer in use. Therefore, it can be a cost-saving initiative for hospitals (Greenhealth Practice, 2017), triggering hospitals' interest. Pilots projects on reprocessing servitization are being done, as having it releases hospitals from the risk

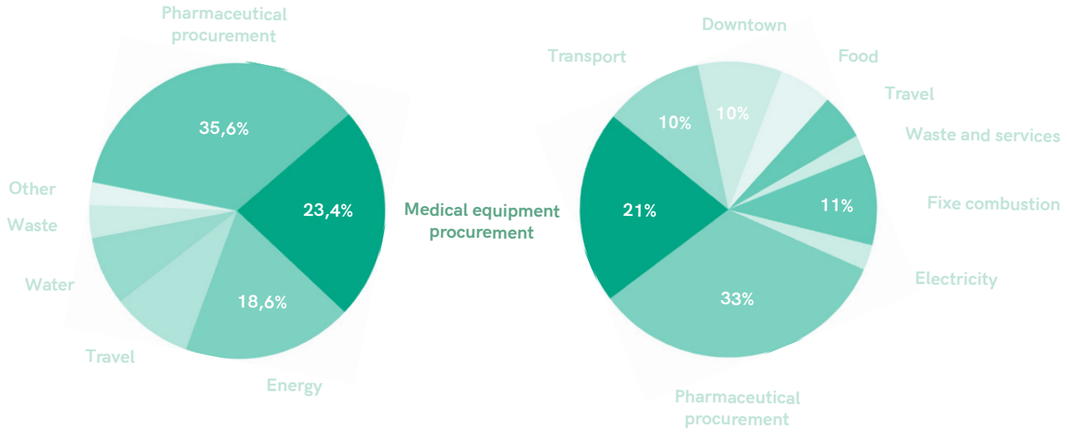


Figure 2.2. Two hospitals emissions distributions. Left: Share of GHG emissions by station in Victoria's hemodialysis unit (Lim A.E. et al, Australian Health Review, 2013); Right: Distribution of emissions from the health sector in France (The Shift Project, 2021)

Figure 2.6. Potential saving in operating rooms through sustainable practices by AMDR 2021 (Practice Greenhealth, 2021)

management and the quality checks that reusing devices implies (Fargnoli, 2018; Guzzo et al., 2020).
However, reprocessing involves extensive use of energy, water and chemicals. As reusability could sometimes not be more sustainable than single-use solutions, assessments of specific system impacts are necessary (Rizan et al., 2021, McGain et al., Bein et al., 2021)

INFORM
Knowing the carbon footprint of medical devices is crucial to locating hotspots.

Requiring transparency from manufacturers regarding life cycle emissions of their products would allow hospitals to be conscious about their current footprint and available alternatives.

REGULATE
Responsible and sustainable procurement policy.

Incentives for manufacturers to act along the value chain and requirements for circular healthcare devices are needed.

RELOCATE
Local production supply

Rethinking the considerable share of international transport in production chains is required to reduce the healthcare sector's footprint. Enabling local production or improving transport methods could reduce GHG emissions.

REDESIGN
Ecodesign approaches, use of recycled materials

'European health system drive markets towards toxic-free products that conserve finite resources, minimise waste and contribute to an ethical supply chain and circular economy' - Practice Greenhealth, 2021
Ecodesign approaches to reduce the toxicity and footprint of materials used in the healthcare sector could reduce theirits environmental impact. For example (01), the use of new, more sustainable materials has been investigated and implemented in Swedish hospitals.

Design for waste separation

As discussed previously, waste separation systems could also improve unsustainable behaviors in healthcare sector as it allows remanufacturing (example 02) or refurbishment and recycling (example 03) of single-use devices.

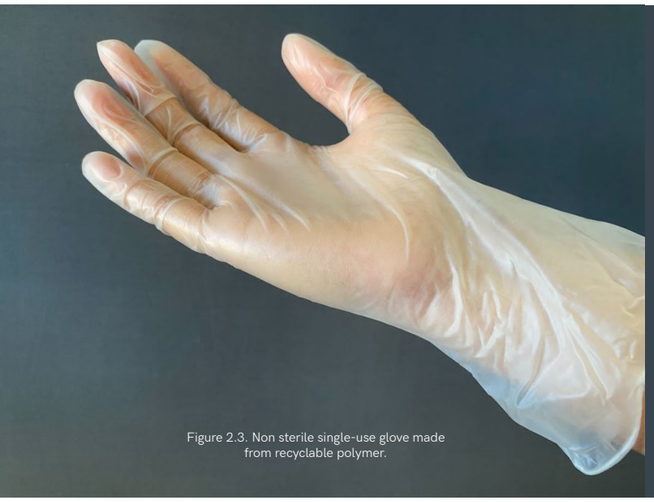


Figure 2.3. Non sterile single-use glove made from recyclable polymer.

EXAMPLE 01
Recyclable single-use protective glove (Sjöberg & Olsson Stjernberg, 2020)

Production of gloves made out of polyvinyl alcohol, a polymer that can be easily dissolved in water, sterilized, and remoulded into new gloves (Figure 2.3). The solution is a machine that encompasses all of these steps, enabling an in-house recycling system.

EXAMPLE 02
Vanguard Medical Remanufacturing (Vanguard, 2021).

Vanguard is a Berlin-based medical remanufacturer. They have set the global standard for medical remanufacturing, enabling healthcare institutions to send products from different manufacturers to be remanufactured and put togther into something new.
Vanguard specialises in remanufacturing of cooled ablation catheters and catheters with 3D mapping systems (Figure 2.4).

Figure 2.4. Catheter dissasembly and check for remanufacturing purpose.

Figure 2.5. Philips Healthcare device

EXAMPLE 03
Take-back program (Philips, 2021)

Philips Healthcare established a take back-program for patient monitors. They initiated 12 pilot projects with partners such as AllParts Medical in the US. The aim of the program is to recover parts and sell them back as refurbished components or to recycle them when they are not longer reusable.

Repercusions climate change and COVID in healthcare?

Climate change

As mentioned in the introduction, climate change is causing an increase in chronic diseases, mental health problems, etc. Vector-borne conditions, extreme climate events and migrations make the global healthcare sector to be one of the most sensitive sectors when it comes to climate change consequences (The Shift Project, 2021).

COVID 19

COVID impacted the healthcare ecosystem in many ways. Supply chain hiccups enhanced collaboration between healthcare stakeholders to overcome problems and accelerated innovation such as the use of novel reprocessing technologies, UVC radiations.

The pandemic also increased societal understanding of infection prevention. There is a public desire to eliminate healthcare-associated infections (Rutala, 2018), which could potentially push the healthcare sector to avoid risks as much as possible, choosing to use disposable devices.

However, COVID has also increased societal awareness of healthcare waste as the waste generated by disposables such as masks became widely visible.

Sum up

RQ1 – What are the laws, regulations and policies guiding procurement and waste management in EU hospitals?

- (EU) 2017/745 regulation which targets medical devices development regulation.
- NEN-EN-ISO 13485:2016 specifies quality management requirements for the organization involved in one or more steps of the life cycle of a medical device

RQ2 – Which current practices make ICUs a non-circular environment and what it the impact of those practices?

- Extensive use of single-use devices to avoid risks of infection.
- Lack of waste separation reduces the possibility of applying R-strategies after the use phase.

RQ3 – Are there already some pilot projects showing potential areas where circular strategies could be applied in ICUs and hospitals?

- Reuse of medical devices.
- Access to information about devices' environmental impact and life cycle for procurement choices.
- Procuring locally manufactured devices.
- Design for waste separation.
- Take back or remanufacturing programs.
- Investigating new materials with a lower environmental footprint than currently used ones.

RQ4 – What are the effects of climate change and COVID on healthcare systems?

- Climate change affects global health in a negative way, increasing pressure on healthcare systems.
- COVID-19 increased the societal fear of infection, reinforcing the already restrictive infection risk prevention.
- The COVID-19 pandemic triggered collaboration between different healthcare stakeholders.

Conclusion

What are the main challenges that the current intubation system presents from a sustainability perspective?

Manufacturers tend to offer single-use products and insufficient information about product life cycles for their own benefit. On top of this, restrictive regulation limits the implementation of innovative solutions, and excessive prevention of risk of an infection increases the waste generated within hospitals. However, numerous studies show R-strategies to be more economically beneficial and environmentally sustainable in the context of the healthcare sector. Collaborations could lead to circular healthcare, where sustainability and safety are equally valued.

Challenges detected throughout the literature review have been organized into three categories:

Use
Challenges related to how devices are used in the ICU (protocols, habits or workflows).

Organizational
Challenges related to EMC logistics, procurement guidelines or waste management.

Ecosystem
Regulations and other stakeholders' initiatives affect EMC practices.

The degree to which an EMC can act upon each of the challenges was color-coded from green (easily changeable) to red (hard to make a change).

Sustainable challenges in the healthcare environment

Impact of manufacturers on the sustainability of hospital practices.

Transparency of the devices' supply chain for sustainable decision support is crucial. However, manufacturers do not have the obligation of providing this information to hospital procurement teams. This entails a lack of ways to quantify the sustainability performance of suppliers.

High regulation on materials and reprocessing techniques

Regulations decrease the implementation speed of technological innovations.

Societal fear for contagion increases risk regulation

Due to the current pandemic, societal fear of contagious diseases has increased, reinforcing the already restrictive infection risk prevention.

Infection risk prevention reduces R-strategies possibilities

Traces of body liquids limits the recyclability of products. R-strategies can only be applied in non-hazardous waste.

The use of stickers jeopardizes R-strategies implementation

Labelling jeopardizes the potential recyclability of devices or packaging.

Limited waste separation

Hospitals do not count waste separation infrastructures, spoiling R-strategies' possibilities. The current end of life solutions mostly rely on the incineration of goods and rarely in giving back the ownership of products to manufacturers.

Conclusions for further research

Manufacturers, society, and policymakers influence decisions made at hospitals. Multiple stakeholders must be involved in the discussion to reduce their environmental footprint.

How does EMC decide which devices and services to procure? Are their environmental footprint considered? If so, how?

Research on the current procurement guidelines at EMC ICU is presented in the next chapter.

Post use R-strategies initiatives to reduce ICU environmental impact are dependent on each hospital waste separation. Reprocessing of used devices is sometimes needed for R-strategies implementation.

These challenges highlight the reprocessing and waste separation potential to reduce the ICU footprint.

What is the current waste separation system at the ICU? Are devices used at EMC ICU reusable or disposable? Which are the factor that led to the use of one over the other?

These were some of the questions researched in the next chapter.

Chapter 3

Research on ICU practices

Now that a better understanding of the healthcare context has been established, a closer attention will be given to the specific scenario this project focuses on: Erasmus MC ICUs. This chapter summarises findings made through observations and interviews at Erasmus MC. Based on the challenges, a set of opportunities is presented.

3·1 · Approach

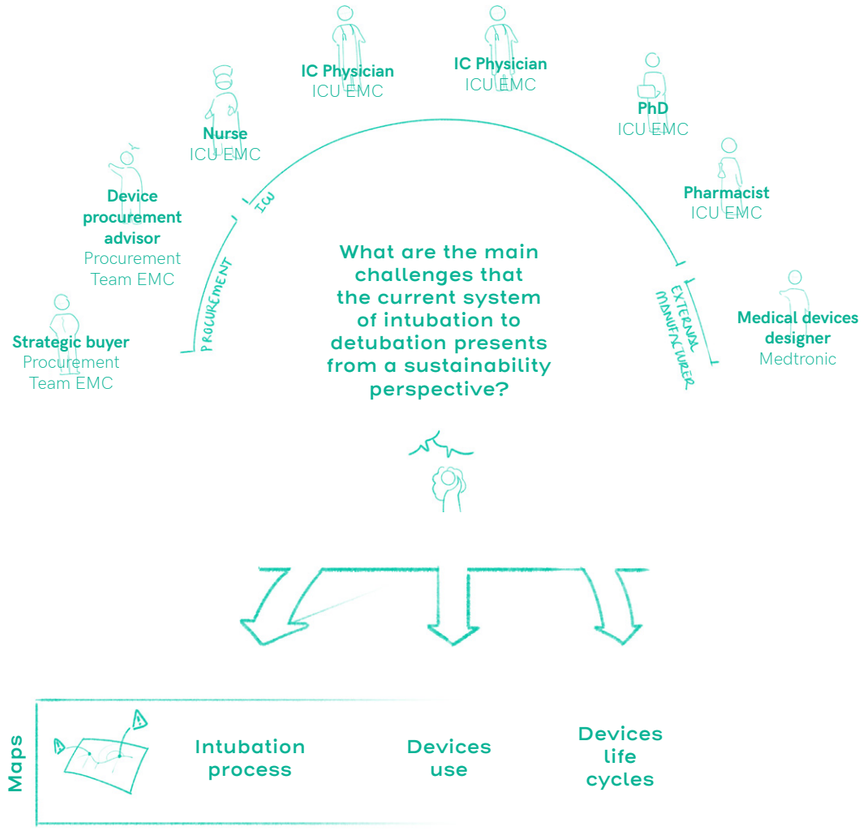


Figure 3.1. Overview interviews realised during the system research phase, which outcomes where summarised as system maps.

This research aims to determine which factors shape the intubation wastefulness at EMC ICU. As for the last chapter, the leading question is: 'What are the main challenges that the current intubation system to detubation presents from a sustainability perspective?'

A set of observations were performed at the ICU of:

- A nurse setting up a room for intubation
- An intensivist performing his daily assessment of intubated patients
- Nurses' general workflow by observing corridor workflows
- Two nurses cleaning a room after an intubated patient stay

A waste observation was also undertaken at the EMC pediatric ICU (PICU).

Finally, several interviews were realized (Figure 3.1). Further description of the arrangement of all interviews and observations undertaken can be found in Appendix D. Outcomes from this research are presented divided into the following areas: Intubation process, Devices' use and Devices' life cycle.

3·2 · Intubation process

First, research was done on the intubation process. An overview of the intubation steps is given in Figure 3.2, indicating stakeholders involved, tasks and times they are performed. The wastefulness of each stage is also visualized at the bottom of the visual. Main sustainable challenges are highlighted in red.

Further explanation and challenges are described in the pages to follow.

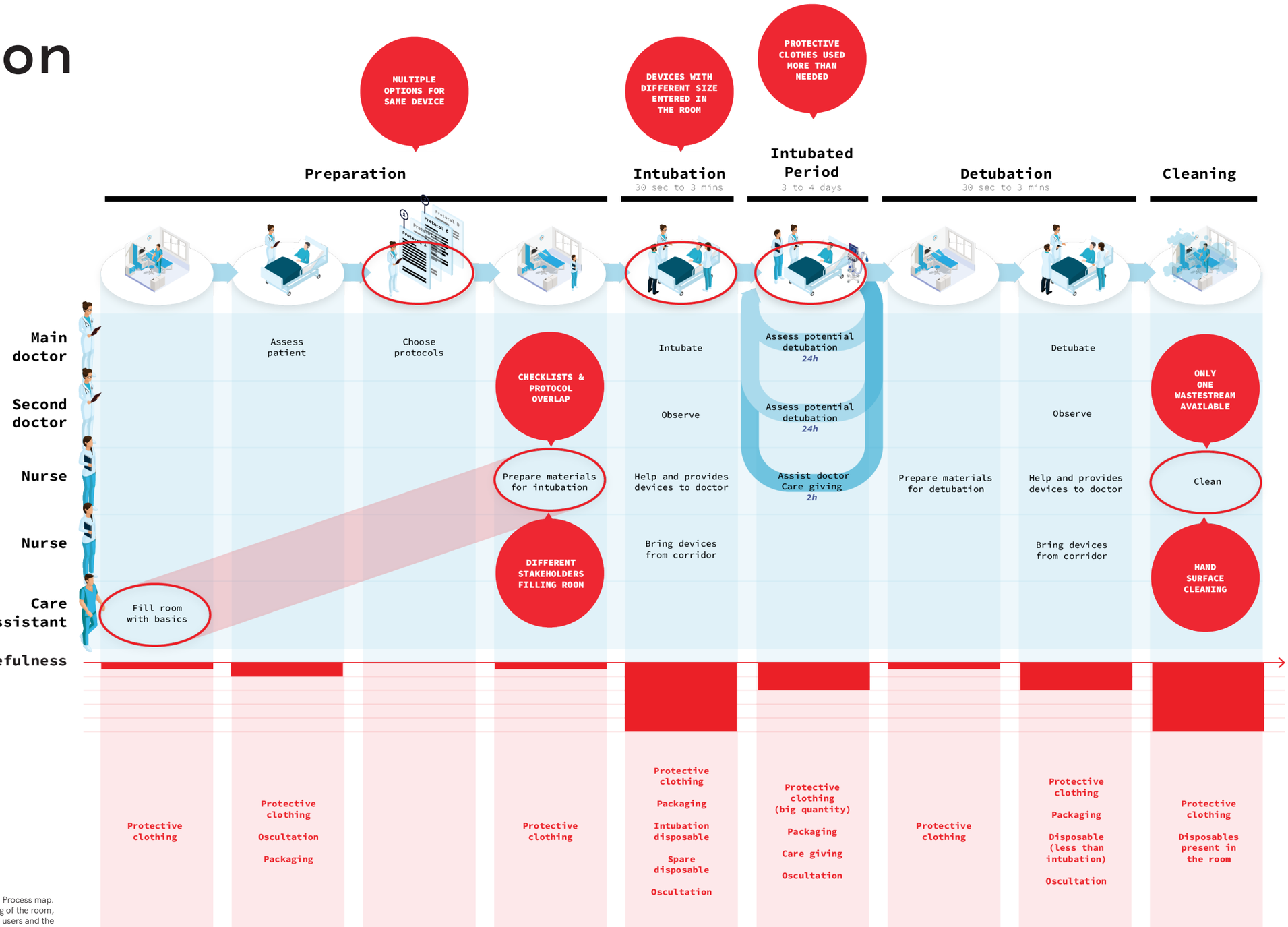


Figure 3.2. Process map.
Intubation process steps from the intubation to the cleaning of the room, indicating for each of them the actions required to different users and the current wastefulness and type of devices disposed.

Scenario

Operations take place in the ICU room. Figure 3.3 presents staff involved and their respective tasks.

Preparation

Doctors choose the tools and protocols used for intubation based on their expertise and the each patient' specific case. Before every intubation, they patient's measurements to determine the device dimensions needed. When uncertain, some doctors get additional device sizes for the room.

Devices listed in the chosen protocols are recommended to be placed inside the ICU room. As Figure 3.4 shows, there are two main storage spaces in the ICU outside the rooms. However, intubation procedure is very rapid, what makes it impossible to access both storage spaces on time. Nevertheless, a trolley with devices used specifically for intubating patients is present in the ICU corridor.
The decision of where to place devices is ultimately in the hands of the doctor operating, what poses a sustainable challenge if the user is unaware of their wastefulness.

Based on the protocol and the doctor's preferences, nurses will prepare and place devices in the prefered location. A set of considered 'basic devices' will be placed in the room in advance by care assistants. Thus, some devices mentioned in the chosen protocols will potentially already be in the room. **The lack of coordination between nurses and care assistants and the overlap of protocols can trigger the same devices to be brought into the room twice.**

Intubation

Doctors must also choose between multiple models of the same device. Changing from one specific device model to another implies various changes in their shape and use. Even if performing the same tasks, changes of instruments imply having to teach staff how to use it.

Over time the staff gains expertise using the same device, which implies:

- Changes to other versions tend to be not welcome as they imply restarting the learning curve.
- Doctors tend to choose the same device model every time, leaving other options unused.

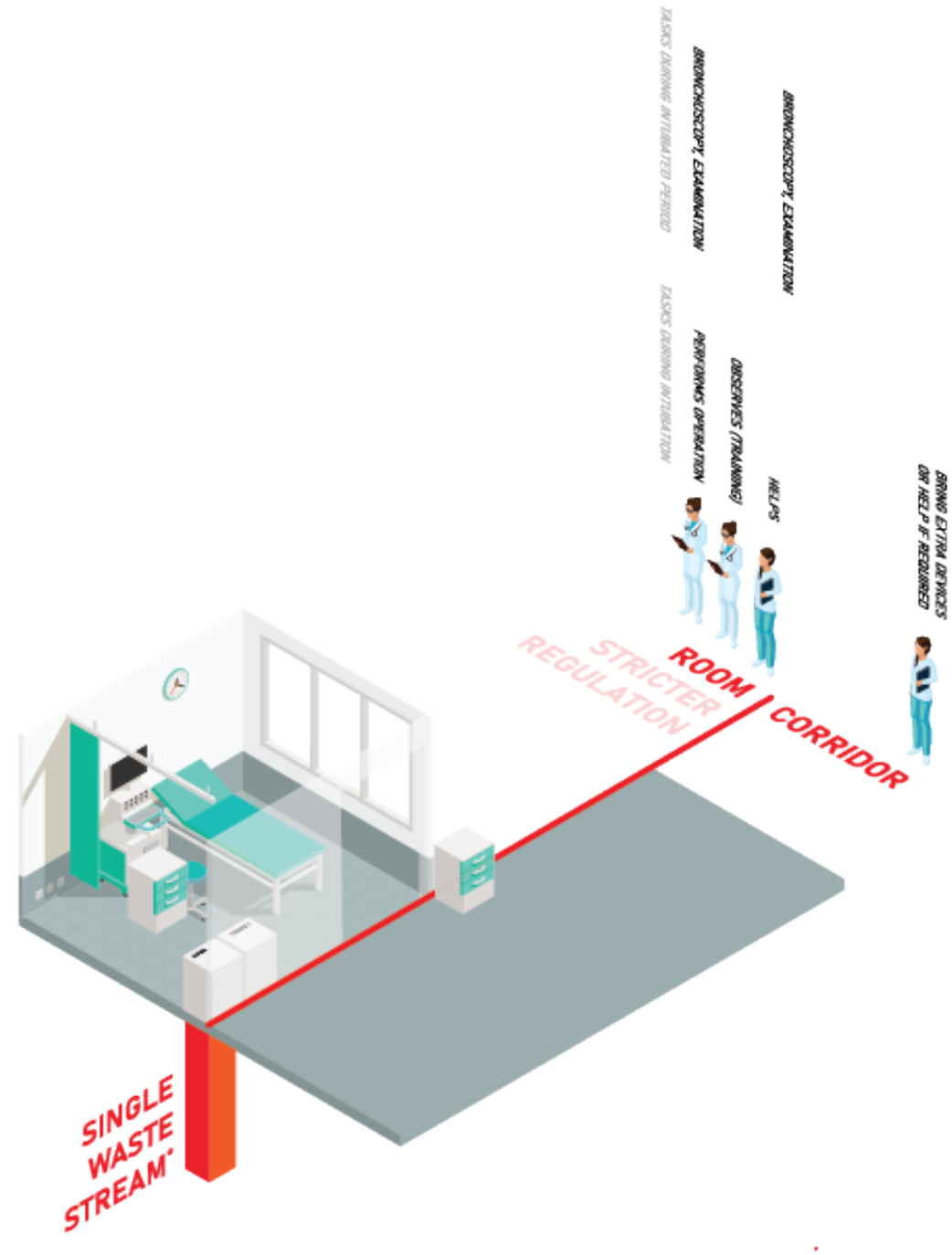


Figure 3.3. Overview of the ICU room and its wastestream. Explanation of the different users involved during an intubation process, their function and location (either room or corridor)

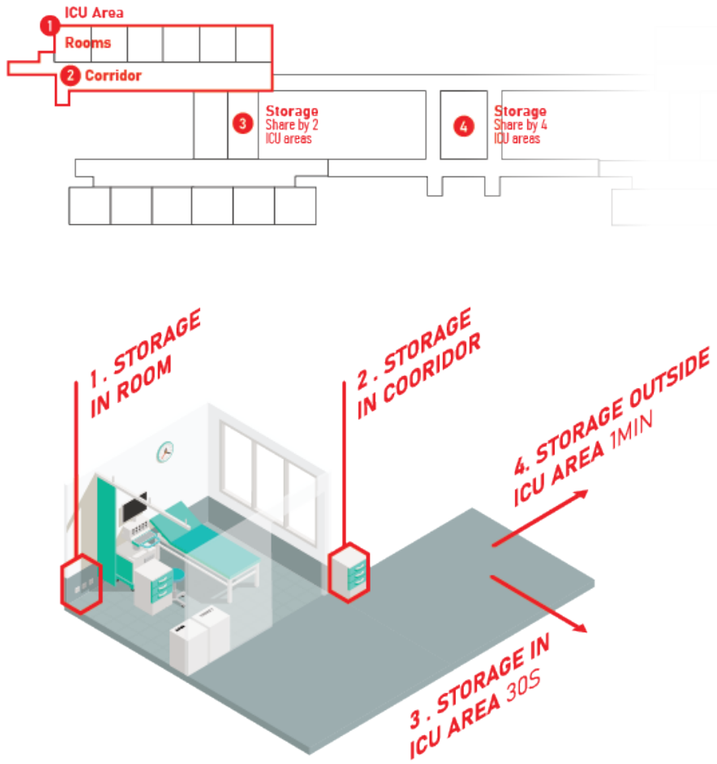


Figure 3.4. Overview storage options within the ICU.

Intubated period.

Both nurses and doctors perform periodic checkups on the patient during their intubated period. Two doctors will assess the patient's status once a day, evaluating future treatments. This procedure will define when the patient is detubated based on their situation.
Next to this, nurses check the patient's status every two hours to provide care assistance or detect any irregularity. They will check their general vital signs, ventilation, water, food, medicine, urine level.

For each checkup, nurses and doctors use personal protective clothing that must be thrown away as they leave the patient's room.

Cleaning rooms

Rooms are cleaned at the end of a patient stay, periodically and after operations. Almost everything but liquids and liners are thrown together, including packaging. Most devices used during intubation are single-use thus discarded at the end of the intubation operation. However, some of these devices could have been kept in the room, potentially reused during the detubation.

Disposables need to be thrown away, even unused, if entered in the ICU room due to infection prevention regulation. Most devices' packaging contains paper, not allowing it to be cleaned with the wipes used by nurses and care assistants.
Even if the packaging could be cleaned with the current technique, current ICU nurses found themselves overloaded with work. This can be seen translated in numerous strikes performed by EMC and other hospitals nurses since the beginning of the COVID 19 crisis. As a result, nurses would prefer not to perform additional cleaning if possible.

Waste exploration

A waste observation was carried out during a set of 4 days at EMC PICU. A total of 104 waste bags were collected and analysed better to understand ICUs' waste nature, separation and quantities. The full report can be found in Appendix E (Figure 3.5).

The primary outcome of this observation week was that the waste was mixed no matter their hazardousness. Food waste from what seemed the cafeteria or the visitors' lunch could be found next to medical devices that still contained body liquids or medication. The quantity of packaging waste generated was also striking, representing almost 13% of the total waste in weight.

A large amount of unused waste was also found. Up to 6% of quantified waste units were unused, most still on their packaging.

Figure 3.5. Photos of the design students going through the PICU waste. Detail of some of the waste separated consisting in tubes and connections.

Conclusions intubation process research

	Challenges	Actionability	Impact
SINGLE USE	**Risky reprocessing** Human error during the reprocessing of reusable devices is associated with infection risks, as its standarization is difficult. This enhances the use of dipsosables over reusables.	Some of the cleaning was previously done by hand at the ICU by nurses. They are reluctant to assume this task again as their current workload is already extensive.	Reusing is a higher R-strategy which preserve material resources and reduces waste. Also called reprocessing, this is sometimes required for other R-strategies such as remanufacturing to be applied, increasing its impact.
UNUSED WASTE	**Redundant and overlapping protocols** Habits are shaped by protocols. Unneeded and repeated devices are entered in the ICU room as they are mentioned in either overapping or redundant protocols. **Multiple stakeholders are involved in filling rooms** ICU rooms are prepared both by nurses and care assistants, enhancing the entrance of the same devices twice into the room. **Opened to check** Some nurses open devices packaging to check beforehand if the device is the desired one. In case of mistake, the product must be thrown away anyways, unusued. **Wasteful doctors decision making** Doctors decide which devices are required, their size and where they should be placed based on the protocols. Current practices tend to enter more devices in the room than eventually used, being thus more wasteful than necessary.	Redesign of protocols could avoid unused waste. This waste can caused by lack of awareness of doctors on their wastefulness. of confidence in less experienced doctors.	Unused represents 6% of the complete waste.
NO WASTE SEPARATION	**Limited waste separation** Most waste generated throughout intubation is disposed together, increasing the quantity of hazardous waste by getting additional devices and waste in contact with body liquid, thus destroying any possibility of recyclability.	Separating waste in the rooms would require additional workload to nurses, which current workload is already extensive.	R-strategies that could be applied after waste separation (remanufacturing or recycling) retain less value than the reuse strategy.Also, most devices would require cleaning to allow remanufacturing, making reuse solutions more impactful.

3·3 · Devices

Figure 3.6 maps non exhaustively the devices used in regular intubation. It visualises how these devices are used (and disposed of) and in which quantity. It is striking that most devices used throughout intubation are disposed of after a single use. Most waste is generated during the intubation period and through extensive use of disposable protective clothing.

In red have been represented the different challenge areas localised, from which further detailing can be found in following pages.

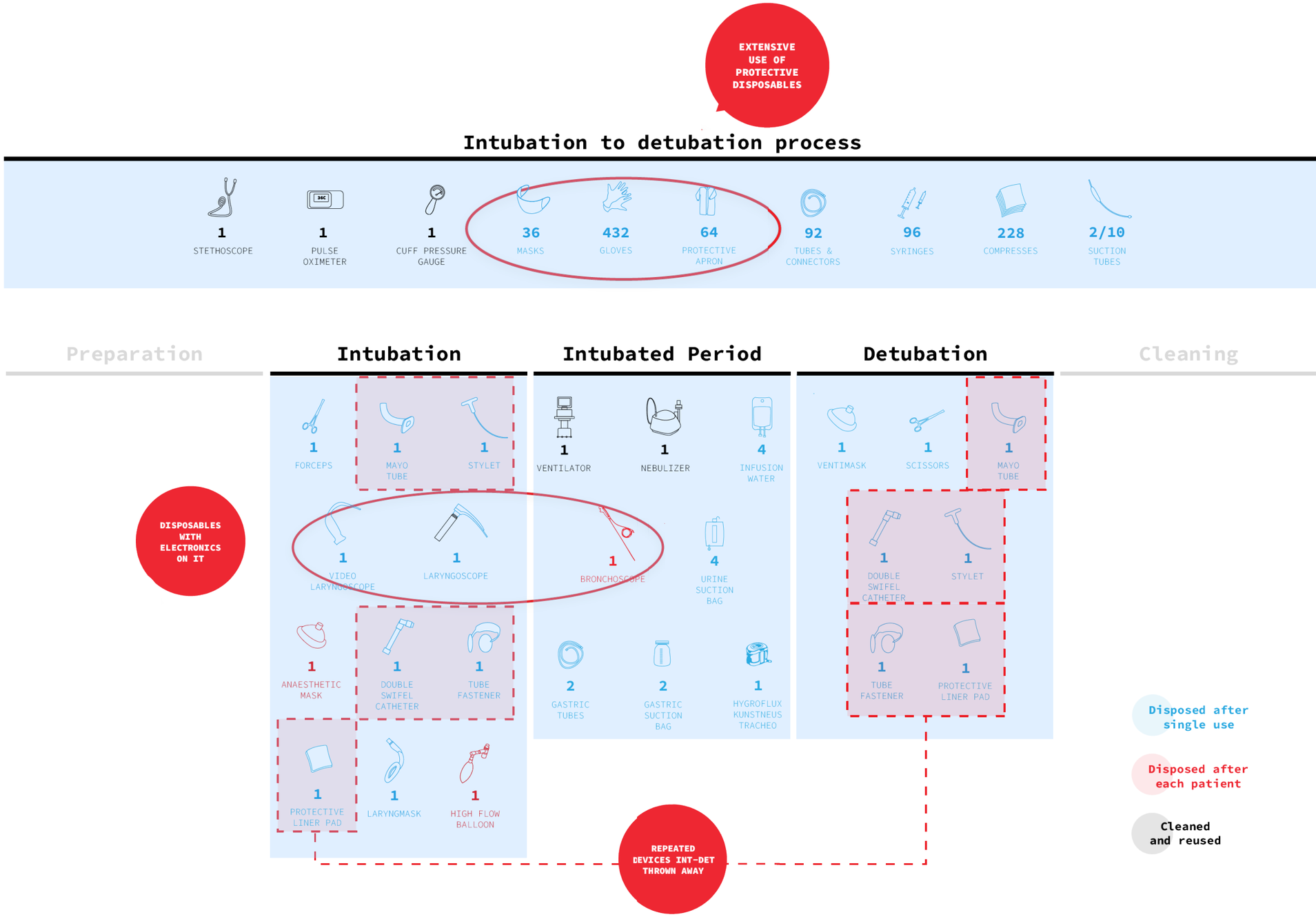


Figure 3.6. Map of devices used throughout intubation. Overlay of some of the challenges related with these devices deducted from the research.

Personal protective clothing

Extensive use of protective clothing

Disposable clothing is used throughout the intubation, intubation period and detubation.

The use of disposables except gloves is not compulsory for non-infectious patients if the user does not touch them. However, users' habits make usage of protective clothing higher than needed.

Disposable devices

As we can notice from the previous map, most devices used throughout the intubation process are disposables.

Some of these devices have reusable alternatives and were reused in the past. What were the reasons behind this change towards disposability?

Technological improvements threaten devices reuse

Technological innovation is always sought in the healthcare environment as it provides higher quality, thus more safety. For example, the inclusion of a camera in the video laryngoscope, a device used to intubate patients, increases the rates of successful intubations (Baek et al., 2018).

Technological features such as this one increase devices' complexity.
Higher product complexity (in shapes and components requirements) reduces the rates of reuse, reducing the efficiency of the cleaning methods (Moses, Bachman, & Prusty, 2021).

Innovation led doctors to prefer disposables

Taking the example of the laryngoscope again, recent innovation allowed the addition of a camera, which simplifies intubations for doctors.

EMC proceeded to buy single-use laryngoscopes with cameras. Use of single-use devices increased as doctors prefered this added feature which was only available on single-use.

Infection risk

Once, a lack of efficient cleaning of a reusable laryngoscope led to Hepatitis B infection transmission from one patient to another. This sporadic case triggered the replacement of this product for single-use ones. Disposability allows the hospital to reduce infection risk management drastically.

Devices Storage and handling

Multiple options for same device led to unused

Multiple versions of the same device are available at the ICU.
During an interview, an intensivist discovered a device model she had never seen or used before. As choosing between all options would make doctors' decision-making process more complex, it could be supposed that too many devices options led some models to be unused.

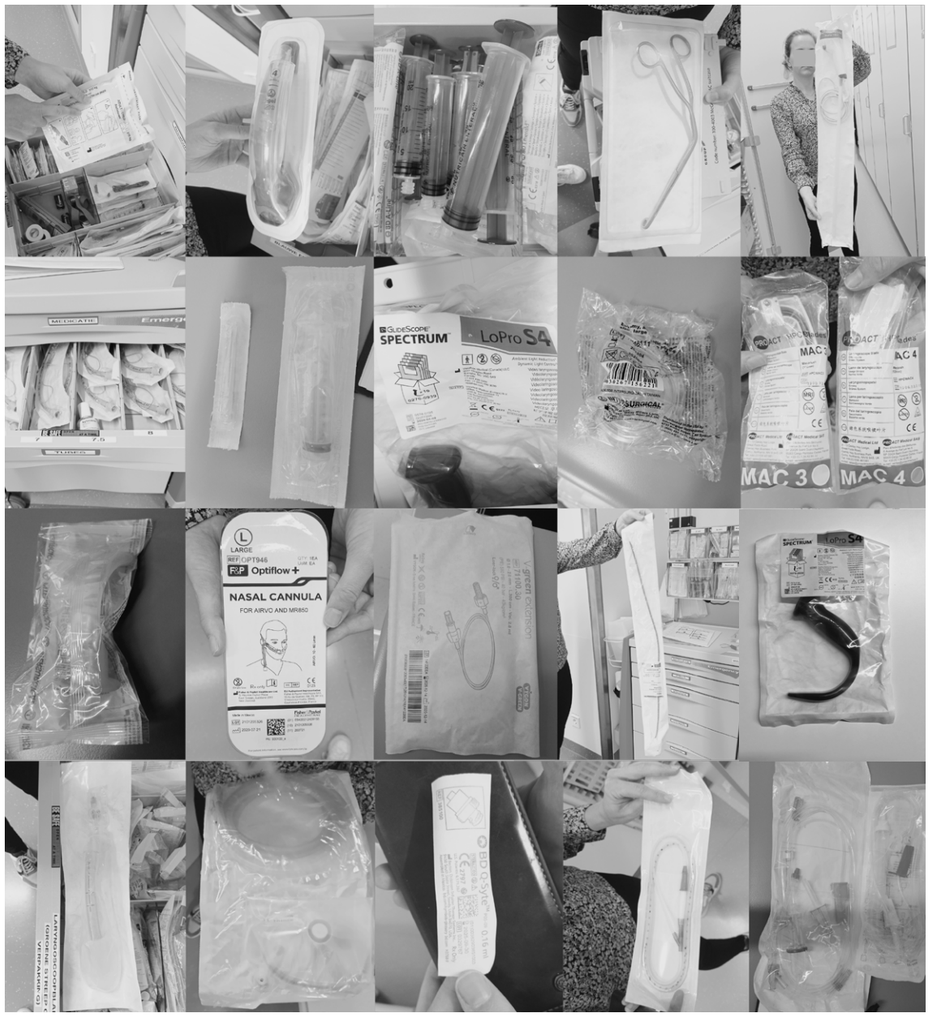


Figure 3.7. Some of the disposable devices used throughout the intubation to detubation system. Non exhaustive collection of photographies.

Conclusions intubation devices research

	Challenges	Actionability	Impact
DEVICES DEPLETION	**Multiple choices for a same device** Multiple versions of the same product are available for some devices, requiring an unneeded and time-consuming choice to doctors. This also results in unused waste of least used versions.	Changes in procurement could be envisioned to avoid this challenge.	Refusing in a first intance the use of devices and reducing unused rates are can reduce waste of more than 6%.
	Excessive use of PPE Throughout an intubated period multiple checks on the patient are needed, however, some of them might not require as much PEE to be used as observed.	Changes in behaviours or protocols could be envisioned.	
	Multiple Storages The ICU counts with multiple storages spaces. Some products are available in multiple locations, jeopardizing their use before the expiration date of less regularly checked ones.	Changes in devices distributions whithin the ICU could be envisioned.	
	Packaging is not cleanable Current devices packaging cannot be cleaned with cleaning wipes. Even unused and still packed devices cannot be taken out of the ICU room as their packaging cannot be cleaned.	Changes in either packaging material or cleaning methods could be envisioned, however requiring external stakeholders involvement.	
NEGATIVE REUSE EXPERIENCE IN THE PAST	**Lack fo availability of reusable devices** In the past, the ICU encountered multiple times the hassle of lacking devices availability due to the mediocre logistics connecting the ICU to the Sterilization Department.	Redesign of either the system between the sterilization department and the ICU or an in-situ reprocessing system could be explored.	Reuse could allow devices to stay longer in use. As refusing would only allow the reduction of a certain waste percentage. However devices would still need to be used extensively in the healthcare environment. Therefore, it is estimated more impactful to research on the reduction of the footprint of needed products by allowing reuse of them.
	Electronics increases, sterilization decreases Products have got complex with latest technological improvement and this decrease their reprocessing possibilities		
	Sceptical towards hybrid devices Some hybrid materials used at the ICU were once not optimal to use. As this interfered in the usability of the products, doctors are sometimes sceptical about it	Research around hybrid devices with low criticality could be done and information provided to ICU users.	

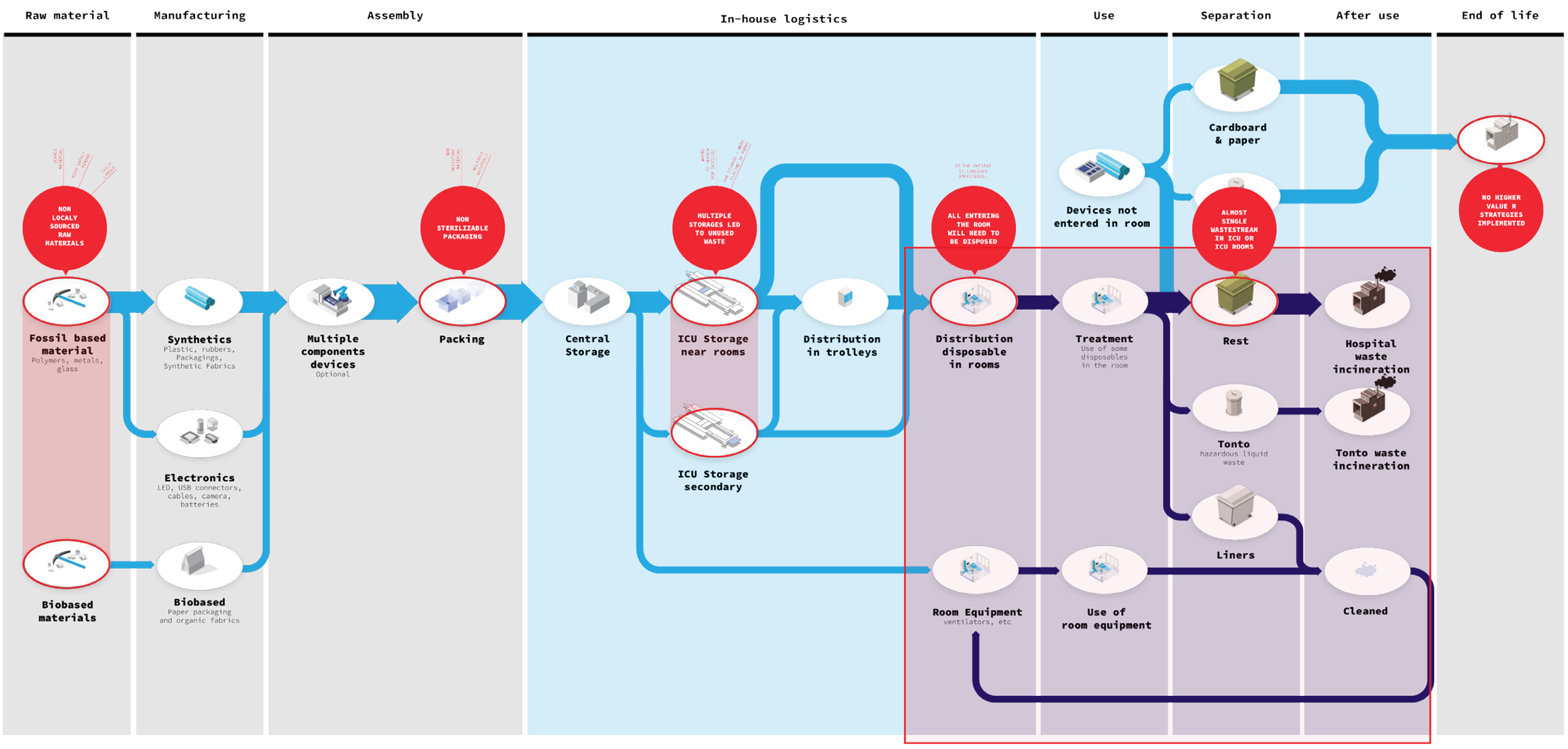
3.4 · Devices life cycle

This map (Figure 3.8) shows the general journey of intubation devices. It shows products over their whole lifespan, as a conclusion to previous research.

Eventually, the procurement process at EMC will be discussed. Procurement decision making impacts the sustainability of devices and ICU practices, as introduced in chapter 2.

Potential challenges from a sustainable perspective are highlighted in red.

Figure 3.8. Overview general devices flow from raw material to end of life.



The procurement team at EMC is responsible for procuring devices for the ICU. As shown in Figure 3.9, ICU doctors can report their necessities to the procurement team. Procurement will then choose devices, stock quantities and types of supplier contracts. They will select a supplier based on factors defined by each project team. Manufacturers define device guidelines, and the implementation of higher R strategies depends on these guidelines. Therefore, procurement has high relevance when deciding between different devices manufacturers.

Prioritizing disposables

Single-use devices are largely preferred and prioritize by EMC procurement team. They have as an objective to achieve a complete disposability when the option is available in the market, thus this applies to most of the devices used for intubation at the ICU. During the last 10 years, some of the devices which were previously sterilized by EMC such as devices with electronics or metal on them were slowly exchange by disposable options.

As mentioned before, disposable is preferred to avoid potential infectious diseases contagions if cleanings are not properly realised.

On top of this, EMC ICU had experienced some in-house logistical hiccups. Receiving back the devices from the sterilization department (SD) was taking too long, thus creating a lack of availability of these devices at the ICU.

Quantifying only procurement costs and safety

The strategic buyer interviewed stated the current way of evaluating suppliers is lowering the sterilizable options. EMC evaluate supplier on quality and price, not on supply chain impact (CO_2, land, water, toxicity, child labour). Pricing is still largely based on the procurement cost of ownership and not on the total cost of ownership. This makes sterilizable devices look more expensive than disposable ones.

It is difficult to assess and quantify the sustainability of a supplier. Currently, to assess suppliers before solutions are assessed, EMC uses declarations of suppliers, such as they do for checking that procured devices follow all EU rules and regulations.

Sustainability perception restricts changes towards circular procurement

A concern of the negative connotation that sustainability has in the healthcare environment was shared by multiple interviewees. Sustainability is perceived as a criterium throughout which safety or quality needs to be sacrificed, or prices elevated.

However circular economy value can be reframed for healthcare environment as a risk prevention. Using less critical materials, or reusable devices can reduce drastically the supply chain hiccups. The intubation of patients is dependent on devices, what if EMC could find itself in the situation of not having them?

COVID 19 made EMC and another large number of hospitals face these circumstances. The use of disposable makes EMC highly dependent on the supply chain efficiency. EMC has normally enough stock of materials for 6 weeks of regular use. During COVID 19, intubation devices were used 6 times more intensively than in normal circumstances. As all hospitals were finding themselves in similar circumstances, manufacturers could not provide stock on time, thus disrupting the use of the intubation system at EMC. EMC has decided to cover their back from this situation by enlarging their stocks for up to 3 months. But more stock means also higher storage necessities, thus a higher cost.

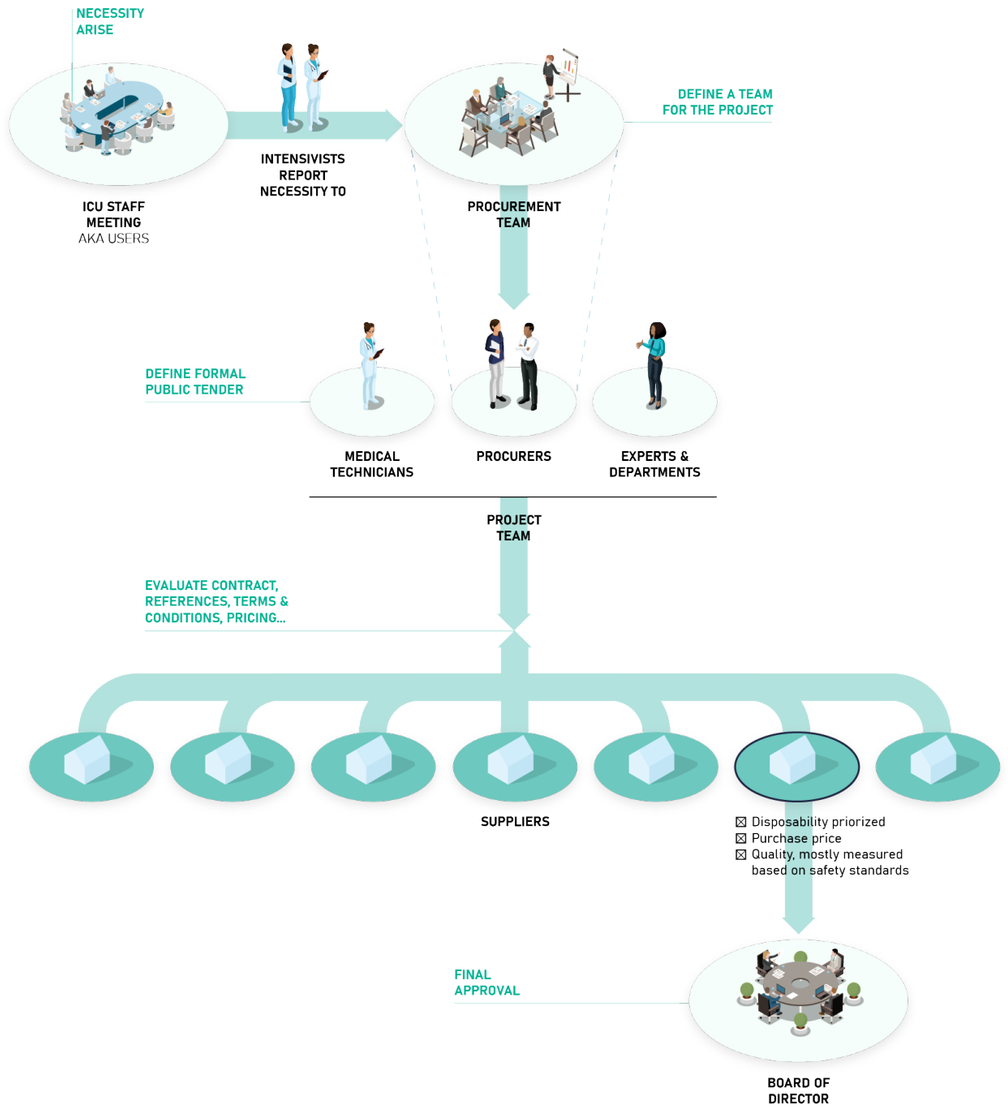


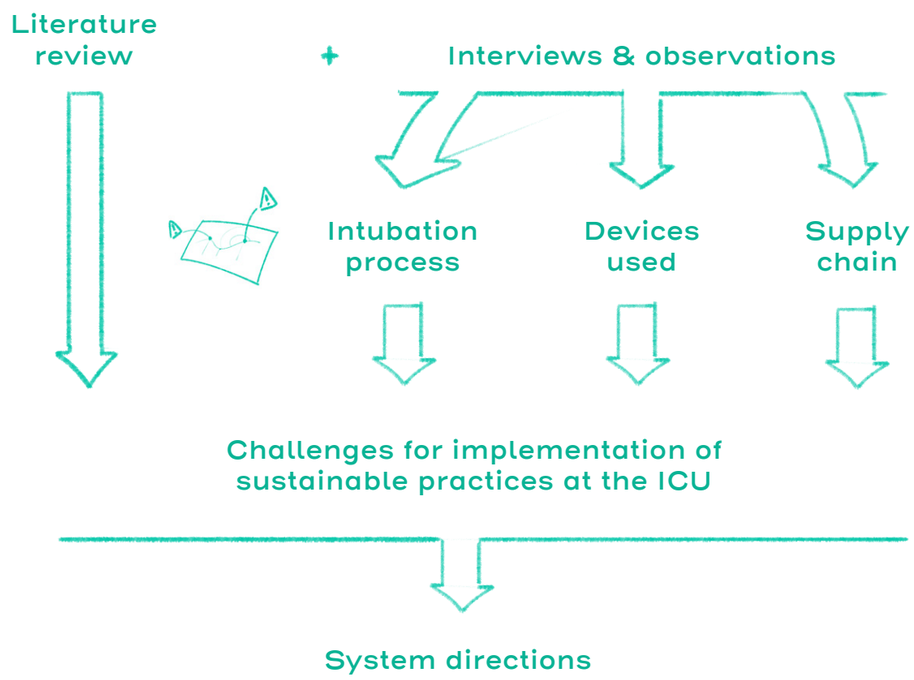
Figure 3.9. Overview steps followed by procurement to procure devices required at the ICU.

Conclusion devices procurement at EMC

	Challenges	Actionability	Impact
LACK OF DECISION MAKING TOOLS TO ACHIEVE CIRCULARITY	**Lack of supply chain transparency** Current supply chains of healthcare devices lack transparency. As a result, estimating devices' environmental footprint is difficult for the hospital procurement team. Current procurement is based on cost and safety and not the TCO or devices life cycles.	Ways to quantify the positive impact of sustainable procurement at Erasmus MC could be explored.	Low actionability
	Sustainability arises negative connotations in healthcare Some users and people working at EMC consider sustainability as a characteristic that reduces the quality and safety of products while increasing their price. Changes of paradigms are therefore required.	Ways to quantify the positive impact of sustainable procurement at Erasmus MC could be explored.	
SINGLE USE	**Manufacturers pressure towards disposability** Devices disposability ensure suppliers and manufacturers constant sales, thus their interest to shift the market towards this type of device. This challenge could be however addressed by making changes in procurement.	Redesign of either the system between the sterilization department and the ICU or an in-situ reprocessing system could be explored.	Reusing is a higher R-strategy which preserve material resources and reduces waste. Also called reprocessing, this is sometimes required for other R-strategies such as remanufacturing to be applied, increasing its impact.
	Enlarged stocks Due to recent supply chain hiccups, the stock of EMC has been enlarged, requiring higher infrastructures, spaces and energy consumption. The supposed use of disposables from a cost perspective is challenged by this extra storage	Redesign of either the system between the sterilization department and the ICU or an in-situ reprocessing system could be explored.	

3.4 · System directions

Five system directions were ideated based on the challenges derived from the research and are presented in the following section. Eventually, one of these system directions was chosen to develop further.



System direction 1

Design for reuse

Healthcare use of single-use devices has only grown over the past years. This first system direction explores a transition towards reusing appliances, as this could keep resources longer in use and reduce the ICU environmental footprint.

Devices must be reprocessed to be reused, but even considering the use of water and energy of the reprocessing process, reusing allows lower environmental impact than disposables (McGain et al., 2017). It could also enable EMC to reduce its total cost of ownership per device.

A highly available and automated reuse system can be envisioned as a system direction. Automation of the reuse process increases the process standardization, reducing its infection risk. It would also avoid any additional workload for Erasmus MC users. Redesigning a reuse system for the ICU should avoid the past lack of availability of reusable devices, making reuse desirable for ICU users.

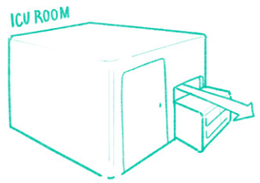
Actionability Medium
Impact High
Strategy Reuse

System direction 2

Design out unused

Currently, more devices than required are placed in the ICU rooms during intubation procedures. The unused waste was estimated at 6% through a waste observation of waste at Erasmus MC Pediatric ICU. A system could be designed to avoid this waste, reducing waste and resources used by the ICU.

This system direction explores changes in the ICU workflows and storage arrangements to reduce unused waste, as optimal use of the storage options could prevent products from entering the room in case they are eventually not used.



Likewise, a system allowing the ICU to clean packaging could be explored, allowing cleaning and thus saving the packed devices from being thrown away unused.

Actionability Medium
Impact Low
Strategy Refuse

System direction 3

Keep in flow after use

Almost everything that enters the ICU rooms is thrown away in a single waste stream, resulting in nearly 40.000 kg of non-hazardous waste incinerated per year. Knowing that 'almost 60% of ICU general waste could be recycled' (McGain et al., 2009) it can be envisioned to ideate a system allowing waste separation in the ICU rooms.

Design for waste separation would allow the implementation of post-use R-strategies. This system direction could reduce the quantities of waste incinerated, the energy usage and the material impact. Devices materials could be reintegrated through recycling or product value preserved through remanufacturing.

Actionability Medium

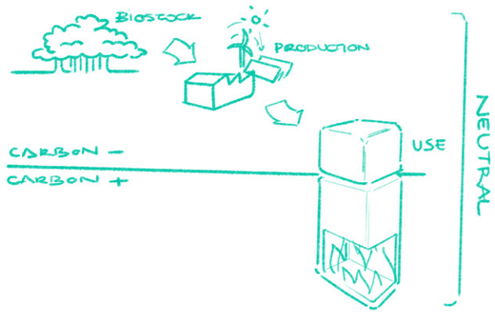
Impact Medium

Strategy Recycle & Remanufacture

System direction 4

Design for minimal impact • Biobased future

Some healthcare products will still need to be single-use to comply with safety regulations, even in an optimistic reuse scenario.
Using carbon-negative materials could ideally balance the emissions hospitals generate throughout use and end of life treatments (Bessai R., 2021). Although most carbon-negative materials are not yet certified by healthcare regulation, this system direction could explore the use of alternative materials in the ICU to reduce its environmental impact.



Actionability Low

Impact High

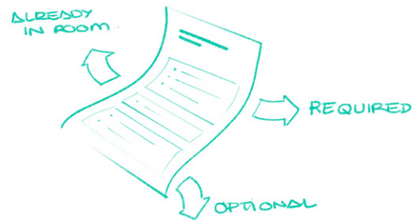
Strategy Reduce

System direction 5

Reducing used devices

Observations highlighted that personal protective clothing is used more than required, and devices enter into ICU rooms that are eventually not used. Also, some devices mentioned in specific operation protocols are already available in the room.

This system direction explores how to reduce unused waste. A redesign of protocols that allows users to know which devices can be potentially already in the room can be envisioned. In addition, raising the awareness of ICU staff on these decisions could avoid nonessential use of resources and reduce waste. This could reduce the environmental impact of the ICU while barely involving changes in the devices themselves, making this system direction highly actionable.



Actionability High

Impact Low

Strategy Reduce

Part 2
Designing circular transition at the ICU
Da tre

Design an intervention allowing reuse
of devices at Erasmus MC

Chapter 4
Ideation

This chapter defines the system direction that will be ideated further: The reuse of intubation devices. To articulate a system that allows reuse of intubation devices, a specific product will be chosen.

4.1 · Selection system & product

System Selection · Design for Reuse

Five system directions allowing the ICU to reduce its environmental impact were presented in the previous chapter. A set of requirements were defined to decide which of these systems should be further explored, which can be found in Appendix E.

The system exploring the use of carbon-negative materials was discarded as it is dependent on regulations and certifications that make this option relatively remote. The two systems that focus on reducing the number of devices entered in the rooms are also discarded as they have a limited impact compared to the other proposed systems.

Therefore, a decision must be made between generating a system for device reuse or waste separation. It is decided to design a system that allows the reuse of devices since it applies 'reuse' a strategy R of greater value than those that could be achieved by waste separation.

In order to redesign a system for reusing devices, additional information on the processes required for reuse in the medical environment will first be presented.

Reprocessing explanation and current reuse scenario at Erasmus MC

For reusing a device in the healthcare environment, this one must go through a reprocessing process. Reprocessing is the act of eliminating microorganisms from reusable devices (Food and drugs administration, 2018). Devices are considered contaminated after usage, as pathogens or transmissible microorganisms from a patient may stay in the product surface.

Depending on the type of contact the product has had with the patient, the reprocessing procedure will be more or less exhaustive. These contact levels are defined as device criticality, further described in Figure 4.1.

Criticality level	Come in contact with
Non Critical	Unbroken skin
Semi Critical	Mucus or membranes
Critical	Sterile tissues or blood

Figure 4.1: Criticality groups depending on the use of the device (Food and drugs administration, 2018)

Based on the product criticality, a different number of reprocessing steps will be required, whether disinfection or sterilization. While disinfection eliminates surface or object microorganisms, sterilization kills all microorganisms, even the ones present in liquids or medication (McKeen L., 2012). Figure 4.2 present the level of reprocessing required depending on the product criticality and the reprocessing techniques used at EMC sterilization department (SD). The SD is mostly used by EMC operation rooms (OR) to its complete capacity of 750 instruments reprocessing per day.

Steam disinfection and sterilization has a high energy demand
Based on McGain study (2017), an autoclave uses **1.9 kWh** per kg of device disinfected.

High water usage
An autoclave uses **58L** per kg of device disinfected.

Trays that also require cleaning
are used to transport devices and will also need to go through the whole reprocessing system, increasing the environmental impact associated with each device.

Figure 4.3: Challenges of reprocessing: Water and energy required to reprocess

The technique used to reprocess semi-critical and critical devices at the SD has a high environmental impact (Figure 4.3) and entails the use of disposables (Figure 4.4).

Multiple disposables are needed to reprocess devices, generating a high material cost and also larger quantities of incinerated waste.

As Leident (2017) indicates in his study, steam reprocessing can cause a higher environmental impact than disposables solutions.

Disposables used during reprocessing

Single use steril Sheets
Used to envelop sterilized devices, around 1.4kg are used per operation set sterilized (Leident at al. 20202).

Packaging
Devices are packed to be brought back to the departments sterile.

Wipes
Used to clean non-critical devices are also single-use, generating waste

Protective clothing
Extensive use of PPE is done at the SD due to high cleanliness regulation of this environment

Figure 4.4: Disposables generated when reprocessing devices.

Takeaways:

Higher devices criticality entails a higher environmental impact during its reprocessing. However, steam reprocessing could be replaced by alternative solutions of lower environmental impact. Products could be redesigned to require fewer reprocessing steps.

To articulate a tangible proposal on how to reuse devices at the ICU, a specific product was chosen.

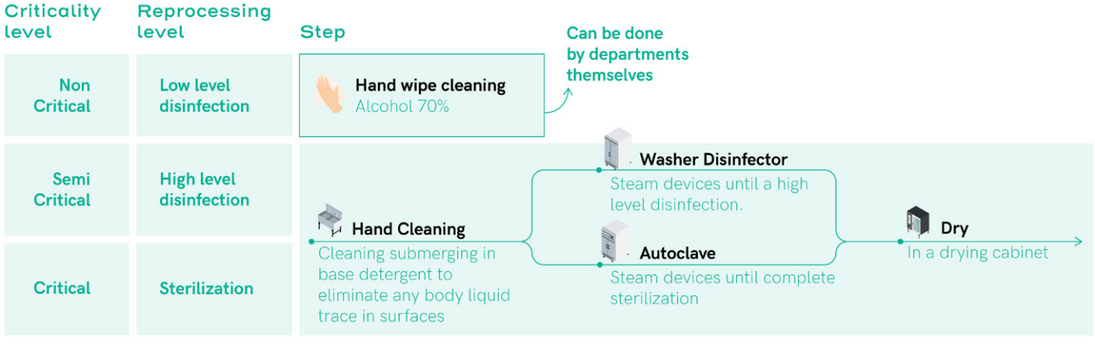


Figure 4.2: Reprocessing method depending on product criticality. Complete reprocessing include more steps of inspection and cleaning not indicated in this graphic.

Product Selection: Video laryngoscope, example product for reuse

To create a tangible pilot towards devices reuse, a specific product used throughout the intubation process was chosen. Further system design is articulated around this product.

A set of criteria were defined to choose between the different intubation devices. The criteria aim to spot devices that cause a higher environmental impact.

- **Material impact** Material harmfulness for planet or people
- **Material scarcity** Possibilities of supply chain hiccups
- **Lifetime** Disposable or reusable nature of each device
- **Weight** Product weight, impact on waste quantities
- **Quantity** Number of different materials per device
- **Cost** Device procurement cost
- **Intensity** Device units used per intubation

Applying these indicators, the video laryngoscope was chosen as the example product for further ideation. Further detail of this decision can be found in Appendix F.

A video laryngoscope is a device used by doctors to see the interior of the patient's throat while placing the intubation tubes into the lungs (Figure 4.5).

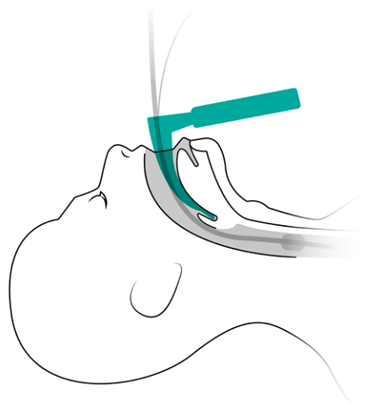


Figure 4.5: Use of the video laryngoscope during intubations.

The product counts with a camera and a light, as the doctor will use the images captured by the camera to place the tube properly within the patient's throat (Figure 4.6).

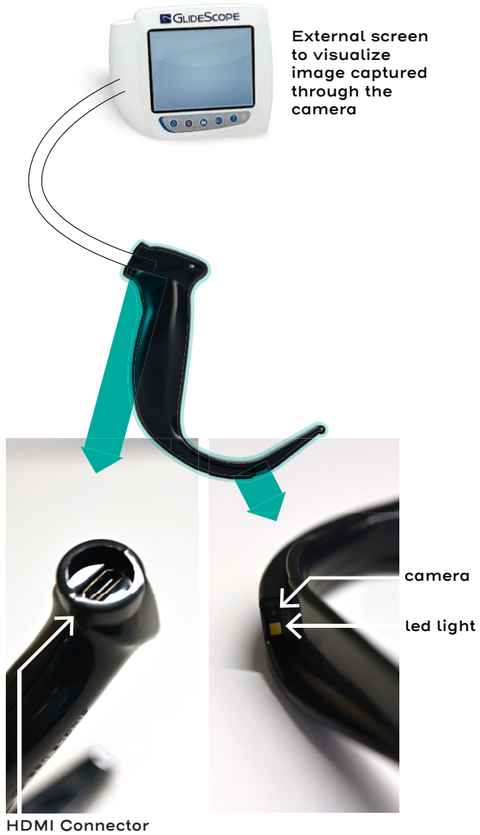


Figure 4.6 Overview components and use of the video laryngoscope.

This device is used for about a minute. After this, it will be disposed of and incinerated, making the current use of video laryngoscopes highly unsustainable due to the following reasons:

Toxicity of e-waste incineration The VL contains materials such as copper, which the residues can result toxic for land and humans (William et al. 1993).

Plastic cover criticality The black cover around the product is made from Acrylonitrile butadiene styrene (ABS). When burned, this material gives off a high smoke generation, which could cause concerns around air pollution. ABS is a petroleum-based and non-biodegradable plastic of high environmental impact.

High Financial Cost
Based on online price research, it has been hypothesized that each of these devices is purchased by EMC to a cost of 60 euros the piece. Knowing that more than 550 intubations are realized per year at the ICU, this device is costly for EMC.

The materials resources and the energy input needed for the production, transport, use and incineration produces a high CO2 footprint (Figure 4.7).

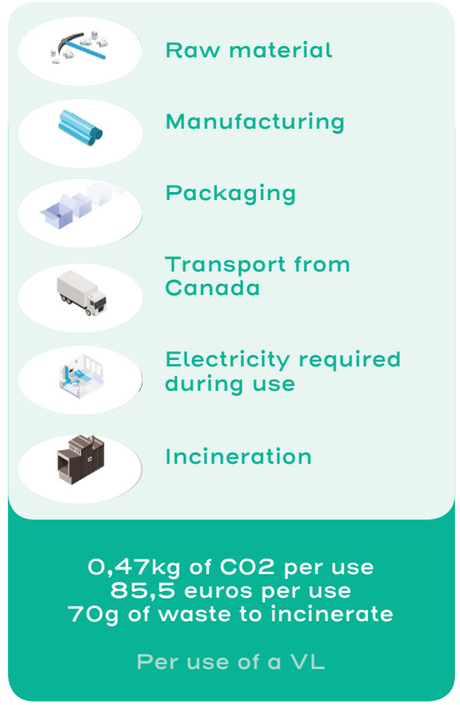


Figure 4.7 Overview steps life cycle video laryngoscope and estimation of waste quantity, price and CO2 footprint (Appendix G).

Reuse of the video laryngoscope

If reused, video laryngoscopes are considered a semi-critical device (Figure 4.8), meaning that high-level disinfection would be required, currently done at EMC with steam disinfection of over 100°C.

However, the current video laryngoscope used at the ICU is meant to be single-use. The product electronics are sensitive to heat and cannot be exposed to temperatures above 60°C (Verathon, 2020).

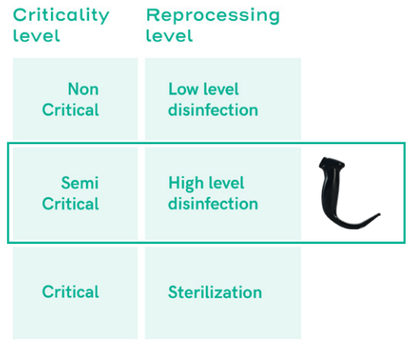


Figure 4.8: Video Laryngoscope, consider semi-critical device unless it enters in contact with blood through the procedure.

The used devices cannot be reprocessed in the current system available at EMC. However, McGain et al study (2017) demonstrate that laryngoscope disposability has a higher environmental and cost impact than their sterilization.

The reuse of the VL could reduce the environmental impact of the intubation process. A system allowing VL reuse without compromising the safety or requiring additional work to the ICU staff can be envisioned. Therefore, ideation upon how to allow reuse of the video laryngoscope at EMC ICU was done.

Concept statement

Enable a safe and hassle-free reuse of the video laryngoscope at the ICU with the lowest environmental impact

4·2 · Ideation Approach

Ideation was undertaken upon how to reprocess video laryngoscope at ErasmusMC ICU. Multiple ideas were generated at different scopes (Figure 4.9).

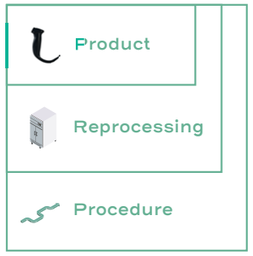


Figure 4.9. Ideation scopes

A set of guidelines were created to guide the ideation:

Environmental

Optimized product
Redesign the video laryngoscope to allow the least reprocessing impact possible. Allow the video laryngoscope resources to have a lower environmental footprint. Redesign the device to stay longer in use.
Optimized reprocessing
Redesign the reprocessing techniques towards minimizing environmental impact. The final system must have a lower environmental impact than the current ICU usage of the video laryngoscope.

Safe

Available
Reuse of video laryngoscope without compromising the device availability at the ICU.
Safety
Without compromising patient safety, allowing reuse with low infection risk rate.

Hassle free

Responsibility free
Redesign the reprocessing system to allow ICU nurses to be as free of responsibilities towards the reprocessing quality as possible. In other words, automating as much as possible the reprocessing system.

Actionable

Technically feasible
The proposed system must make use of technologies already on the market, and it must comply with the EU 2017/745 regulation.
Feasible for EMC
The proposal must fit within the current ICU scenario.

The ideas generated have been organized into four categories:

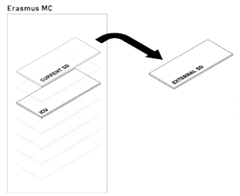
- **Where**. Presents the ideas generated on where to reprocess the video laryngoscopes within Erasmus MC.
- **Product**. Presents the ideas generated around the product itself to allow its reuse.
- **Reprocessing**. Presents the ideas generated on how to change the reprocessing system that Erasmus MC is currently using towards lower environmental impact.
- **Procedure**. Presents the ideas generated on how to improve the reuse logistics at the ICU.

Finally, some ideas were selected from each category and merged into a pilot allowing reuse of the video laryngoscope.

4·3 · Ideas overview

Location Reprocessing

The current sterilization department (SD) is already used to its maximal capacity, therefore a new facility is needed.
The SD could be outsourced and developed by an external company, kept in-house with a bigger central location or decentralised and done at the ICU itself.

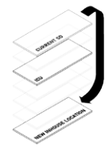


Outsource SD

Outsource the reprocessing

This would allow lower management complexity of risks, standards, inspections, etc. It could be also envisioned to further collaborate with other hospitals, or sterilization innovations such as gamma or UVC. It is also more easily scalable.

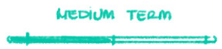
However, longer distances need to be travelled by the devices, increasing the video laryngscope stock needed at EMC. It would also lower EMC resilience.

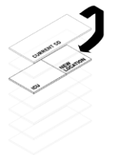


In house relocation SD

Relocate the reprocessing department

In house relocation of the sterilization department would allow higher control, as it would still be a centralized in-house process. However, this would require a high investment.



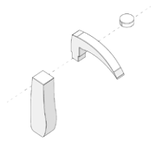


SD at the ICU

Allow reprocessing at the ICU itself
Reprocessing the devices in the ICU would avoid the transport of contaminated devices, allowing a higher availability and control over the devices. However, its scalability is restricted.

Product level ideation

First, ideation was carried out focusing on the video laryngoscope. It was investigated how the product could be redesigned to reduce the environmental impact its reuse entails.



Modular & Dissasemble

Hybrid devices

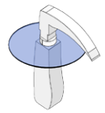
The video laryngoscope is reprocessed as a semi-critical device. However, the handle of the product, which the doctor uses to hold the product, does not come into contact with the patient. Therefore, this part could be reprocessed as a non-critical device if it could be separated from the rest of the product.

Could a modular video laryngoscope be designed? These types of products are called 'hybrid devices' in the medical environment, consisting of a product with detachable parts, which allow the reprocessing of each part using different methods. These kinds of devices are already available for video laryngoscopes in the market.

This would extend the use life of each part to their maximum, as each piece could potentially have different fixed reusing cycles (Kane et al., 2018). Each component can have its own resistance to fatigue or damage without compromising the other parts.

- Save resources by refusing additional reprocessing steps
- Allows different lifetimes for each part optimizing material resources.

- Connections might make reprocessing more complex



Physical infection barrier

Product Indicators

Design of physical barrier for infection prevention.

The video laryngoscope should be completely reprocessed as a semi-critical product.
What if a physical barrier could be designed between the patient and the product to reduce the device's criticality? This could lower the number of reprocessing steps required and reduce the environmental impact of reuse.

- Reduces the device criticality, allowing reprocessing using less resources.

- Increases the number of product parts to be reprocessed, or generates a product to be discarded.

Product indicators

Design for a product that indicates the cleaning needed. What if materials used in devices could help nurses at the ICU quickly identify which level of sterilization the device parts need?

- Ease nurses' workflow by giving visual clues.
- Refuse additional reprocessing steps, saving resources.

- Technical feasibility to be proven.
- The redesign involves manufacturers more than EMC.

Reprocessing level ideation

As stated before, the reprocessing system itself has an environmental impact. The following three ideas reflect on how the environmental impact of the video laryngoscope reprocessing process could be reduced.

Alternative Sterilization

Alternative reprocessing tecnologies

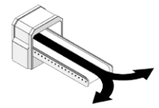
Sterilization by steam has a high environmental footprint. However, alternatives such as gamma or UVC sterilization have environmental benefits compared to steam sterilization as less energy and no water is required (Leiden, A. et al., 2019).

These technologies that do not require the use of high temperatures to disinfect would allow a broader range of materials to be reused. The use of polymers in the video laryngoscope instead of metals could be considered, thus reducing not only the environmental impact of the reuse process but also the environmental impact of the product.

- Allows reuse of a wider variety of materials than steam disinfetion.
- Reduction of the environmental impact of device reprocessing.

- Gamma requires major structural changes in order to be implemented.

MEDIUM TERM



Refuse additional steps

Identify a device's criticality level to refuse additional reprocessing steps

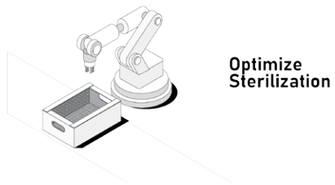
The video laryngoscope is considered a semi-critical product. But in case it comes in contact with patient's blood, it should be considered as critical and receive a different reprocessing, with a higher environmental impact.

Sterilization of the device is needed only when it crosses the patient blood barrier.
This idea consists in having a blood detector module to detect if the blood barrier has been crossed or not to avoid the sterilization step when possible.

- Refuse additional cleaning steps than required, saving resources.

- High investment
- Technical feasibility to be proven.

LONG TERM



Optimize Sterilization

Optimizing reprocessing trays

If the space inside steam disinfection machines is not properly optimized, the environmental impact of the reused devices increases (Leiden at al., 2020).

A process that optimizes space within the steam disinfection machines could be designed. The space could be optimized by placing devices in modular trays instead than in individual sets of instruments.

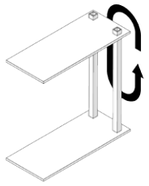
- Reduces environmental impact of steam disinfection.

- High investment
- Technical feasibility to be proven.

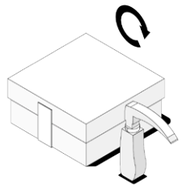
LONG TERM

Procedure level

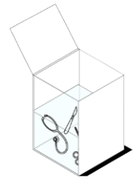
It has already been explained that the UCI stopped reusing devices due to logistical and other inconveniences. Therefore, an ideation on how to improve the logistics around the reuse of video laryngsocopies was carried out.



Compressed air pipe system



Reusable packaging



ICU cleaning Automation

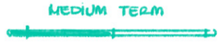
Compressed air pipe system

Inspired by the current pipe system used to transport medicines between different departments of Erasmus MC, a compress air pipe system could be designed to transport the devices from the ICU to the sterilization department.

Using a dedicated pathway to move these contaminated devices from the ICU to the central sterilization facility would reduce the risk of infection during transport. It could also increase devices availability as this system offers fast transportation.

- Time saving
- Reduction of infection risk during trasnport.

- High investment
- Restricts dimensions of reusable devices.



Reusable packaging

A redesign of the video laryngoscope packaging that also can be reused could improve the logistics around the product reuse.

Having each reusable device associated with its own hard container could make handling of the product easier both at the ICU and SD. It could enable better traceability of the product throughout the reprocessing procedure.
A reusable packaging could reduce the use of other containers, packaging and wrapping papers throughout the reprocessing system.

- Avoid usage of wrapping paper, repacking every cycle, etc.
- Can optimize workflow at the ICU

- Throwing away the packaging may result in less environmental impact than to reuse it.

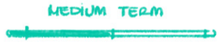
Reprocessing automation

When devices were reused in the ICU, nurses had to clean the products themselves. This step consisted of clearing semi-critical and critical devices from blood or other body liquids before sending them to the sterilization department. How could this step, which generates dissatisfaction among ICU users, be eliminated?

A device that would automate the cleaning system to be carried out in the ICU can be imagined. This would reduce the workload for ICU nurses, as well as reduce the chances of human error that manual cleaning entails, leading to a lower risk of infection.

- Reduces risk of infection
- Reduces nurses' workload

- Feasibility to be proven.



4.4 · Selection

A set of selection criteria were developed to evaluate the ideas presented previously:

User interest
The different ideas were presented to a nurse to evaluate the desirability of each idea (Appendix H). From this interview, it was concluded that users are mainly interested in the automation of the reuse process.

Implementation speed
Ideas selected should be implementable in a short term scenario. Ideas which required redesign of either the product or the reprocessing system which where not yet available in the market were not further considered.

Environmental impact
Proposals reducing the environmental impact of the reuse system of VL will be priorized. The ones that might increase the footprint should be not further consider.

Circularity demonstrator
Ideas selected should demonstrate an application of circular practices. They should allow the ICU to catalyse further circular practices implementation

Selected ideas

Four ideas were selected for further development, that will be further explored and combined into a system in next chapter. Appendix H further explains this selection process (Figure 4.10).
It was decided to opt for a pilot system that would allow reprocessing of the video laryngoscope in the ICU itself. This location was selected because it enables the ICU to be resilient and could be implemented in the shorter term than the other alternatives considered.

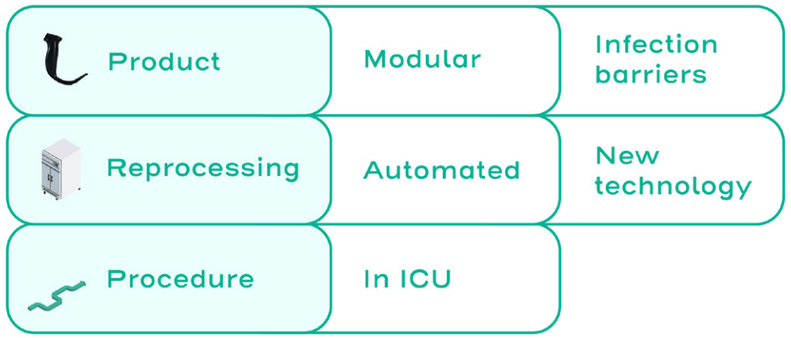


Figure 4.10. Selected ideas that will be combined into a system proposal.

Chapter 5
System design for VL reuse

In the following chapter, the system proposed for reusing video laryngoscopes at EMC ICU is presented. First, an overview of the roadmap will be given, followed by some description the two stages of the pilot as well as how could it be further scaled up. Finally, an evaluation of the proposal is presented.

5·1 · Proposal overview

This proposal proposes an actionable plan to reduce the impact of intubation procedures at the ICU. A first pilot proposal allowing the reuse of video laryngoscopes is presented, from where further expansion can be envisioned.

The system allows reuse at the ICU itself to allow the feeling of manageability and feasibility.
The transition of reuse at EMC could happen in four steps: Reduce, reuse, expand and replicate as Figure 5.1 presents. Details on the pilot proposal can be found in the following pages.

Horizon 1: Complete reuse of the example product, the video laryngoscope.

- **REDUCE** Allows reuse of the current ICU video laryngoscope by adding a cover. The cover allows the device not to touch the patient, lowering the product criticality. The video laryngoscope could be reused, and a reprocessing system of non-critical devices at the ICU itself is proposed.
- **REUSE** Proposes complete reuse of a hybrid video laryngoscope using UV-C reprocessing. Design of the reprocessing area and device traceability is proposed.

Horizon 2: EXPAND. Expand the system of reuse to other devices used at the ICU

Horizon 3: REPLICATE. Replicate reuse system of the ICU in other departments of EMC.

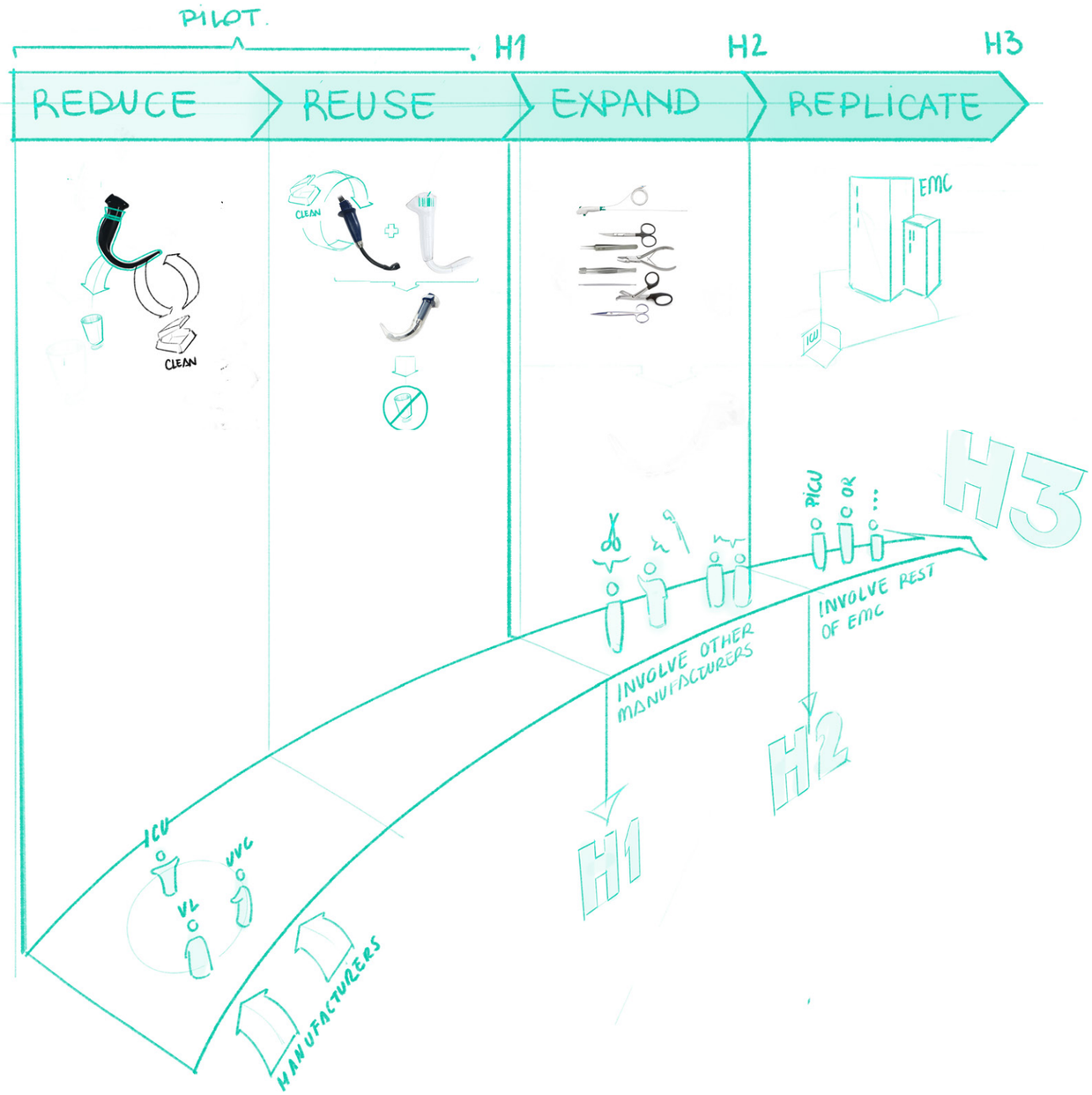


Figure 5.1. Overview proposal horizons

5·2 · Reduce

Reduction of waste using covers

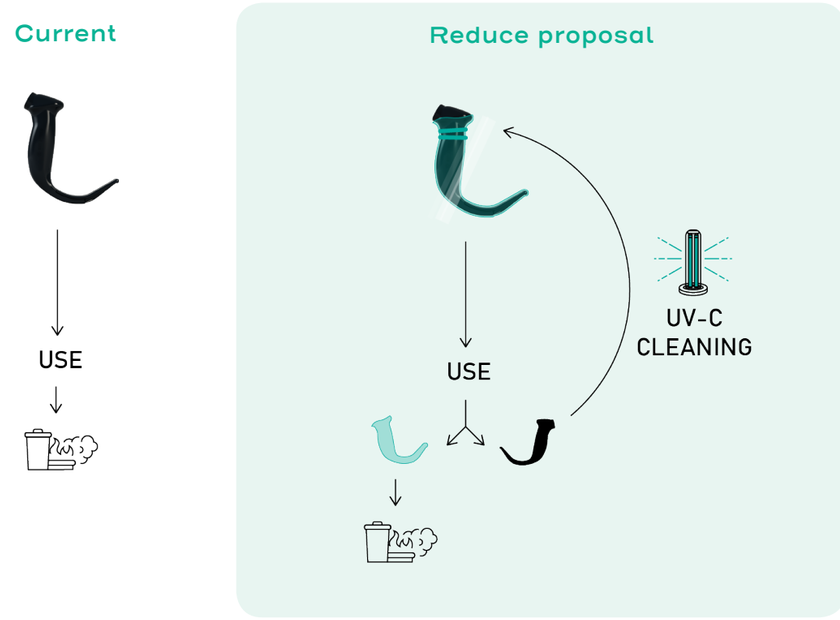


Figure 5.2. Overview current and proposed use of the VL.

The first proposal involves adding a transparent thin plastic cover made from polyethylene (PE) on top of the product during its usage (Figure 5.2). This keeps the video laryngoscope out of body liquids contact, allowing its reuse as a non-critical device.

Non-critical devices only require low-level disinfection that can be done automatically at the ICU with UV-C technology. UV-C would replace hand cleaning with cleaning wipes, making the process quicker and more automated.

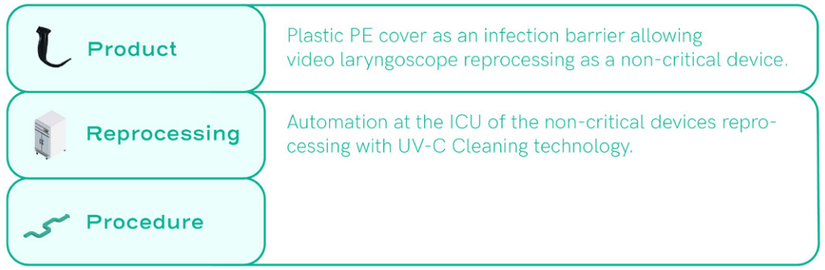
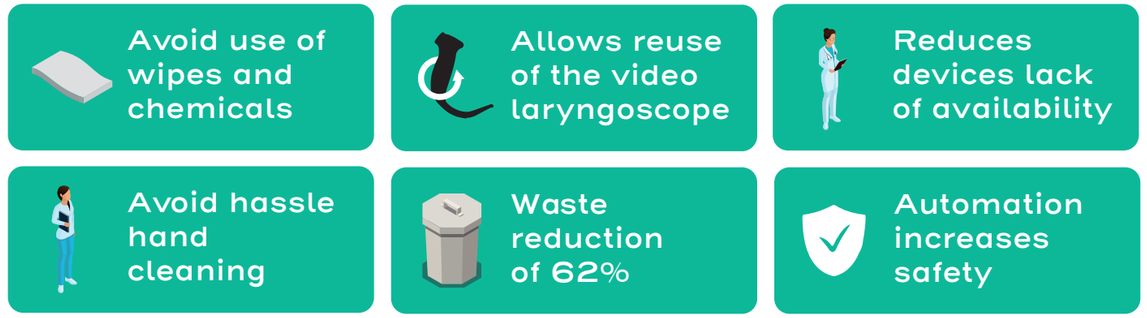


Figure 5.3. System changes at a product, reprocessing and procedure level



Environmental	
CO2	Waste
This proposal would allow us to reuse the same video laryngoscope 1000 times instead of only once. The CO2 footprint (kg) would reduce by 92% for each intubation (Appendix F), considering the material production, device transport, reprocessing and end of life treatment.	Per intubation, the waste quantities generated by a video laryngoscope (kg) compared to the current scenario would be reduced by 69% (Appendix F), considering the device and its packaging. Waste is reduced as each video laryngoscope is reused up to 1000 times instead of only once. Also, automating the cleaning avoids the use of cleaning wipes. This waste and the chemical toxicity the wipes imply is avoided.
People	
User	Patient
Covers are already used for similar devices. ICU doctors and nurses already use similar protocols and workflows, increasing the proposal acceptability. The video laryngoscope model remains the same, also increasing doctors' acceptance.	The lack of availability, which could jeopardize patients' treatment quality in previous reuse scenarios, is avoided by keeping the whole reprocessing system in the ICU. The cover, only part in contact with the patient, would still be disposed of, avoiding infection risk.
Organizational	
Risk Management	Financial
The product in direct contact with the patient is still disposed of after a single-use, allowing infection risk avoidance. Additionally, automation of the cleaning procedure allows higher standardization than hand cleaning. Therefore, this would suppose a lower level of risk management than previous reuse of non-critical devices could imply.	Investment in a UV-C low disinfection machine and on the covers is required. However, this would allow the reuse of a 60 euro piece video laryngoscope up to 1000 times.

Proposal detailing

Reprocessing

This system proposes to explore new technologies for reprocessing medical devices, as previous ideation revealed the environmental potential that alternatives to steam sterilization may have. An investigation of the different alternatives for reprocessing non-critical and semi-critical medical devices was carried out, and can be consulted in Appendix H. This search concluded that UV-C radiation technology has the most significant potential for implementation in the ICU.

UV-C radiation is a radiation of a specific wavelength. Lamps emitting this radiation can be used to disinfect surfaces. Indeed, UVC radiation has been used for decades to reduce the spread of bacteria, and its use during the COVID-19 pandemic has allowed this technology to be recently certified for use in hospitals. Even if only suitable for decontaminating surfaces, this technology fits this pilot purpose as the video laryngoscope requires disinfection only on its external surfaces.

With UVC technology, cleaning of non-critical medical devices can be fully automated, avoiding any additional device cleaning work for ICU nurses. UVSmart, a dutch start-up based in the Hague (the Netherlands) developed a UV-C disinfection appliance that allows cleaning of non-critical devices in 25 seconds (UVSmart, 2018). This result is five-time faster than manual cleaning, and reduces responsibilities for the nurses. Also, UVC requires drastically less energy and resources than wipe or steam disinfection. In this pilot, UVC would replace the use of detergent-impregnated wipes, reducing the quantity of waste to incinerate.

Due to the numerous benefits of this technology, its use is proposed in this pilot project. The disinfection devices developed by UVSmart will be considered, as their location makes them potential collaborators. Also, their devices are already certified, which facilitates the implementability of this proposal.

Figure 5.4: D25 UV-C Cleaning device

D25 (Figure 5.4) facilitates the reprocessing of non-critical devices automatically, and complies with (UVSmart, 2020):

- NEN-EN 60601-1 meaning it complies with the general safety requirements for medical electrical equipment (UVSmart, 2021).
- EN 14885, meaning it achieves the same level of disinfection as wipes and liquid.
- NEN-EN-ISO 13485, demonstrating compliance with the legal requirements for medical devices.

Product

This pilot proposes to reuse the video laryngoscopes currently in use in the ICU. Using the available video laryngoscope allows the ICU to use their stock until depletion, ensuring that no additional waste is generated by discarding them unused.

However, this model is supposed to be used only once. In order to use this device, the manufacturer, Verathon, would need to approve the following two changes in their product use procedure:

· The reuse of the device through a UV-C low-level disinfection procedure
This product could be reused with UVC technology since it only needs disinfection of its external surface. Also, the product is made of ABS, a plastic compatible with UVC technology (as it will be explained in more detail in the evaluation section).

· The use of the device with a cover
As discussed above, using a cover over the video laryngoscope is proposed to prevent the product from coming into contact with the patient. By not bringing the device into direct contact with the patient, fewer reprocessing steps will be required, as fewer microorganisms will come into contact with the video laryngoscope.

For manufacturers to approve the use of a cover on top of the product, the product performance must not be threatened by the cover. A first hypothesis was formulated that a cover already used by the ICU for another device could be reused in the video laryngoscope (Figure 5.5). After testing the use of this product with the cover, it was found that the cover should be redesigned specifically for the video laryngoscope used so as not to affect its usability.

Figure 5.5: Video Laryngoscope with the plastic cover available at the ICU, intended to be used on another device.

A number of requirements that such a cover should meet are listed below. For each of these requirements, a series of tests that could be carried out to develop a functional cover are also proposed.

- The cover surface should be as close as possible to the camera.
- The cover surface should not have any wrinkles in front of the camera.
- The surface of the cover should be parallel to the camera to not generate any deformation in the image captured by the camera.
- The material of which the cover is made should be clear to not interfere with the quality of the image captured by the camera.

This graduation has not generated a final model of this cover but has performed some shape explorations, presented next.

Cover shape exploration

The geometry of the video laryngoscope generates a cavity where the camera is located. It can be investigated to generate a tight surface between the walls of the product (Figure 5.6a). Conversely, a test to minimize the distance between the camera and the cover can be carried out (Figure 5.6b). To generate a surface that is parallel and close to the camera, the following techniques could be explored:

- A series of specific guided folds could be designed into the cover to conform to the shape of the product.
- The use of heat shrink wrapping techniques could be investigated. This technique allows thin plastic surfaces to adapt their shape under heat. This can be used to adapt the cover shape to the one of the video laryngoscopes.
- It could be experimented with to create a cover with a thicker rigid part in front of the camera (Figure 5.6c).

Figure 5.6: Cover shape exploration

To conclude, additional tests should be carried out to develop the cover. Based on this exploration, an action plan is presented in Figure 5.8 which sets out the next steps that should be carried out by Erasmus MC in order to reach an implementable level of this pilot project.

Procedure

The dimensions of the UVC disinfection devices are relatively small (55.7 x 48.9 x 29.7cm), which allows their incorporation in the current ICU setup.

As the reprocessing of non-critical devices does not require a sterile environment, this means that the machines could be placed in numerous locations throughout the ICU. After consultation with users, it is suggested to place the disinfection device next to the intubation trolleys, where numerous devices used for intubation are stored. This way, nurses could quickly implement the additional reprocessing step in their workflow.

Figure 5.7 presents the different steps that a nurse should perform in the proposed system and visualizes the locations where the reprocessing system can be placed.

Points of vigilance

Covers could potentially break in some scenarios due to the contact with the patient teeth. In such a situation, the video laryngoscope would have to be disposed. The criticality of the product would be increased and no reprocessing technique available at EMC could reprocess the product without damaging it. For this reason, tests have been added to the action plan (Figure 5.8) to evaluate the resistance of the cover in use situations.

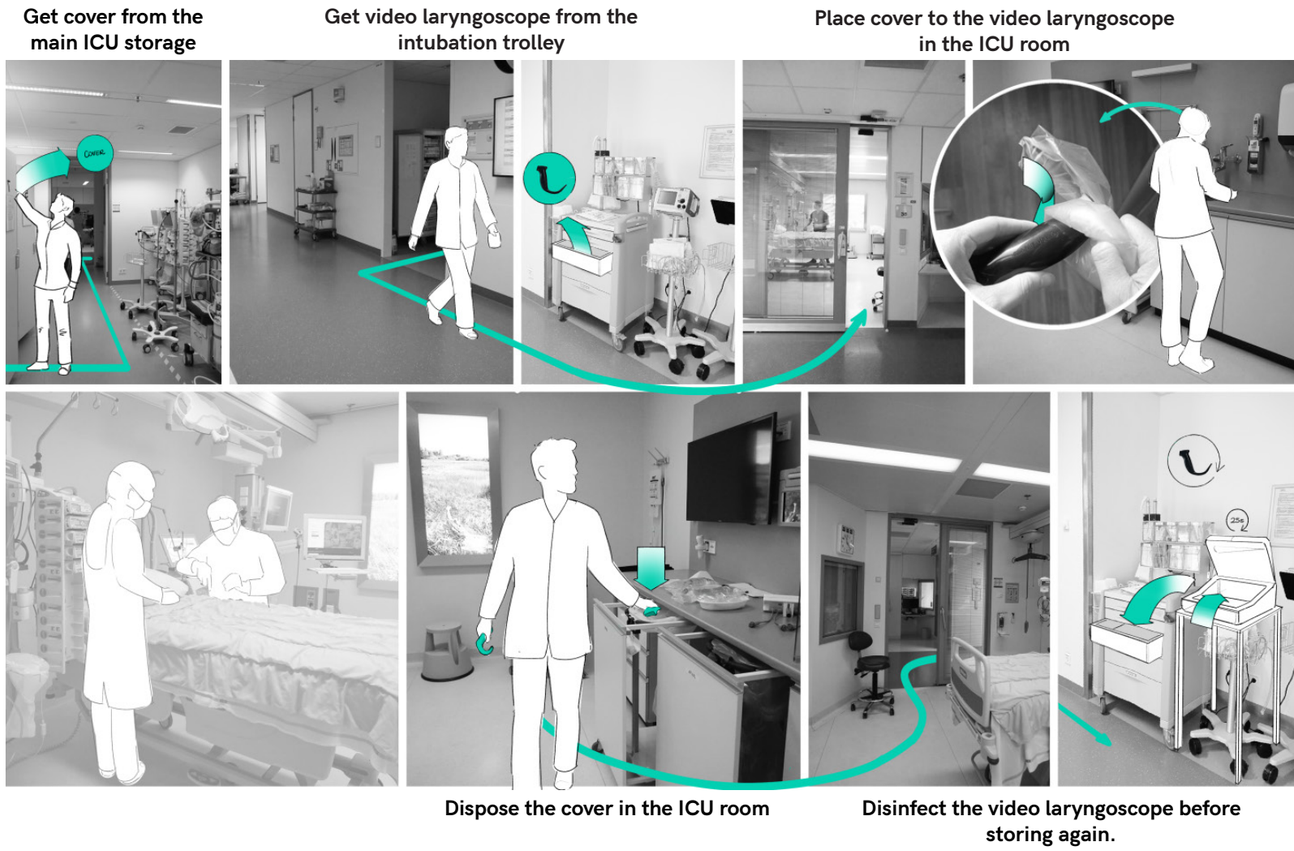


Figure 5.7: Overview procedure.

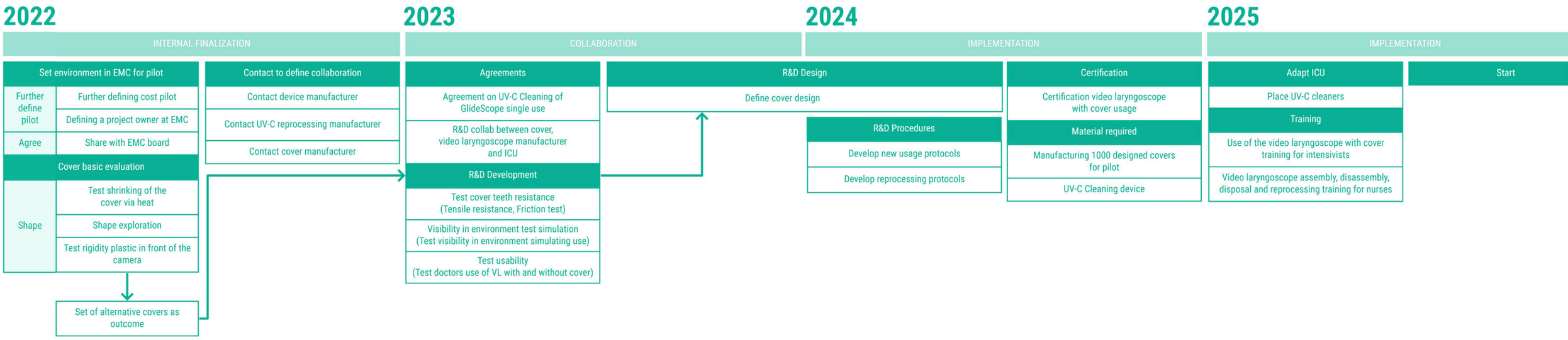


Figure 5.8: Action plan for REDUCE pilot proposal

5·3 · Reuse

Redesign for reuse through UVC disinfection

Figure 5.9. Overview current and proposed use of the VL.

VL reuse can be pushed further, towards the reuse of all physical parts of the device.

'Reuse' consists of making use of both a UV-C high disinfection system and a hybrid device. Parts of the VL in contact with the patient are separated from the ones that have not and each reprocessed with their corresponding disinfection level.

Reprocessing of non-critical and semi-critical devices can be done both using UV-C technology, resulting on a lower environmental impact than current technologies (Figure 5.09 and 5.10).

Product	The hybrid VL comes in 2 parts: the main body and an external blade. The body will not get in contact with the patient, thus can be reprocess as with low disinfection. The semi-critical blade is made from PC, allowing reuse through high-level disinfection.
Reprocessing	High level disinfection can be also done using UV-C technology, at a lower environmental cost than the currently used steam based reprocessing.
Procedure	The UV-C device dimensions and technical requirements fits the current ICU, reuse of the whole VL can be done at the ICU itself and with maximum automation.

Figure 5.10. Overview changes on a product, reprocessing and procedure level.

Allows reuse of the whole device

No use of water

Reduce devices lack of availability

Waste reduction of 80%

Reduce energy consumption

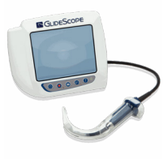
Environmental	
CO2	Waste
The CO2 footprint (kg) could reduce up to 83% for each intubation, considering the material production, device transport, usage, reusing and end of life treatment.	This proposal would allow the same video laryngoscope blade to be reused around 100 times instead of only once. The video laryngoscope body could be reused for a 1000 cycles. Compared to the current scenario, the waste quantities generated by a video laryngoscope would be reduced up to 80% per intubation (Appendix F).
People	
User	Patient
The new hybrid video laryngoscope presents multiple similarities to the video laryngoscope currently used at the ICU, as the same manufacturer produces it. This increases the physicians' acceptance of the pilot.	Reprocessing of the video laryngoscope could be done entirely at the ICU. Not relying on the sterilization department allows the ICU to be resilient, to increase devices availability and patient safety.
Organizational	
Risk Management	Financial
Reuse allows hospital resilience by not being dependent on single-use devices manufacturers.	Reprocessing semi-critical devices through UVC technology would allow EMC to economize on both water and energy consumption compared with current reprocessing technologies based on steam disinfection. The payback time of this pilot, supposing 600 intubations are performed per year at the ICU, is of 5 years.

Proposal detailing

Hybrid medical devices allow us to separate the parts of the same device according to their level of criticality. In this way, additional steps during the device reprocessing are avoided, saving resources.

A number of video laryngoscope models have been compared in Appendix I, from which it was decided to choose the model shown in Figure 5.11c for this pilot project, the GlideScope Video GVL. This product has a central body (Figure 5.11b) where all the electronics are located, and a solid, translucent blade above it (Figure 5.11c).

(a)



(b)

(c)

Figure 5.11: Proposed videolaryngoscope

Keeping all the electronics in the central body of the video laryngoscope reduces the criticality of this product, avoiding electronic connections between the two modules. This increases the acceptance of this product by its users and the product use safety.

Finally, using a device from the same manufacturer as the video laryngoscope currently in use also increases the acceptance of this device change by doctors, as the shape and use of the device are similar. In addition, the screens and cables that the ICU already has could continue to be used.
The current product's instructions state to discard the blade after a single-use. The blade is considered a semi-critical element, as it comes in direct contact with the patient's mouth. According to the manufacturer, this blade made of polycarbonate (PC) should not be exposed to more than one 60°, according to the manufacturer. Therefore, the reprocessing this product is not considered because the most common way of disinfecting semi-critical items involves the use of high temperatures and steam.

This pilot proposes to reuse this blade using UV-C technology.

As in the previous system, this system proposes to reprocess the product with UVC technology. The difference is that this time, the blade has been in direct contact with the patient and therefore requires a high level disinfection. This technology is currently available, the use of D60 (Figure 5.12), allows the disinfection of semi-critical devices in 60 seconds.

Figure 5.12: D60 UVSmart (UVSmart, 2022).

In order to reuse this blade, which is currently designed for single use only, it was redesigned.

It is proposed to change the blade material to one that is highly resistant to UVC radiation, as well as to add a traceability system to the product to count the number of reprocessing cycles it has undergone (Figure 5.13).

The current blade design offers no means to trace the product record. This feature is required to count reprocessing cycles the devices have gone through and ensure that the product has been properly reprocessed before reuse.

By adding a barcode on the external surface of the product, the product could be scanned each time it is to be disinfected. This scanning system, which is already included in the UVC machine, ensures that the disinfection process has been correctly performed before storing the device for further use. Eventually, It would inform

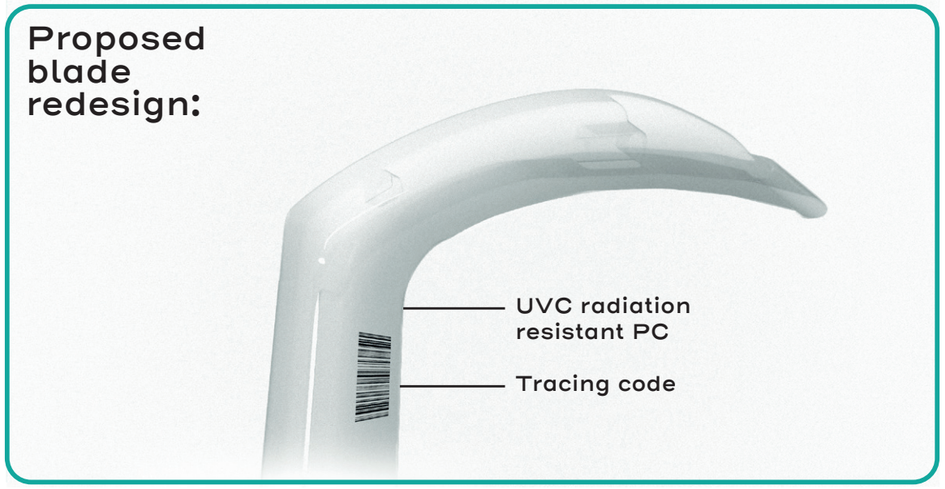


Figure 5.13: Blade redesign proposal: Change of material and addition of a QR code.
The shape of the transparent blade would not be adapted from the current Verathon design.

the user when the product has reached its maximum number of reuses, allowing nurses to discard the product in time.

Procedure

The main body would be, likewise the first proposal, reprocessed after not having been in contact with the patient. Reprocessing the blade would entail the following steps (Figure 5.14): First, the nurse would manually clean the product in the room. Then, in the reprocessing area, she would first use the high-level disinfection machine to scan the product and place it inside. Then, when the cleaning cycle is complete, the product would be placed in a sealed plastic wrapper until its next use.

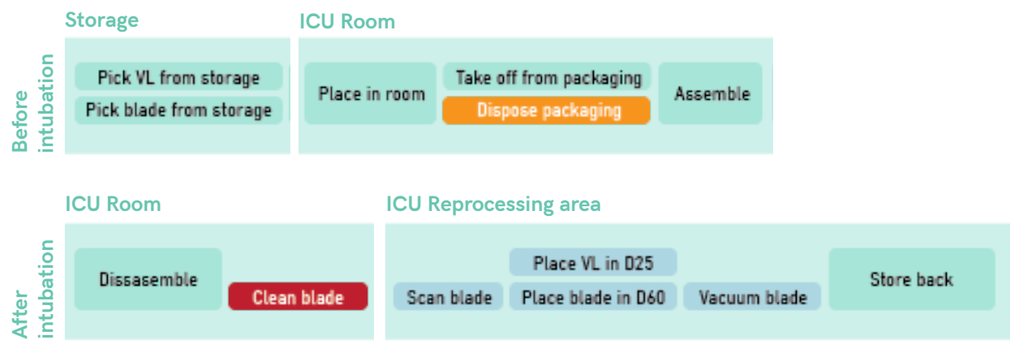


Figure 5.14: Nurse workflow to reuse a video laryngoscope

The reprocessing area would need to include the UVC low and high level disinfection machines and a sealing device for the packaging. These devices would require a surface of 165cm x 90cm every two ICU units to be located at (Figure 5.15). After users consultation, it is considered to locate this reprocessing area in one of the corridors connecting two ICUs areas.

The action plan presented in Figure 5.16 proposes the steps that UCI should undertake in order to further develop this pilot proposal to an implementable level.

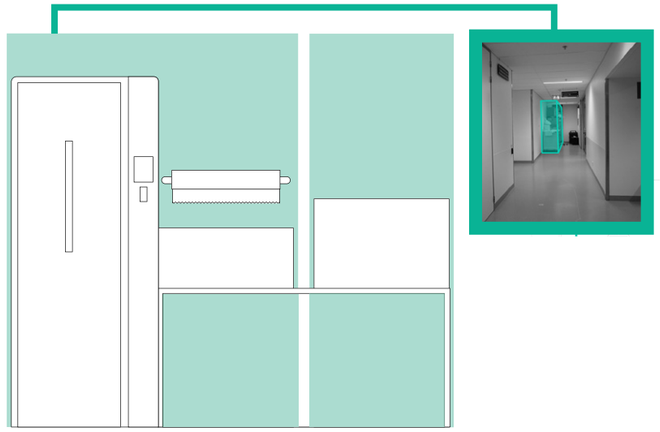


Figure 5.15: Map of the reprocessing area layout. (Left to right: D60 High Disinfection - 86.1 x 47.3 x 203.3 cm, sealing machine - 59 x 48.7 x 24.1 cm, D25 Low disinfection - 55.7 x 48.9 x 29.7 cm)

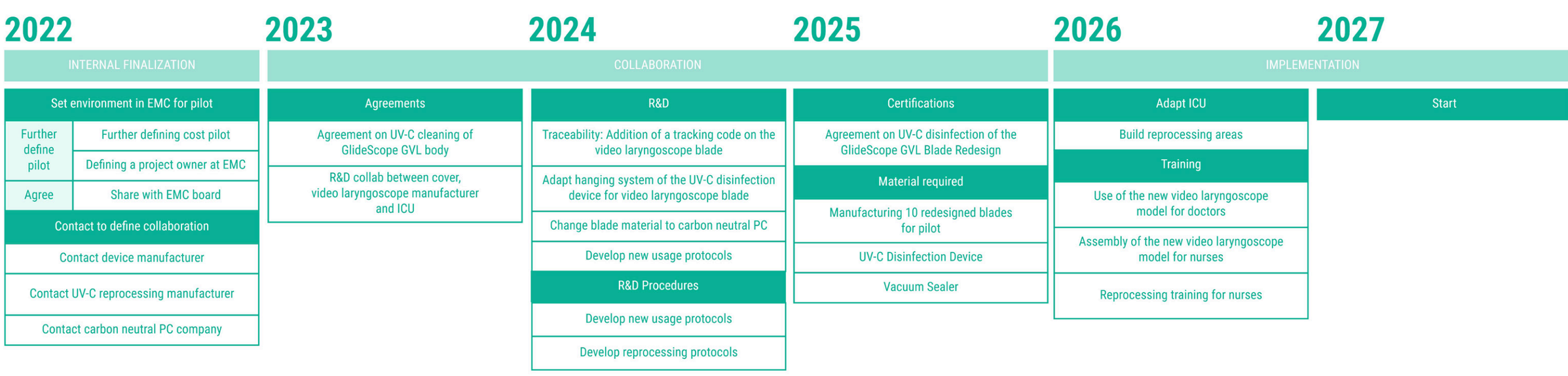


Figure 5.16: Action plan for REUSE pilot proposal

5.4 · Expand

Reuse other ICU devices

The pilot proposes the reusability of specifically the VL as a forerunner. If the pilot is implemented successfully, transition to further devices reuse can be done. The different ways the pilot could be expanded in the ICU are mentioned hereunder.
In Figure 5.17, we have evaluated which devices used throughout the intubation to detubation system could be reused through this pilot expansion. It should be noted that the studied system only uses a limited amount of devices. Other devices used at the ICU might also be able to be reprocessed with this system.

Non-critical device reuse

Automated UVC cleaning could be also extended to other products as long as they fit whithin the cleaning device. This would allow nurses to avoid the hassle of hand cleaning. In the intubation to detubation scenario, 80% of required manual cleaning of devices could be automated. Devices compatible with UV-C cleaning are marked with red circles in Figure 5.17.

Semi critical device reuse

Reuse of semi-critical devices through hand cleaning and automated UVC disinfection could be also extended to other products, as long as they present the following characteristics:

- All surfaces which may have been in contact with body liquids need to be accessible to wipe cleaning (no tunnels, etc.) and reachable to UVC radiation.
- The device and its material are waterproof and cleanable with wipes.
- Devices material presents resistance to UVC exposure.
- The product must fit within the dimensions of the UVC disinfector.

21% of the devices used throughout an intubation to the detubation of the patient could be reused through applying the previous reuse workflow, highlighted in green in Figure 5.17.

Use of covers

Some products may also allow the use with covers, reduce waste by allowing disposing only the cover instead of the product.

Avoid unused! Cleaning of packaging

Last but not least, it had been mentioned during the research that some devices needed to be thrown away without being used if placed in the ICU room. UVC cleaning would allow the cleaning of these devices packaging, thus their restorage.

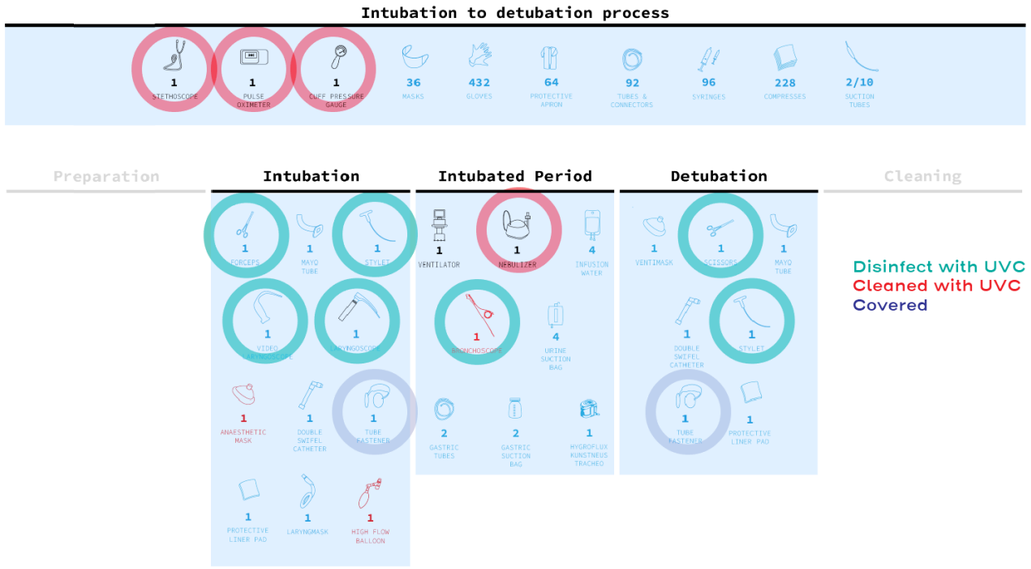


Figure 5.17: Devices map highlighting devices that could be reprocessed using the UV-C technology proposed for the pilot.

5.5 · Replicate

Replicate reuse system in other EMC departments

The reuse proposal of keeping the reprocessing of non-critical and semi-critical devices in the department itself could be extended to other departments within EMC.

5·3 · Evaluation

The proposed system will be evaluated through the use of design thinking. This consists in assessing if the proposal brings together "what is desirable from a human point of view with what is technologically feasible and economically viable" (IDEO, 2018). Requirements from Figure 5.18 are evaluated one by one in this section.

Desirability

The system reduces the environmental impact of VL usage at the ICU.

It must feel easy to implement at EMC.

It must present further step for transition to reuse beyond the VL.

It must be accepted by its users.

Feasibility

The system must not interfere with the patient safety.

It must make use of technologies that are already on the market.

It must allow material resources used to stay longer in use.

Viability

The system must comply with the (EU) 2017/745 regulation.

The pilot payback time must of 5 years or less.

The proposal must fit within the current ICU.

Figure 5.18: Pilot requirements for evaluation

Desirability

The system reduces the environmental impact of VL usage at the ICU

Requirement

The environmental impact of the usage of a video laryngoscope in these scenarios was assessed by:

- Comparison of the quatity of waste generated.
- Comparison of the CO2 footprint.

These calculations were done for current, reduce and reuse scenarios. The end of life considered is still incineration, as the proposed system does not focus on the product's end of life.

The CO2 footprint contemplates the material production, transport, reprocessing and incineration of the devices.

Many assumptions had to be made for this calculation, listed in Appendix G. For example, the CO2 footprint of packaging and reprocessing devices were not included in the analysis.

Material production footprint and combustion CO2 numbers were taken from the EDUPack 2019 Sustainability DataBase. Transport costs per tkm were estimated based on the Fast Track LCA template. Appendix G further details all the calculations.

Compared to the current scenario, the waste generated through using a video laryngoscope in the reduce and reuse scenarios would decrease by 69% and 80%, respectively. The CO2 footprint is also reduced by 94% and 83% (Figure 5.19)

Therefore, the environmental impact of the video laryngoscope usage is reduced in both scenarios.

However, it should be noted that the calculations do not consider situations in which:

- The cover breaks
- The reusable blade gets in contact with patient blood.

The video laryngoscope or blade would have to be disposed of in both situations, decreasing these percentages.

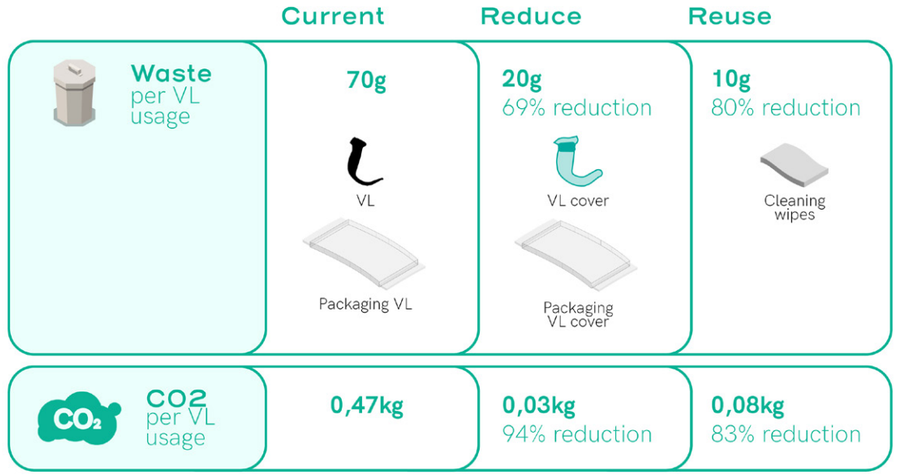


Figure 5.19: Results from waste and CO2 footprint estimations (Appendix G)

The system must be easy to implement at the ICU.

Wish

The pilot aims to explain the benefits of reusing medical devices. It seeks to further provoke interest within Erasmus MC to evaluate the implementation of the proposals. This possible scenarios could also be presented to external stakeholders to develop the pilot further. A first iteration of the action plan was presented to a specialist from the EMC procurement team, which indicated that the first actions were realistic.

The pilot proposed is aims to reuse the video laryngoscope. Knowing that around 600 intubations are realised at the ICU per year, the changed workflows would have to be realised only twice a day during the pilots. This ensures that the user workload will not be increased, allowing easy implementation. It would also allow both the ICU and procurement to evaluate if the future horizons proposed are desirable based on the pilot experience.

The system must present further steps towards the reuse transition beyond the video laryngoscope.

Wish

As described in the 'Expand' section of this chapter, three systems can be escalated to other devices:

- The use of UV-C low-level disinfection to clean non-critical devices.
- The use of the reuse system to reprocess semi-critical devices which only require surface cleaning.
- The use of covers to reduce disposability

An assessment was done to define which intubation devices could follow each of these systems. This led us to think that the system could be scaled up to other devices used at the ICU.

The cleaning cycles of the low-level and high-level disinfection machines are 25 and 60 seconds for each device. About two video laryngoscopes are used at the ICU per day. Therefore machines would be available to be used to reprocess other devices.

However, further development of the nurses' workflow if more than the video laryngoscope is reused is required.
An additional job addressing this reprocessing task could be created at the ICU, not to overload nurses with additional work.

The system must be accepted by its users

Wish

The proposal was shared in an early conceptual phase with both doctors and nurses.

Doctors recognized the use of covers on other products. He felt comfortable with the idea of extrapolating this usage to another device if the patient safety and product usability were not threatened.

The nurse highlighted her interest in automated cleaning. The proposed workflows were compared to previous reuse of video laryngoscopes at the ICU (Figure 5.20). Although the procedure would take additional steps compared with a complete disposability scenario, the new systems reduce manual cleaning.
A more automated workflow allows the reprocessing to be more standardized, releasing nurses from responsibilities.

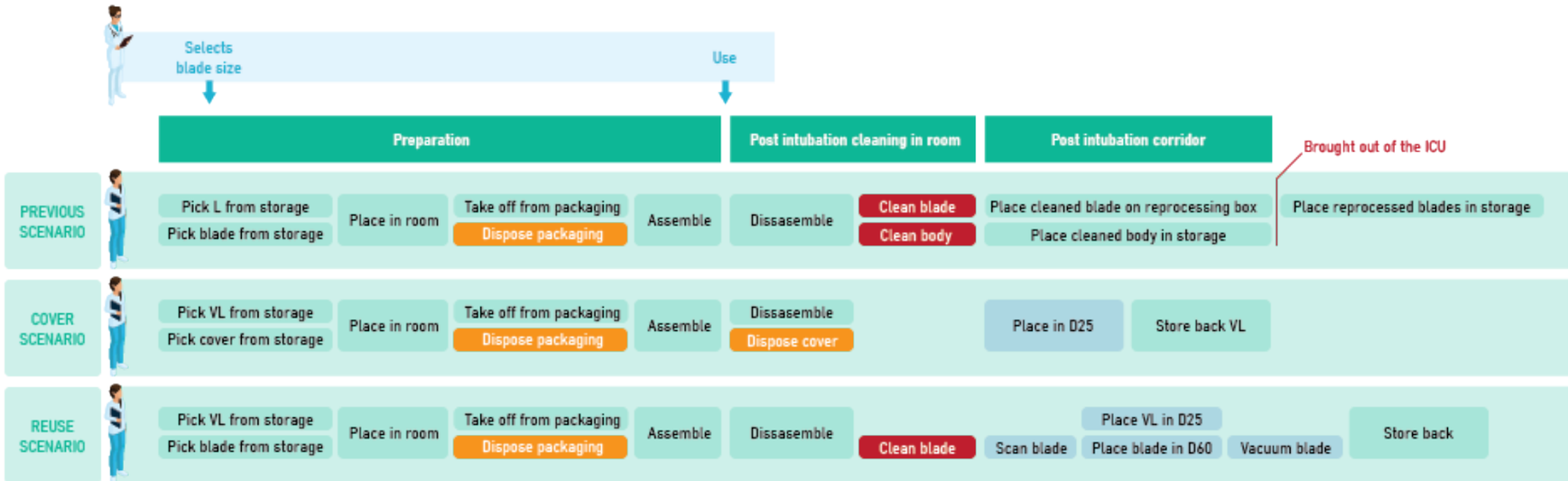


Figure 5.20: Comparison of the cover (reduce) and reuse scenario with previous reuse scenario. Previously, the video laryngoscope blade was brought to the Sterilization Department.

Feasibility

The system must not interfere with the patient safety

Requirement

Two topics will be addressed. First, the visibility and usability of a video laryngoscope with a cover will be evaluated. Secondly, the UV-C tolerance of the devices to reuse will be assessed.

1. Cover safety

For a cover to be usable, doctors must use the camera of the video laryngoscope. The cover must not reduce the image quality.

A test was done (Figure 5.21) to assess the image quality of the video laryngoscope with a polyurethane cover used at the ICU for another device (a transducer, ultrasound scope).
The test aimed to compare a set of three scope covers available in the market. However, due to the lack of answers from suppliers, the testing was realized with available cover, the CIV Flex Transducer. The test procedure and results can be found in Appendix K.

Figure 5.21: Image of the testing, video laryngoscope with the CIV Flex transducer cover.

The current cover affected the image quality of the video laryngoscope. Using other devices covers on the video laryngoscope is not feasible, a redesign must be done.

A set of takeaways were taken from the test:

Shape

- The cover shape must be adapted to the video laryngoscope, as this would reduce the wrinkles the current cover presented in front of the camera.
- The distance between the camera and the plastic must be reduced as much as possible. The surface of the plastic must be parallel to the camera lens to avoid distortions of the image.

How could this be done?

- The shape of the cover itself could be adjusted.
- Heat shrink wrapping techniques could allow a loose cover to adapt to the video laryngoscope shape.

Material

A higher transparency plastic is needed to ensure the image quality.

The use of polyethylene (PE) instead of polyurethane (PU) is proposed.
PE CO2 production footprint is lower than PU (EduPack 2019). Also, this material has been already used in similar covers for transducers. PUs materials can therefore comply with regulations this product needs to follow. However, no research on PE materials transparency was done within the scope of this graduation. Further evaluation would be required.

To conclude, the feasibility of the cover needs still to be proven through further embodiment.

2. UV-C disinfection safety

Disinfection of the devices with UV-C is proposed. This section will assess the devices' resistance to UV-C radiations.

Reduce scenario

The current video laryngoscope used at the ICU has an ABS cover. Studies using high doses of UV-C light showed good long-term property retention in PC/ABS blend (Covestro 2020). The ABS blade should be suitable for UV-C disinfection. Research should be done to assess if the camera lens is not affected over time by UV-C radiations.

Reuse scenario

In the reuse scenario, the blade must be done from a material allowing both high transparency and UV-C resistance. This material should be certificated for healthcare usage.
The use of Makrolon RE, a PC from Covestro is proposed. Its properties and other materials considered can be found in Appendix M.

A sample of this material was tested by Covestro exposed to UV-C. The colour shift of a clear sample was tested (Covestro, 2021) exposed to 120 J/cm2 of UV-C radiation. This cumulative dose of 120 J/cm2 studied approximates thousands of disinfection cycles. The colour shifting generated was of 3 points, mildly perceptible (Figure 5.22). Another test shows the evolution of PC properties (Figure 5.23).

Makrolon® 2458 550115 (clear PC)			**No UVC** Control	**Post-UVC** Continuous	Intermittent	High-Intensity
Izod notched impact strength, 23°C (3mm)	ISO 7391 / ISO 180/A	kJ/m²	56	60	62	56
Tensile modulus	ISO 527-1, -2	MPa	2460	2460	2440	2460
Tensile yield stress	ISO 527-1, -2	MPa	62.8	62.9	62.9	62.9
Vicat softening temp. (50 N, 120°C/h)	ISO 306	°C	144	144	144	144

Figure 5.23: Properties evoluation under UVC LED exposure of continuously at 0.10 mW/cm2, intermittent on/off at 0.10mW/cm2, or at a higher intensity of 0.35 mW/cm2 (Covestro, 2020)

Figure 5.22: PC before (left) and after (right) exposure to UV-C (Covestro, 2021).

A hundred UV-C disinfection cycles of the PC blade could be done without affecting the product transparency and properties drastically.

"Polycarbonates and PC blends appear to be well suited to applications in which they are repeatedly disinfected by UVC" (Covestro, 2021)

UV-C disinfection should be therefore feasible for both scenarios.

3. Blood barrier

Reuse scenario

The system proposed the reuse of video laryngoscopes through high-level disinfection. This follows the NEN-EN-ISO 13485:2016 regulation and manufacturer's guidelines. Both state that the video laryngoscope can be considered a semi-critical device if the blood barrier is not crossed.

However, it is possible that in some intubations, the patient presents blood. When the ICU reused laryngoscopes in part, they considered the device as always critical. Laryngoscope reprocessing included an additional step of sterilization not always needed. This additional step had a risk prevention value but also a high environmental and economic impact.

If the blood barrier is crossed in the reuse scenario, the blade would have to be disposed of as the UV-C radiations only offer high-level disinfection, not complete sterilization.

4. Reuse implies risk

Reusing devices implies a higher infection risk for the patient than single-use devices. However, these risks are still within the strict European regulation that hospitals must compel to be, thus, highly safe.

The system must make use of technologies that are already on the market

Requirement

UV-C disinfection devices are recently available and certified for high and low-level disinfection (UVSmart, 2022).

In addition, vacuum sealing machines of small dimensions and certified for healthcare usage are also available (Appendix L).

The system must allow material resources used to stay longer in use

Requirement

Both scenarios propose the video laryngoscope reuse. Less waste would be generated, as reuse allows material resources in the product to stay longer in use.

Viability

The system must comply with the (EU) 2017/745 regulation.

Requirement

All devices required for reprocessing are already procurable and certified. The blade redesign uses a material that compels with healthcare regulation and can be used in medical devices (Appendix M).

The current cover does not comply with the video laryngoscope safety regulation. Therefore, the redesign of the cover is required.

The pilot payback time must be a maximum of 5 years.

Requirement

Appendix G presents an estimation of the payback time of these two scenarios' implementation. The calculation considers the procurement price, reprocessing energy and waste management cost between others.

The current result can only be considered indicative as most data had to be hypothesized. The system's payback time would be five years based on the estimated numbers. If the proposed pilot system is further developed, this template could be used again to reassess the payback time.

The proposal must fit within the current ICU layout.

Requirement

The reprocessing area includes the UV-C low-level disinfection device, the UV-C high-level disinfection and a sealing machine.

These devices require a surface of 165cm x 90cm for every two ICU units. Different potential locations for this reprocessing area are market in the following Figure 5.24 map.

Location A was chosen as it provides enough space without interacting with sterile devices (C) or waste (B and D).

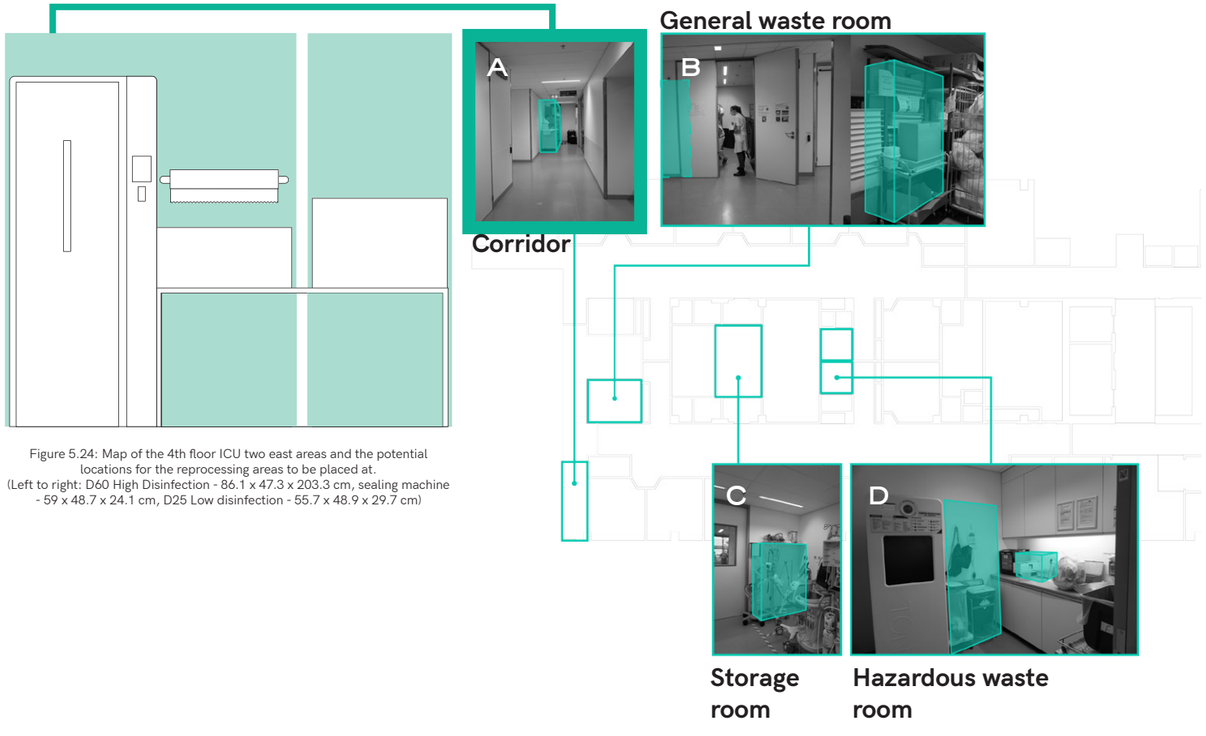


Figure 5.24: Map of the 4th floor ICU two east areas and the potential locations for the reprocessing areas to be placed at.
(Left to right: D60 High Disinfection - 86.1 x 47.3 x 203.3 cm, sealing machine - 59 x 48.7 x 24.1 cm, D25 Low disinfection - 55.7 x 48.9 x 29.7 cm)

5.5 · Conclusion

Two pilots allowing the reuse of the video laryngoscope were evaluated. Its desirability and positive environmental impact have been demonstrated. It would reduce the ICU environmental impact and engage the ICU into a transition towards device reuse.

However, the feasibility of the **reduce** pilot is still far from reach, as the use of covers available at the ICU for the video laryngoscope was evaluated as not feasible. A redesign of the cover is therefore required to make this pilot possible.

Two action plans are proposed to achieve an implementable level for each pilot, both involving close collaboration with manufacturers. This leads us to the question stated at the beginning of this report: What are the first action points and potential redesign that could be implemented at the ICU in upcoming years?

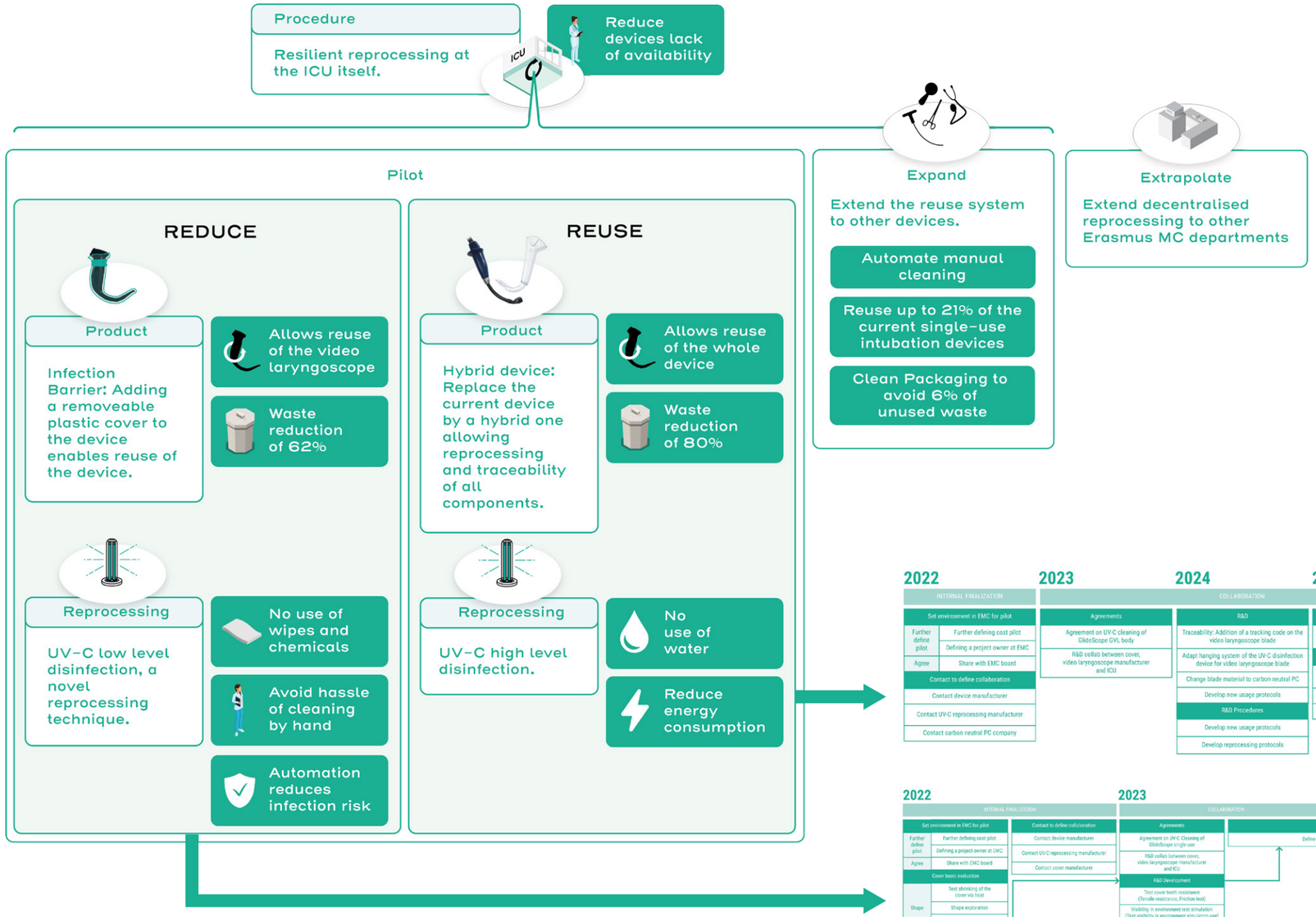
A transition towards the reuse of intubation devices could be achieved by assigning an EMC employee the task of coordinating further detailing of this proposal. This would allow EMC to involve external manufacturers such as UV-C disinfection or video laryngoscope manufacturers. Within this collaboration, the design of a feasible cover could be further researched.

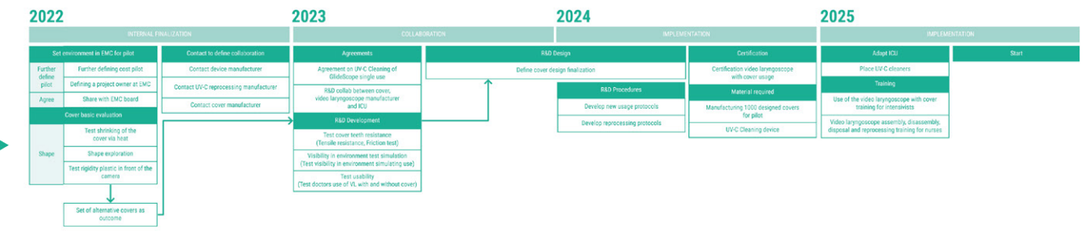
Chapter 6
Summary deliverables

Previous chapters explained the whole graduation process which led us to the stated outcomes. This chapter will summarise all relevant outcomes into a pitch deck and a recommendation booklet which could be easily shared with stakeholders not involved in the project. The aim of such deliverables would be to trigger action and convince needed collaborator to actionate sustainability at Erasmus MC.

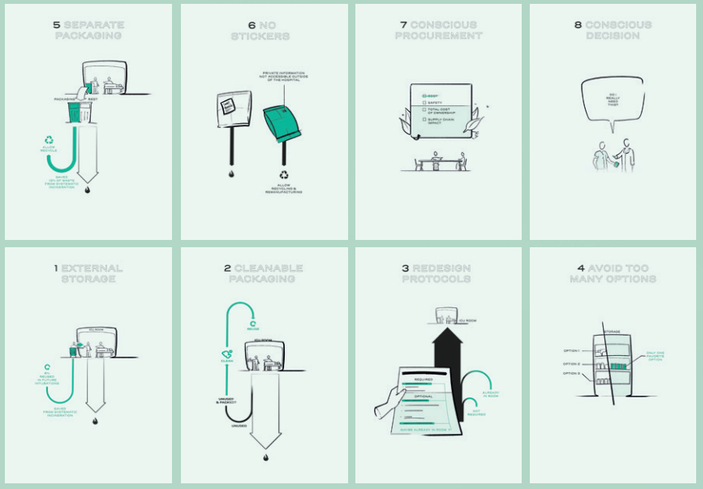
Systemic research on the current practices and waste at Erasmus MC ICU was undertaken, from which understanding of its impact and complexity was achieved.

Two pilot systems are proposed to reuse the current single-use video laryngoscope. For both, an action plan to achieve an implementable level was created. Future scale-up of the reuse system to other devices is envisioned, as well as replicating it into other Erasmus MC departments.





A set of system direction were deduced from the study around intubations at Erasmus MC ICU presented in chapter 2 and 3. Next the pilot proposal, a set of actions that Erasmus MC ICU could take to transition to full circularity by 2030 are summarized in this booklet, complementing the reuse pilot proposed (Appendix A).



Chapter 7
Conclusion

In this last chapter, the proposals that have been developed throughout this graduation project will be recapitulated. A set of recommendations and reflections will also be presented.

7.1 · Summary

Project

This project aimed to design a pilot system that could initiate a transition in the ICU towards a circular intubation to detubation process.

Research was done to understand how and why hospital practices are currently wasteful. In this process, different system levels and stakeholders were considered (Figure 7.1).

A set of challenges were synthesized from the research and used to ideate on different system directions which could improve sustainability at the ICU. It was decided to detail further a system allowing the reuse of devices. This system was articulated around a specific product, the video laryngoscope. This device is used to intubate patients. It is composed of various plastics and electronics and has a relatively high procurement cost. Nevertheless, it is a single-use device, disposed of and incinerated after a few minutes of use.

Reusing devices in the healthcare environment, also called reprocessing, does not come without challenges. It requires different steps depending on the criticality of the product, meaning the product's level of contact with the patient (Figure 7.2). According to regulations, different reprocessing techniques can be used depending on the product criticality.

Each additional reprocessing step implies additional environmental impact. The ecological implications also vastly differ depending on the technology used.

Ideation on a system **enabling safe and hassle-free reuse of the video laryngoscope at the ICU with a lower environmental impact** was done. The pilot considered three levels: product, reprocessing and procedures.

System design

Two pilot systems were proposed:

Product

The first proposal, **reduce**, enables Erasmus MC to reuse the current video laryngoscope in use at the ICU. Adding a removeable polyethylene plastic cover to the device enables reuse of the device. By not bringing the device in direct contact with the patient, fewer reprocessing steps are required.

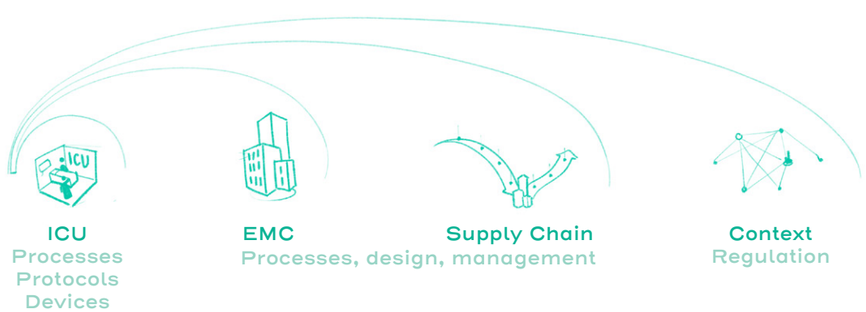


Figure 7.1 Levels of healthcare system researched upon and research theme on each

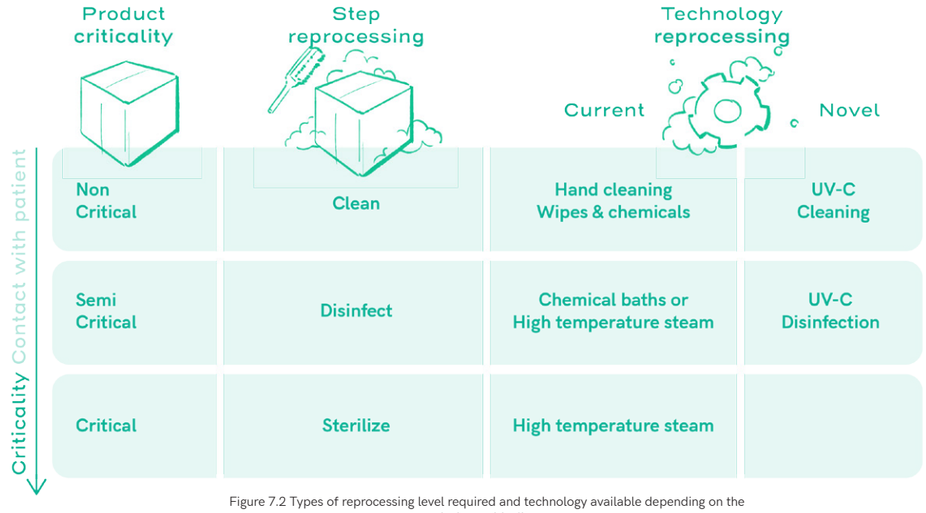


Figure 7.2 Types of reprocessing level required and technology available depending on the devices criticality.

The second proposal, **reuse**, offers the complete reuse of a modular video laryngoscope. Similar to the first proposal, the main body would be reprocessed without having been in contact with the patient. A redesigned polycarbonate hardcover would surround the product and allow reuse, as well as traceability of the number of reprocessing cycles it has gone through.

Procedure

Reprocessing in both proposals could be done at the ICU. Not relying on the sterilization department allows the ICU to be resilient and to increase device availability.

Reprocessing

The use of a novel reprocessing technique, UV-C radiations, is also proposed. Compared to current reprocessing techniques, it consumes less water, electricity, and space. In addition, UV-C reprocessing allows a high level of automation of the process, increasing its safety and reducing the hassle for ICU workers.

Pilot as catalyse for systemic change

Future scale-up of the reuse system to other devices is envisioned, as well as replicating it in other Erasmus MC departments. The scalability of these proposal aims to catalyse systemic change towards a circular healthcare.

It should however be noted that these pilots focus on extending the use phase, and full circularity is far from reached (Figure 7.3). Other recommendations to transition towards full circular intubation systems are gathered in a recommendation booklet.

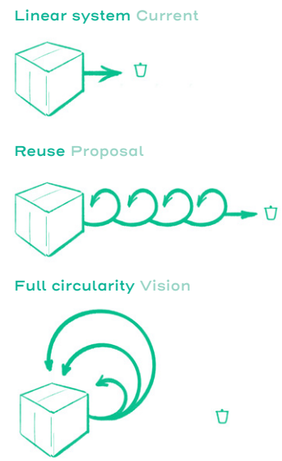


Figure 7.3 Post use value retention comparison of the current, proposed and envision healthcare device.

7·2 · Discussion

Value

Based on discussions throughout the project, procurement as shown interest in allowing EMC to lead product redesign projects. Currently, manufacturers collaborate with hospitals mostly late in the design process. Allowing redesign to adapt to the hospital practices sooner could bring value to healthcare product design.

If the use of UV-C technology and decentralized reuse lives up to expectations, this system could be extrapolated to other departments or hospitals, reducing environmental impact.

Limitations

Reduce scenario
In the original design, it was assumed that an existing cover for another medical device could be used for the video laryngoscope. However, evaluation demonstrated that this is not possible, as the visibility of the camera is decreased, threatening patient safety. Redesign of the flexible cover is required.

Reuse scenario
Reuse requires some minor changes. Even if its feasibility has been proven, certifications and manufacturers' approvals are needed.

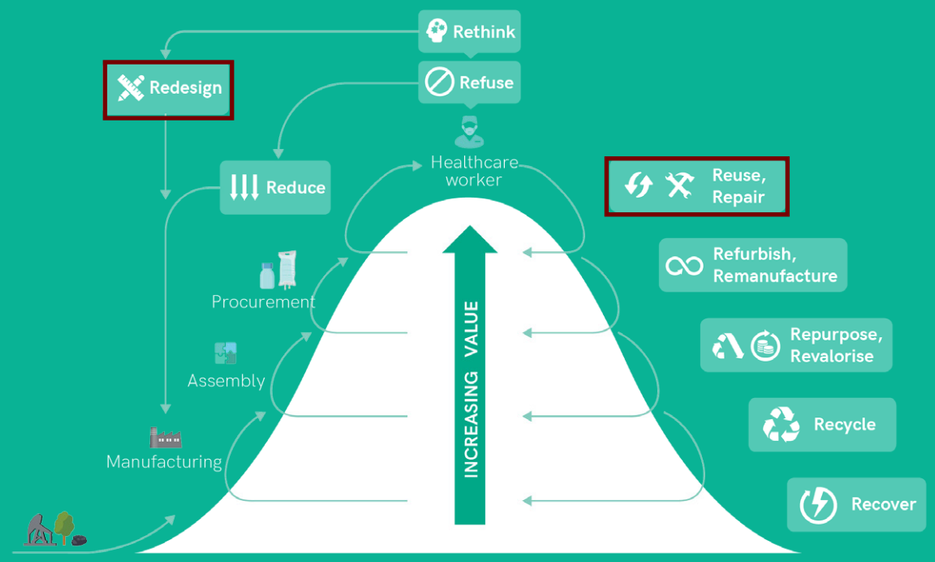


Figure 7.4 Value hill highlighting the two R-strategies that have been addressed through the system proposal.

7·3 · Recommendations

Pilot related

- **Further testing cover feasibility**
  The solid blade redesign guidelines are defined. However, the cover design still requires further exploration. A set of tests to explore the cover shape, rigidity, strength and usability are needed before the action plan can be considered actionable. These tests are mentioned in Chapter 6.
- **Refine viability numbers**
  The current cost evaluation uses estimates. Closer collaboration with Verathon, UVSmart and other stakeholders mentioned in the pilot is recommended to assess the financial savings more accurately.
- **Choose a project leader.**
  A particular person at EMC or an external service company should receive the role of supervising the pilot implementation. As the pilot proposal places EMC as the project leader, a person in charge must coordinate stakeholders towards improved collaboration.

Reuse & R-strategies

- **UV-C supplement for complete reuse.**
  The pilot explores the opportunities of UV-C low and high-level disinfection. This technique cannot be used for critical devices or devices requiring reprocessing of internal surfaces (such as tubes). Designing a system allowing critical device reuse within the ICU could be explored.
- **Circular intubations** This proposal focuses on extending the use-life through reuse and redesign (Figure 7.4). Material input, manufacturing, distribution, disposal, end of life, and other R-strategies are almost not explored. Further research on these topics is required to achieve complete intubation circularity.

Opportunity areas

Figure 7.5 gives an overview of all opportunities derived from the research that could be further explored. These recommendations are summarized in a booklet in Appendix A.

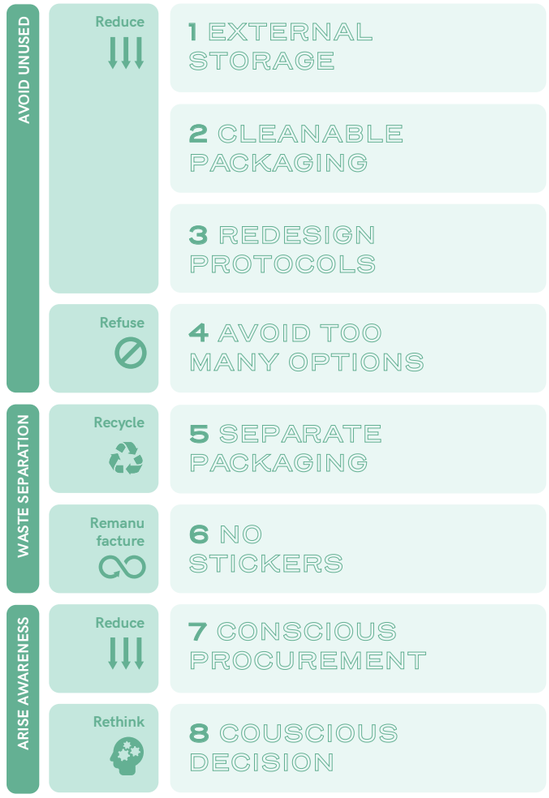


Figure 7.5 List opportunities areas defined in the recommendation booklet based on the intubation system research

7·3 · Reflection

Sustainability and individual patient safety, value tensions.

Individual patient safety-centered design limits the radical changes needed to make healthcare sustainable. As mentioned in chapter 1, this is paramount to mitigate far larger health risks associated with climate change.

Current hospital risk management focuses exclusively on individual patient safety, leading to an excessive avoidance of specific risks, at the wider expense of unsustainable practices. As such, to catalyze systemic change in health care, a reframing of risk management is needed.

Reuse implies risk

This report proposes the reuse of medical devices. This will result in decreased environmental impact, but may slightly increase infection risks. Even if the infection risk is low and compliant to regulation, tensions arise that can be leading us to the core of health wastefulness. A major takeway from this project is that most unsustainable ICU practices are closely related with the reduction of safety risks to an absolute minimum.

Changes in our healthcare consumption as a society are required. Reuse practices would not make the Erasmus MC a less safe hospital but one that places more attention on their impact at an environmental and societal level instead of only searching for safety at an short-term and individual level (Figure 7.6).

Circular healthcare would provide higher value (Figure 7.7) even if the patients individually might be exposed to slighly increased infection risk. This can be likened to the fears associated with small risks of vaccine side effects associated with COVID-19. While the overwhelming societal result of vaccines is the prevention of death, it is true that a tiny percetage of people may experience side effects.

$$\text{Value} = \frac{\text{Outcomes for patients and populations}}{\text{Environmental + social + financial impacts (the 'triple bottom line')}}$$

Figure 7.7: Measuring values of healthcare provider (Mortimer et al. 2018)

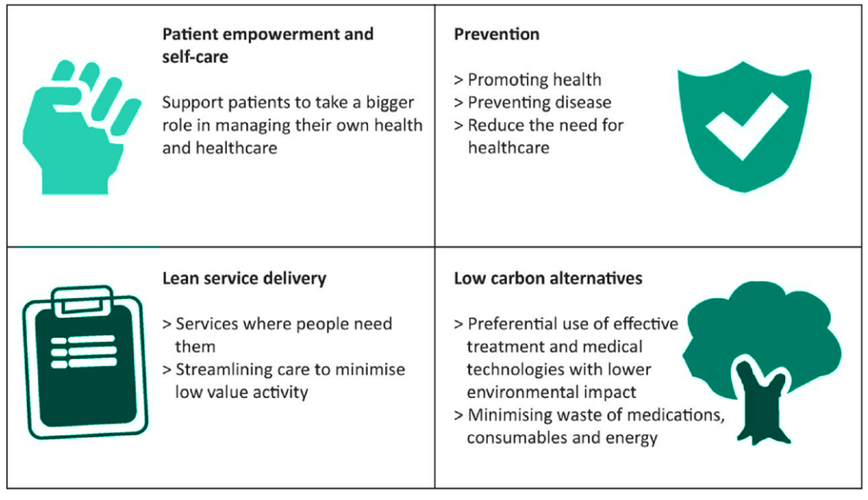


Figure 7.6: Aspirations of circular healthcare (Mortimer et al. 2018)

Preventing

Another clear approach to sustainability in healthcare is by preventing unnecessary intubations or ICU admissions. The ICU, as its name indicated, is reserved for patients that require constant care. The most efficient reduction of resources consumption can be achieved by avoiding inappropriate ICU admission for patients that would not require constant care, or by avoiding unnecessarily prolonging ICU length of stay (Anesi et al. 2017). The same applies for intubations, which have shown to be a wasteful process. Avoiding intubation or unnecessary extension the intubation period can also enable reduction of the environmental impact of the ICU.

Questions of ethics arise making these decisions, and the tension between individual patient health and societal wellbeing becomes apparent. Furthermore, with sustainability acting on spatio-temporal scales that are not directly apparent, it becomes challenging to make decisions now that may have directly visible drawbacks (increased risk), while only offering invisible future benefits (mitgated climate change). Healthcare cannot be free of risks, and a better understanding of the value of sustainable health by organizations and society would allow for innovations toward a circular future.

Personal

The graduation project has been a journey to reflect on the role of design in circular transition and my future path as a designer. I would lose myself in curiosity, and seek to constantly gather more information. This made it a challenge to consistently articulate my full design intentions throughout the process. This has led me to embrace the importance of design as a storytelling tool. I have come to understand my value as a designer in framing the benefits of circularity for different stakeholders.

The restrictive healthcare environment was a challenge that provided me with a good understanding of the complexity of systemic design. Sometimes frustrated due to the lack of open-ended results that I could achieve, I found myself energized once and over by the close collaboration with Erasmus MC staff. I am incredibly grateful for all the insights experts and users had and their willingness to share their experiences. Close collaboration has nourished my project, allowing me to feel confident in decision-making moments and grow as a designer.

This project also let me reflect on the tension between the scale of impact and actionability. The more I tried to achieve project actionability, the less scale of impact the results offered. However, I am happy to see the project part of a bigger set of graduations. Also, I trust sustainability awareness has been raised by sharing my surroundings and process with the Erasmus MC staff. I believe all this can help in the transition towards a greener future.

All in all, I confirmed throughout this graduation that I love learning how design can help fight climate change, and that is what I want to keep on doing.

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