Appendix

Master thesis – Integrated Product Design & Medisign
Margot Honkoop

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Appendix A Project brief kick-off

IDE Master Graduation

Project team, Procedural checks and personal Project brief

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

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

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

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

STUDENT DATA & MASTER PROGRAMME

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

family name: Honkoop

initials: M given name: Margot

student number: 4452119

street & no.:

zipcode & city:

country:

phone:

email:

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

IDE master(s): ★ IPD ○ DfI ○ SPD

2nd non-IDE master:

individual programme: - - (give date of approval)

honours programme: ○ Honours Programme Master

specialisation / annotation: ★ Medisign / ○ Tech. in Sustainable Design / ○ Entrepeneurship

SUPERVISORY TEAM **

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

** chair: Ruud Balkenende dept. / section: SDE

** mentor: Armagan Albayrak dept. / section: AED

2nd mentor: N. G. M. Hunfeld

organisation: Erasmus MC

city: Rotterdam country: The Netherlands

comments (optional)

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

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

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

APPROVAL PROJECT BRIEF

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

chair Ruud Balkenende date - - signature

CHECK STUDY PROGRESS

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

Master electives no. of EC accumulated in total: 27 EC

Of which, taking the conditional requirements into account, can be part of the exam programme 27 EC

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

★ YES all 1st year master courses passed

NO missing 1st year master courses are:

name C. van der Bunt date 17 - 09 - 2021 signature

FORMAL APPROVAL GRADUATION PROJECT

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

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

Content: APPROVED NOT APPROVED

Procedure: APPROVED NOT APPROVED

comments

name date - - signature

Initials & Name M Honkoop Student number 4452119

Title of Project Reduction of environmental impact of syringes in the Intensive Care Unit

Reduction of environmental impact of syringes in the Intensive Care Unit project title

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

start date 10 - 09 - 2021 18 - 02 - 2022 end date

INTRODUCTION **

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

Currently, the healthcare sector caters us with high-quality healthcare, but unfortunately on the other hand has a great environmental impact. The healthcare sector contributes to 4,4% of the global net greenhouse gas emissions and toxic air pollutants (Karliner, 2019). In the Netherlands, the healthcare sector even contributes to 5,9% of the national footprint, which is above the global average. The majority (71%) of these emissions come from the production, use, transport and disposal of medical products used in the hospital. (Metabolic, 2021).
The Intensive Care Unit (ICU) of the Erasmus Medical Center (MC) has noticed this impact and initiated to make the transition towards are more sustainable ICU. To do this, Metabolic performed a material flow analysis (see figure 1) of the ICU in 2019 to identify hotspots in the system. This analysis showed 7 different hotspots, one of them being the disposable syringes and its packaging (see figure 2).

On average, 24 syringes are used per patient per day, which is equal to 0,35 kg of aggregated mass of single use syringes per patient per day (Metabolic, 2021). Syringes are used constantly in hospitals, for example for infusion pumps to administer fluid to a patient, or for giving injections. The use of a syringe involves a lot of different stakeholders, such as the patients, nurses, doctors, pharmacists and the cleaners who need to empty the waste containers.
The syringes consist of a complex assembly of different materials (mainly polycarbonate) and its components are difficult to separate at the end-of-life. The disposal is a complex process, since the syringes are considered as infectious waste, in combination with a sharp needle. A laminate of different plastics is used to wrap the syringe, to keep it sterile. The laminate of plastics contributes significantly to the carbon footprint of the syringe's packaging.

These single use syringes are considered as a "high-criticality product" (a product which enters tissue of the vascular system) with a low value, since there are only used once. According to Kane (2017), products in this category are the most challenging to develop a circular strategy for, because of the combination of a high cost of recovering the product and a low cost of disposal and replacement. Recommended strategies are: design for separation, design for recycling, design for infectious waste management and design arounds.

The extensive use and disposal of syringes in combination with the difficult to separate materials results in a high environmental impact, according to the analysis performed by Metabolic in 2019. Therefore, the Erasmus MC is interested in finding solutions to decrease the environmental impact of the use of syringes in the ICU.

Sources:
Browne-Wilkinson, S., van Exter, P., Bouwens, J., Souder, J., & Chatel, E. (2021). Circular Intensive Care Unit - opportunities for human and planetary health. Metabolic and Erasmus MC.

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

Karliner, J., Slotterback, S., Boyd, R., Ashby, B., Steele, K., & Wang, J. (2020). Health care's climate footprint: the health sector contribution and opportunities for action. European Journal of Public Health, 30(Supplement_5). https://doi.org/10.1093/eurpub/ckaa165.843

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introduction (continued): space for images

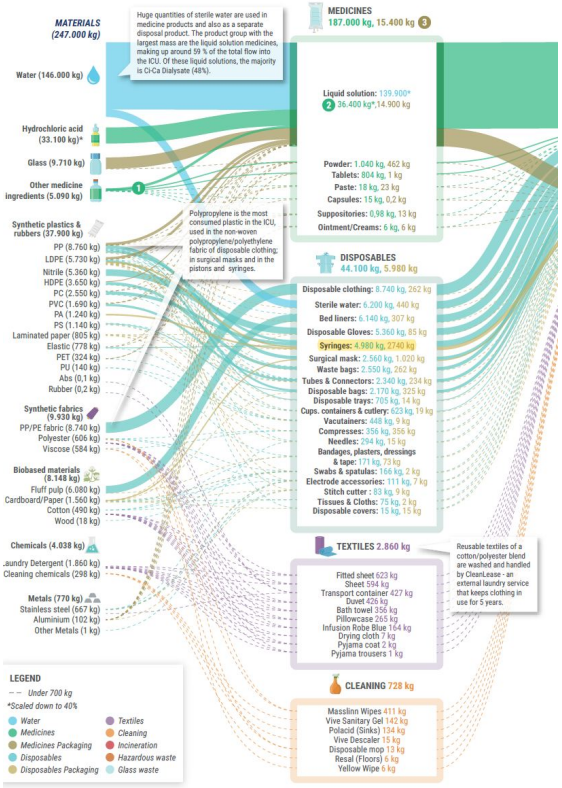


image / figure 1: Material flow analysis (MFA) conducted by Metabolic for the Erasmus MC ICU in the year 2019.

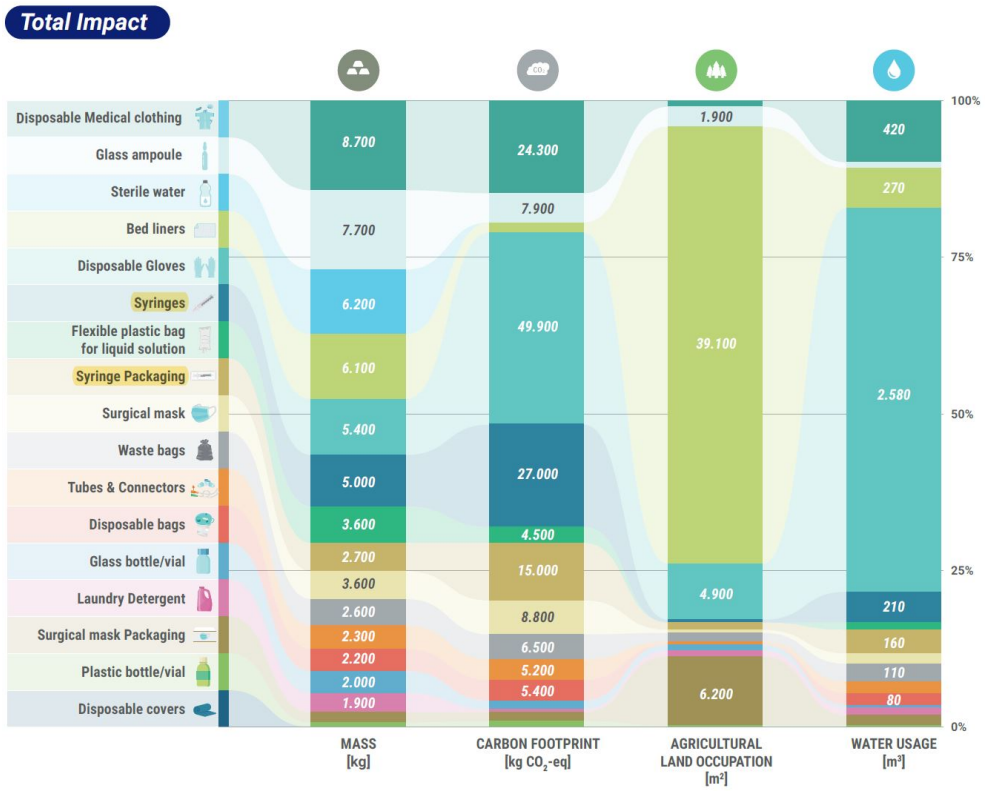


image / figure 2: Estimated contribution of the most important product groups on the ICU (Metabolic, 2021)

Initials & Name M Honkoop Student number 4452119

Title of Project Reduction of environmental impact of syringes in the Intensive Care Unit

PROBLEM DEFINITION **

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

Erasmus MC and Metabolic performed a study on environmental impact at the ICU by doing a material flow analysis and an impact assessment. This study resulted in 7 hotspots that have the biggest impact on the environment at the ICU. Syringes and its packaging are defined as one of the hotspots at the ICU causing significant environmental impacts. According to Metabolic, this is due to:
- extensive use of syringes per patient per day (24 per patient per day)
- difficult material separation at end-of-life of both the syringe and its packaging
- disposal of unused syringes due to limited shelf life
- complex disposal due to the sharp needle and due to the fact that it is infectious waste

The underlying problem of the high environmental impact of syringes is that the current system is a linear system, without using one or more circular R strategies (reuse, refurbish, repurpose, recycle and recover). It is clear that the impact at the end of life of a syringe and its packaging has not been taken into account during the design process. This results in syringes being used only once, disposed afterwards and incinerated in the end.
This linear system needs to be transformed into a more circular system by using design, to limit the amount of waste incinerated and to reduce the use of natural resources.

ASSIGNMENT **

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

The assignment is to redesign the syringe, packaging and its use, according to circular design strategies suitable for medical products, in order to decrease the environmental impact of the use and disposal of the syringe and its packaging at the ICU. This is done by analysing the current context, material and use of the syringe and its packaging. The use of syringes should remain convenient and safe for the healthcare staff and patients.

The first goal of this assignment is to perform an analysis on the use and disposal of syringes on the ICU. This is done by doing observations, interviews with people who use syringes (nurses, doctors, pharmacists), performing a product life cycle analysis and making a product, nurse and pharmacy flow. Results from this analysis will indicate starting points for design solutions that decrease the environmental impact of syringes.

After the analysis, the syringe, packaging and its use can be redesigned according to one or more circular design strategies. Kane (2018) suggest the following strategies for redesigning products like syringes, due to the fact that syringes are considered as high-criticality and low value products: design for separation, design for recycling, design for infectious waste management and design arounds.

Possible final results could be
- Packaging that is made of easy to separate materials
- Recyclable syringes and packaging
- New protocols for using and disposing a syringe

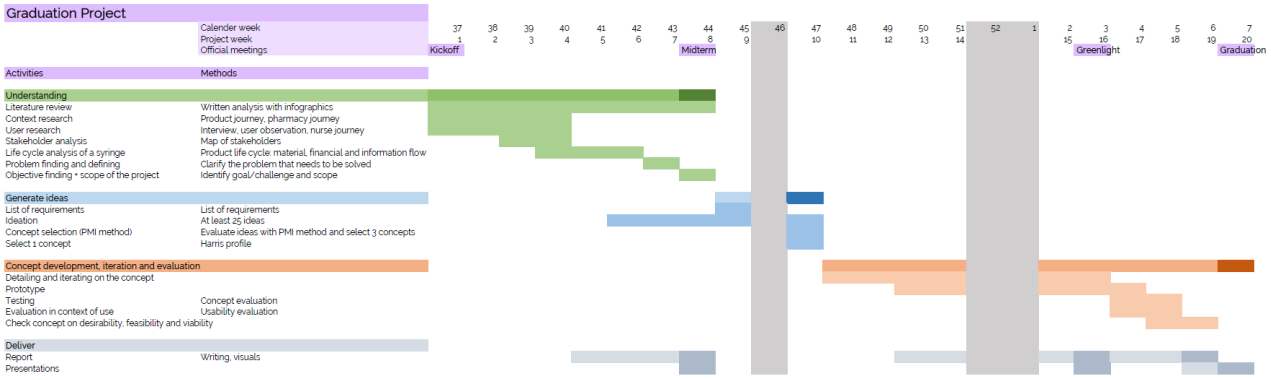
Initials & Name M Honkoop Student number 4452119

Title of Project Reduction of environmental impact of syringes in the Intensive Care Unit

PLANNING AND APPROACH **

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

start date 10 - 9 - 2021 18 - 2 - 2022 end date



The project is divided into three phases, as can be seen in the figure above. The first phase is about understanding the topic in depth, which includes literature, user and context research. Methods used will be: literature review, product journey, nurse journey, pharmacy journey and a product life cycle analysis. This phase concludes with a problem statement, the scope of the project and the challenge that will be tackled during the rest of the project.
The second phase is about generating ideas and selecting the most promising ideas to develop into concepts. Ideas will be generated by using methods like brainstorming and by organising creative sessions with fellow students. In the end, one concept is chosen, by using a Harris profile, to develop further. A list of requirements is made to check what functions, dimensions, etc. the concept must comply with.
The third phase is about detailing this concept, testing the concept in the context of use and making iterations based on the tests. The concept will be validated and evaluated according to requirements regarding desirability, viability and feasibility. Prototypes will be tested with nurses and other stakeholder who use the syringes. Iterations will be made to improve the concept after testing and evaluating. A proper method to assess whether the environmental impact has actually decreased will be determined later. In the end, one concept will be presented, together with recommended steps for the future.

I plan to graduate in 20 weeks, with a one week holiday in week 40 and a two week Christmas holiday. On Monday and Tuesday I have a workspace at the Erasmus MC at the convergence square. On Fridays I will work at the IDE faculty, the rest will be at home. Every Monday there is a meeting with Nicole Hunfeld (Erasmus MC), JC Diehl (TU Delft) and two other students who work on a similar topic. Every two weeks, I will join the meetings of the Green Team of Erasmus MC. With my mentors, I would like to meet every two weeks.

Initials & Name M Honkoop Student number 4452119

Title of Project Reduction of environmental impact of syringes in the Intensive Care Unit

MOTIVATION AND PERSONAL AMBITIONS

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

During this project I want to learn more about designing for the healthcare sector and designing for circularity/sustainability.

During the master courses I have learned a little bit about designing medical devices (rules and regulations, eHealth, and designing for people with dementia). I would like to expand this knowledge by doing this project for the ICU, which involves a lot of rules, regulations and protocols regarding a safe and clean environment. I think that this adds to the complexity of the project and will enable me to gain more in depth knowledge about designing for the healthcare sector.

Furthermore, I would like to learn more about circular and sustainable design. I have not done a project that focuses mainly on sustainability or circular design yet, so that is why I would like to learn more about this. In particular about circular strategies that are suitable for medical devices, concering hygiene etc.

Lastly, I would like to learn to manage the project (planning the project, managing expectations and bringing all stakeholder together). Especially leading meetings and taking initiative in the project are things I would like to improve.

FINAL COMMENTS

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

Initials & Name M Honkoop Student number 4452119

Title of Project Reduction of environmental impact of syringes in the Intensive Care Unit

Appendix B 7 hotspots of the ICU identified by Metabolic

HOTSPOT PRODUCTS FROM THE CURRENT STATE ANALYSIS

The current state analysis revealed certain product groups as hotspots from the quantitative material and impact analyses, and products identified as high impact through interviews with the ICU team. These product groups were singled out as core areas for circular innovation and hence, were the point of departure for the solution pathways described in the next chapter.

The packaging associated with the liquid solutions also formed a large portion of the total mass - with the glass and flexible plastic packaging forming around 35 % and 16 % of the packaging materials, respectively.

The largest number of individual units procured in the ICU are nitrile gloves, with an average of around 108 gloves being used per patient treated on the ICU. Their aggregated weight also makes up more than 12% of the total weight of disposable medical devices used. From the impact assessment, nitrile was highlighted as the material with the highest impact intensity in terms of carbon footprint (9.3 kg CO_2-eq/kg nitrile) and water usage (0.5 m^3 water/kg nitrile). Figure 9, it can be seen that the huge quantities of gloves procured in 2019, contribute to making the total impact of gloves significant compared to other products.

It can be seen from the MFA that the use of plastics is embedded in the care provision on the ICU - making up 54 % of the total materials, excluding sterile water. Of these plastics, the bulk is coming from the PP/PE non-woven fabric from the disposable gowns used on the ICU (18 % of all synthetic plastics, rubbers and fabrics).

The majority of biobased materials are coming from fluff pulp used in bed liners - this material is found to contribute significantly to the agricultural land use of the bed liners.

Both the syringes and the syringe packaging were identified as hotspot material. Syringes have a complex combination of materials and components that cannot be easily separated by hand. Flexible packaging is used to wrap each syringe individually to keep them sterile and is made from a laminate of different plastics and paper. These laminated plastics have been identified as the material contributing significantly to the carbon footprint of the packaging.

Polyvinyl Chloride (PVC) was found to be contained in the infusion pump tubing sets. Although only making up 4.5% of the synthetic plastics and rubbers presented in the MFA, PVC is toxic during use and when incinerated.

Although having a smaller estimated impact than other disposable PPE, the use of surgical masks has surged due to infection prevention measures in response to the COVID-19 pandemic. Their ubiquity in all healthcare operations and their single-use nature has highlighted them as a hotspot for further research. Furthermore, their associated packaging (a printed cardboard box) contributes significantly to the agricultural land requirement.

Appendix C waste management in Erasmus MC

The environmental permit regulations state that Erasmus MC must at least separate the following waste flows: specific hospital waste (SZA), paper and cardboard, hazardous waste, glass, other industrial waste (general waste), metal, debris/large waste, waste oil, VGF/swill and wood (Erasmus MC, 2014). Waste concerning syringes and packaging falls into two categories: general waste and specific hospital waste. The table below (Table C1) shows what type of syringes should be in either SZA or the general waste bin.

General waste

This waste stream concerns the general waste that does not fall under one of the other waste streams. Concerning syringes, the following rules apply (Erasmus MC, 2014):

- All excretions (not contaminated) such as blood, plasma, serum which are absorbed directly during the release in specifically applied or applied materials (such as plasters, bandages, pads, incontinence material, gel bags) resulting in a drip/leak-free disposal is possible to dispose of in general waste.
- Minimal amounts of drop-shaped contaminants (not contaminated) which are left behind in consumables, such as infusion bags, jars and tubes that can be removed drip/leak-free can be disposed of in general waste.
- General waste is incinerated by an external company.

Specific hospital waste

Specific hospital waste (SZA, UN 3291) is waste that is released during medical treatment or research on humans or animals. SZA is – possibly – infectious and/or carcinogenic and may not end up in general waste for ethical and/or aesthetic reasons. Infectious waste refers to substances that are known to have pathogenic properties and which, if exposed, can cause diseases in humans and animals. Concerning syringes, the following rules apply (Erasmus MC, 2014):

- All liquid excreta (not dried up) such as blood (also in blood tubes), plasma, and other pasty and liquid waste products (such as drain fluid, serum, pus, wound fluid) regardless of origin or type of contamination
- All sharp objects, regardless of origin or type of contamination, go into the sharps container, such as opened ampoules, cut capillaries, diffusion glasses, glass blood tubes and pipettes, hypodermic needles, broken instruments, loose metal spikes, blades, scalpels, etc.

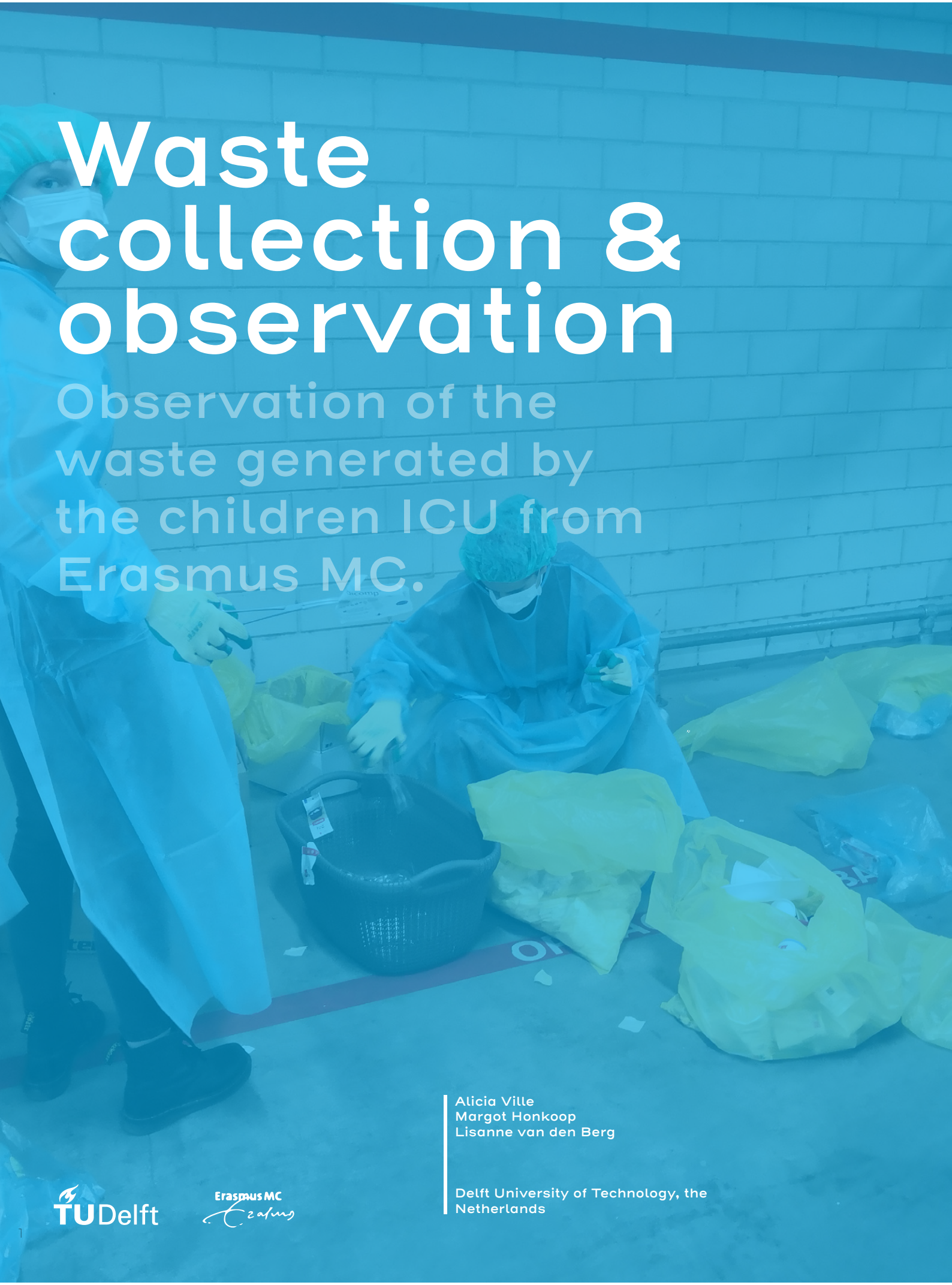
Specific Hospital Waste (SZA) is incinerated in the Hospital Waste Processing Installation Netherlands (ZAVIN) in Dordrecht. This incineration generates electricity for 1,000 households on an annual basis (Renewi, n.d.).

These rules described above apply to the entire hospital, but during the observations and interviews, it became apparent that there is a thin line between the two types of waste.

Table C1: categories of syringes and waste

Syringes, contaminated	SZA
Syringes, with needle	SZA
Syringes, plastic, packaging, without needle, not contaminated	General waste

Appendix D waste audit



Waste collection & observation

Observation of the waste generated by the children ICU from Erasmus MC.

Alicia Ville
Margot Honkoop
Lisanne van den Berg

Delft University of Technology, the Netherlands

Introduction

Context

The Pediatric Intensive Care Unit (PICU) from Erasmus Medical Center (Erasmus MC) has 4 areas:

1 Short stay area
2 Conventional ICU
3 Conventional ICU
4 Long stay area

Each area has its own green container where all domestic waste generated ends up. These containers are unfilled two to three times per day.

Each area counts as well with numerous hazardous waste containers. These containers waste will not be separated because of safety reasons and available time. The procedure used to unfill these containers is different than the one followed for the green containers. Adding these into the scope of the project would increase the complexity of the same to an unreachable level. Although hazardous waste will not be analysed, we will take a picture of their content to get an indication of what is in there. We will weigh them as well.

Aim

The waste of the green containers will be analysed throughout four days. Each day, one of the unit's green containers will be analysed. On the first day, we start with unit 4 and the time needed to analyse one container will be defined. If there is enough time, more than one unit can be measured per day. To differentiate the containers from each area, a sticker will be placed on the lid of each of them when positioned emptied.

Although the morning shift starts at 7:45, separating waste will start from 8:30. All trash bags will be brought throughout the day to the collection point by the workers assigned to do so. These workers are informed by Sascha and Suzan to collect the containers from the PICU. Two shifts during night, one at 10:00am. No previous separation of the waste placed in the green containers is needed.

Setup

Apparatus

- 2 garbage bins
- 3 scales
- 1 phone camera
- 3 forceps
- 1 computer
- 12 sets of protective clothes
- 1 set of plastic bags
- 1 tape (to fix the garbage bags outside)

Procedure

ICU: Children IC; WCP: Waste collection point

[ICU] Wearing protective clothes and picking up all utensils used for the waste separation.

[ICU] Taking pictures of the specific hospital waste (blue container) present in all four areas of the ICU.

Procedure per bag:

[WCP] Weighing bag

[WCP] Identifying waste per garbage bag. One to two observant(s) separate the waste using forceps. The content will be separate between the following areas. See list of subsections in excel.

- Used (Criteria: Out of packaging*)
- Unused (Criteria: Still in packaging)

[WCP] The number of gloves and syringes separated will be counted**

[WCP] Each of aforementioned area will be placed in a different garbage bag (8 bags).

[WCP] Each bag will be weighed at the end of the day or when filled.

[WCP] Weighed garbage bags will be placed back in the containers.

* We will only consider this criterion when separating between used or unused as the circumstances does not allow us to be accompanied by an PICU worker that could give us more insights.
** The second observant would also proceed to take photos along the day and complete the excel file.

Results

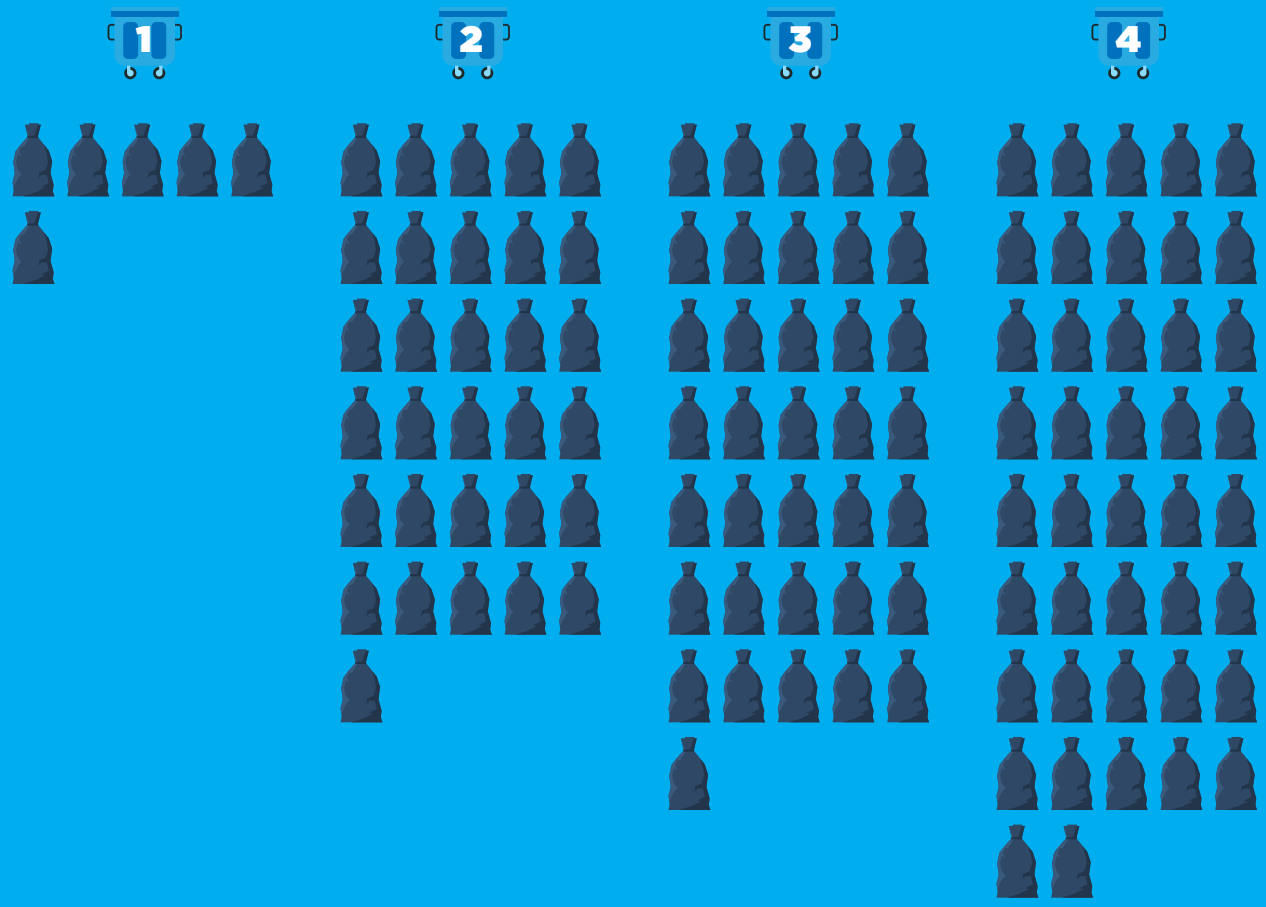


Figure 1. Trash bags per day per unit of the PICU

NB: For Unit 1, the bags might correspond to a longer period of time of between 2 to 4 days.

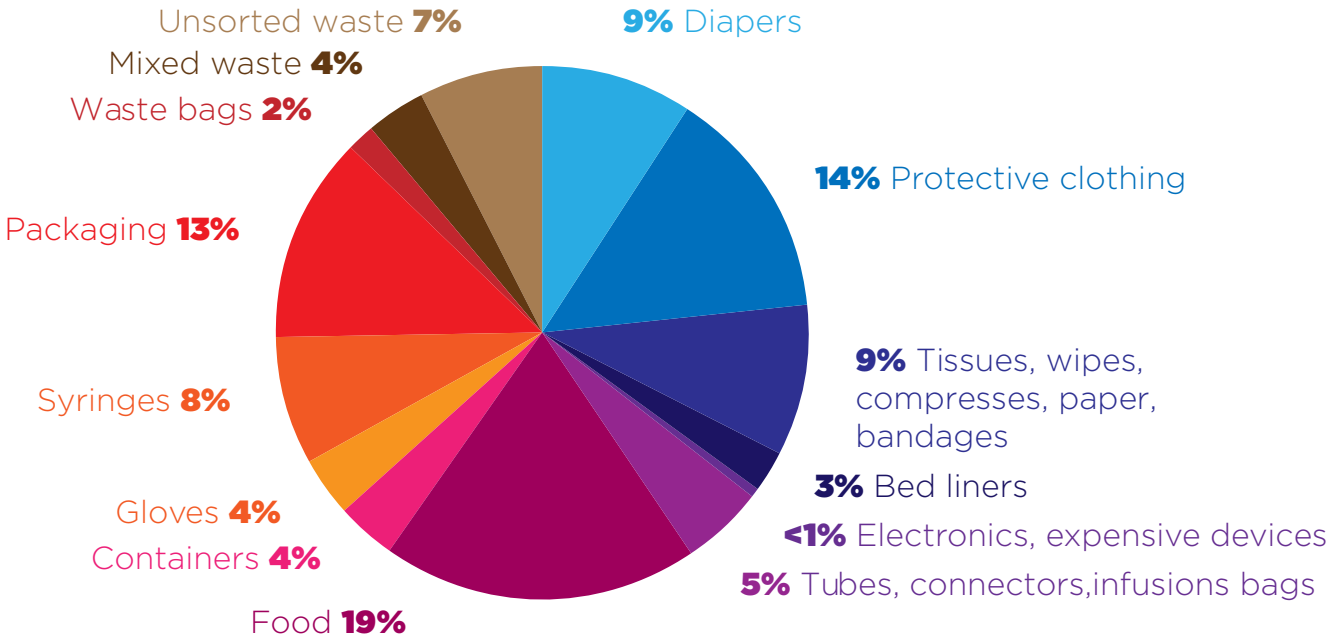


Figure 2. Waste percentages per typology

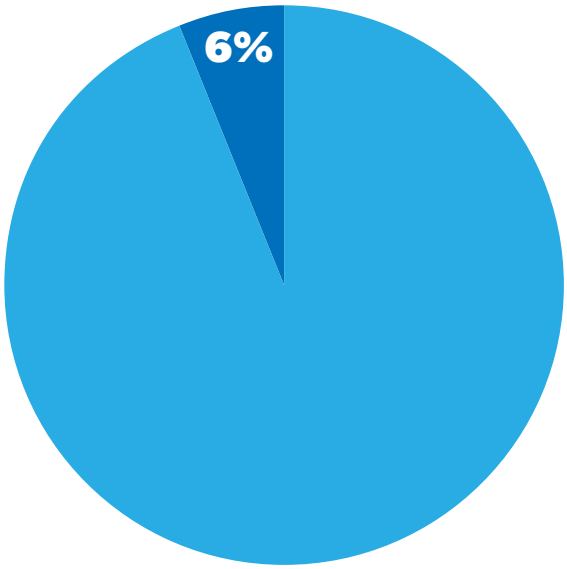
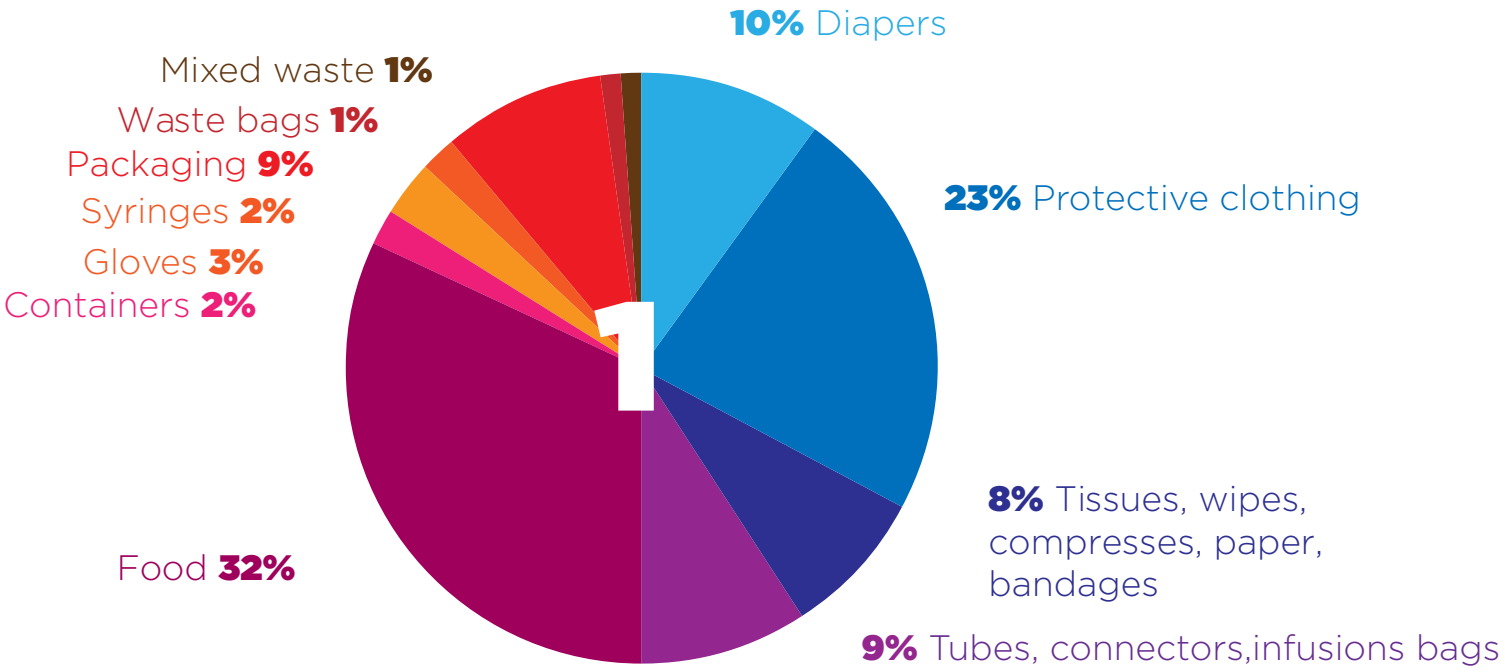
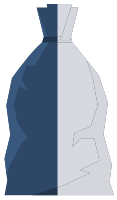


Figure 2. Unused waste percentages from the quantified items

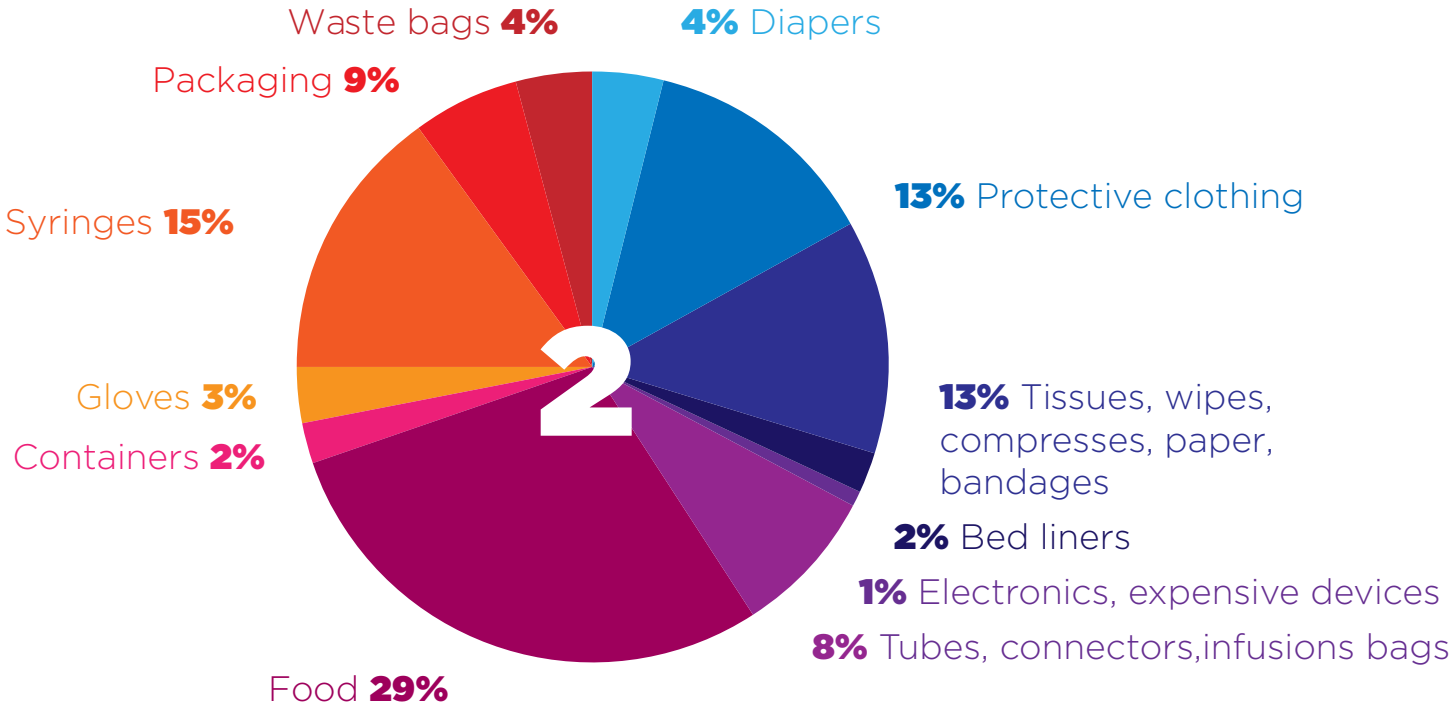
Per

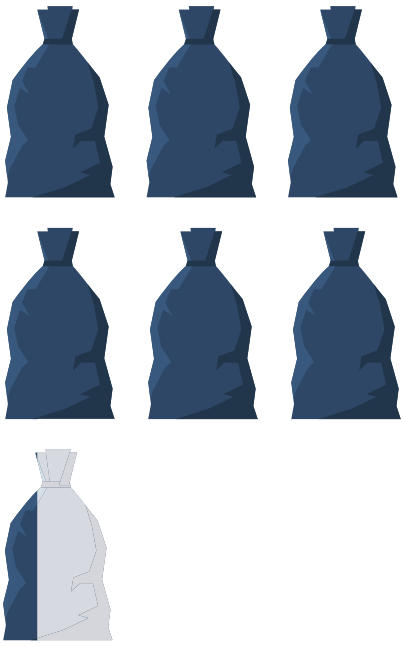




0,6 trash bags per person per day

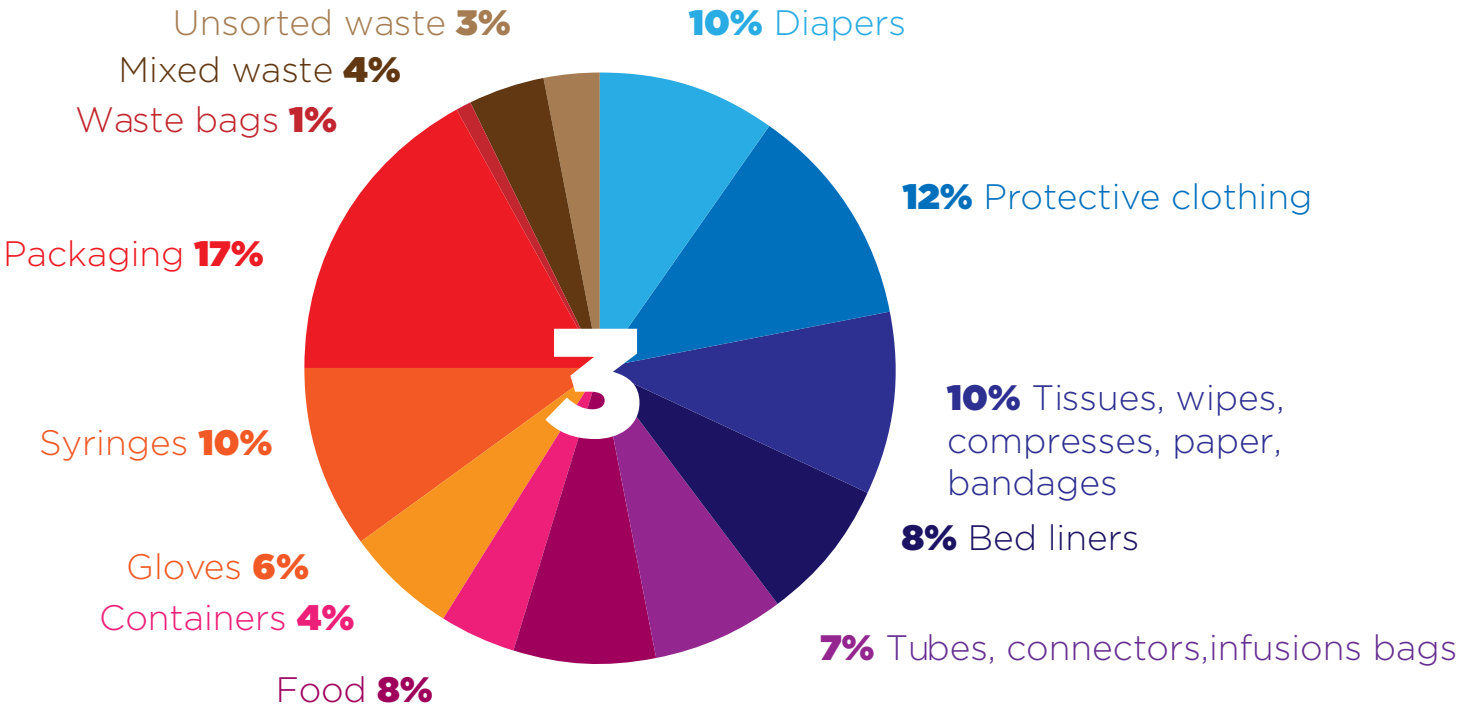
unit

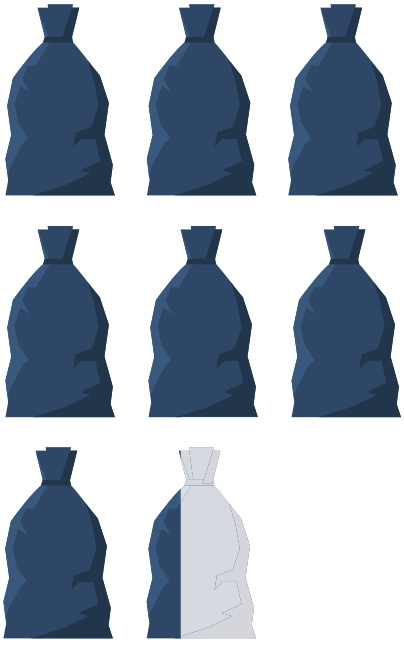




6,2 trash bags per person per day

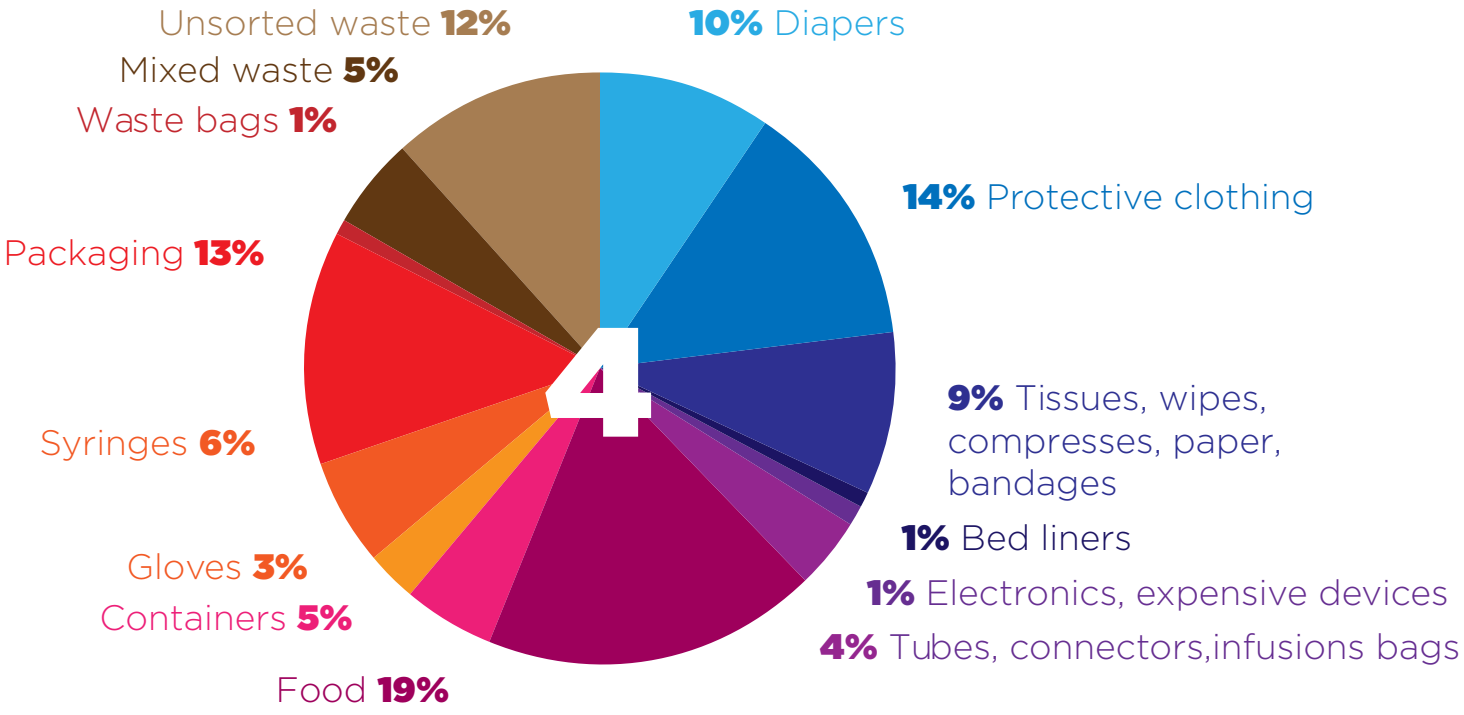
Per u

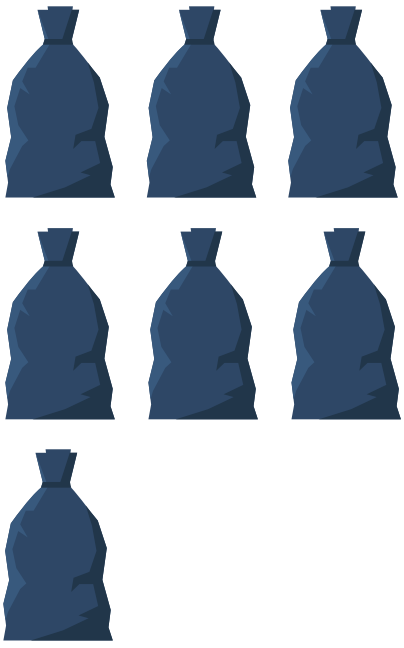




7,2 trash bags per person per day

unit





7 trash bags per person per day


TOT HIER HOOGTE OPSLAG


Cutisoft
Cutisoft


OPSLAG PLASTI


362


DANGER

Observations & Recommendations

Limitations study

- Some trash bags contained infectious materials, like blood. Due to the potential danger that this could generate to open such bags, they were consider as unsorted waste.

- A high number of syringes were found with the tubing still connected. As all syringes in this status contained some remaining liquid on the interior, the tubes were not separated, thus counted as syringe-related waste.

- First day weight result resulted slightly unprecise. Although the weighting method was corrected for the following days, these might results on some overall unprecise numbers.

- For some products it was difficult to distinquish whether they were used or unsused: gloves, syringes, some loose tubes. If there was doubt, the products were placed in the used category.

General observations

- The waste generated at area 1 is considerably less than in the other areas of the PICU.

- Gloves were found sometimes filled with liquid, therefore considered as mized waste.

- We could recognize as a pattern that some containers contained a bag we suppose came from the farmacy. This deduction was done as the bag contained mostly packaging from syringes and medication. Here, syringes and tubes are not normally present together but separated.

- Some of the waste found in the green container seemed to be products which should have been disposed differently:

A blanket was found, a supposition was done that this product could have been thrown with liners. Syringes containing blood, glass and needles which seemed hazardous were also found in the green container, although their condition seemed to indicate they should be treated as hazardous waste.

- Waste typologies come highly mixed in some bags. Food related waste can be found in trash bags next to syringes and intubation devices.

Unused devices observations

- The syringes that were thrown away unused were in the mayority containing a medication which had expired. This was not the case for the rest of the unused waste.

- Some baby food containers were found still mostly full in the containers.

- There was a high amount of unused tissues present, but all of them were out of their packages.

- From the unused waste, most is connectors Packed connectors were found in several occasions.

Recommendations

- Staff working at the PICU could be reinstruct about waste separation: This would ensure that all wastestreams are correctly separated.

- Protective clothing resulted on a big amount of the waste, reusable alternatives could be analysed.

- Unit 4 had the biggest amount of waste, studies could be undertaken to understand why is this happening and how to tackle it.

- Food was the biggest amount of waste, which was non hazardous but mixed with the rest. A separation of food waste from the hospital waste could be an alternative to look into

- Implementation of reusable hot water bags instead of filling gloves with hot water.

Appendix E staff on the ICU

In the ICU intensive and special care is provided to patients in a life-threatening situation. This is done by a team of specialists, who are all described below.

Intensivist
The intensivist is a medical specialist who is specially trained to treat patients in the ICU. To do this, they first trained as an internist, anaesthetist, cardiologist or neurologist. The intensivist is the main responsible doctor and keeps an overview of all the patients on a specific unit and is responsible for deciding on medical treatments and diagnostics.

ICU doctors
The ICU doctor assistant is a MD who is not yet a medical specialist and who works under the supervision of the intensivist. Usually, this doctor follows training as a medical specialist, e.g. anaesthetist or internist. For this training, he/she does an internship at the ICU.

ICU nurse
The ICU nurse is specially trained for the care and treatment of ICU patients. Their role is to provide all care necessary by constantly monitoring a patient, administering treatment and providing support during a patient's stay at the ICU.

Pharmacist
Together with the doctors, the pharmacist optimises the medication in the ICU. He/she also ensures a safe and secure medication process with the right medicine, for the right patient at the right time.

Pharmacy technician
Prepares the medication in syringes and infusion bags and Is 24/7 available in the ICU. The pharmacy technician also orders and stocks the prefilled syringes.

Specialists
Sometimes specialists are needed for specific treatments, like physiotherapists, respiratory therapists, microbiologists and ethicists.

Care assistant
Care assistants are supporting the ICU nurses by conducting logistical, minimal care and household tasks.

Management
The management consists of the head of the department, a nurse manager and different team leaders, who are together responsible for the functioning of the ICU.

Patient
The patient undergoes treatment in the ICU.

Family
The family is allowed to visit the patient at certain time slots.

Cleaner
The cleaners empty the waste bins and clean the room of the patient.

Staff on the ICU

Intensivist

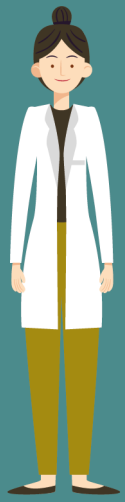
Pharmacist

Pharmacy technician

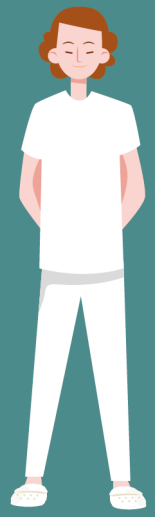
Nurse

Care assistant

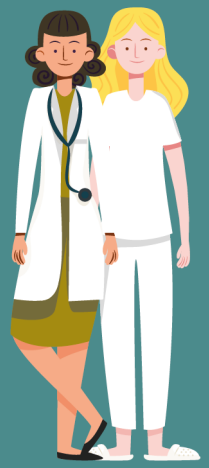
Cleaner



Management



ICU doctor



Specialists

Patient

Family

Figure E1: visual of all different staff members on the ICU

Appendix F stakeholders

A stakeholder diagram (see figure F1) is made to identify the interested parties, their concerns, influence and the ways they interact with each other (Ashby, 2016). The stakeholders are arranged according to interest and influence in transforming the ICU towards a more sustainable ICU. The diagram consists of the following four quadrants:

- Context setters: great influence and little interest, influential but uninterested, need to be satisfied
- Key players: great interest and great influence, need full involvement in making decisions
- Bystanders: little interest and little influence, don't demand attention, but need to be informed
- Concerned citizens: great interest but little influence, need to be consulted and informed

Key stakeholders: single-use device manufacturers, medical equipment manufacturers, procurement, ICU team, waste management team, policymakers.

Each stakeholder has their own interests, concerns and interactions. These are described below:

- Government (Rijksoverheid): made agreements to achieve goals stated in the Green Deal Sustainable Care for a healthy future, as well as in the climate agreement (Ministerie van Algemene Zaken, 2021, April 14). They are interested in seeing overall results but are not specifically interested in this ICU. They influence by setting up these agreements.

- Policymakers: have no particular interest in

Figure F1: stakeholder diagram

making the ICU more sustainable, but can have influence through making laws concerning medical products and sustainability.

- Manufacturer: BD Plastipak is the manufacturer of the syringes; their interest is to sell their products to hospitals. There are not many manufacturers that make syringes, so there is not a lot of competition on the market. Therefore they have a big influence on what is available on the market.

- Logistics: syringes are transported to the hospital, and the waste from the hospital is transported to waste processing companies. They have little interest and little power.

- Waste processing: waste is processed by an external company. They influence the end of life of the product.

- Patients: patients have no particular interest in making the ICU more sustainable, but they have an interest in being handled safely and getting better as soon as possible. This means that sustainable solutions should be as safe and convenient as the current products used.

- ICU Erasmus MC: Erasmus MC signed the Green Deal Sustainable Care for a healthy future, so they have an interest in transforming the ICU into a sustainable ICU.

- Strategic buyers Erasmus MC: the strategic buyers choose what they buy for the ICU. They are interested in complying with the green deal, but also do not want to spend too much money.

- Staff of the ICU (nurses, doctors, pharmacists): employees from the ICU have complained about the amount of waste, therefore they have an interest in a sustainable ICU, but they do not have a lot of influence.

- Apotheek A15: apotheek A15 produces prefilled syringes and delivers these to the ICU. It is a commercial company, but the hospitals have a share of the profit, hospitals are stakeholders. Board members are from the academic hospitals.

Appendix G list of requirements

General

- The product must decrease the overall impact of the syringe in the short and longer-term.
- The product must change the linear system into a more circular system.

Desirability: Does the product address the user's values and needs?

- The product must not increase the workload of the nurses, regarding time and number of actions. It must be as efficient (in time and amount of actions needed) to attach to the patient as the current syringes.
- The product must be safe for both the patient and staff to work with
    - The product must meet the rules of the infection prevention protocol.
    - The product's sterility and safety must be guaranteed by following the current regulation.
- The product must be accessible close to or in the patient's rooms, to ensure that the nurses can access a syringe in a short time.
- The product must show what medication is in the syringe, who it is for, the time and date it was placed in the pump.
- The nurses must be able to look through the material to see the fluid inside the syringe.
- The product must be easy to (re)place and dispose of.
- The product must be usable with medical gloves.

Feasibility: can it be done?

- The product must be able to be mass-produced: at least 68.000 per year only for Erasmus MC ICU.
- The product must anticipate developments in for example biobased plastics, to avoid lock-in situations.
- The material must be non-absorbable, and not harmful or reactive with medication.
- The product must withstand a sterilisation process (type of sterilisation is to be defined), and not deform or melt in any way.
- The product must fit the syringe pump used on the ICU (B-Braun pump): max length of 150 mm, a diameter of 30 mm, and a flange with a width of 50 mm.
- The product must be able to be connected to the syringe pump and patient for at least 24 hours straight.
- The product must be able to be filled with up to 50 ml of fluid medication
- The product must comply with the extension lines that connect to the patient: a Luer-Lock connection.
- The product must be able to be stored at room temperature (20-22) or in the fridge (2˚C-8˚C).
- The material properties must be: high transparency, high chemical resistance, toughness, and resistance to bacteria (Joseph et al., 2021)

Viability: will it survive in the longer term?

- The product must (in the end) be financially viable for Erasmus MC and potential stakeholders.
- Erasmus MC must be able to work with the proposed solutions, either in house or by approaching existing/new stakeholders.
- The product must be implementable in 8 years since the ICU has a goal of being fully circular in 2030.
- The product must not form a lock-in situation for the future development of sustainable syringes.
- The product must anticipate developments in for example biobased plastics, to avoid lock-in situations.

Personal interest

- The product must fit the direction of my master study (integrated product design).

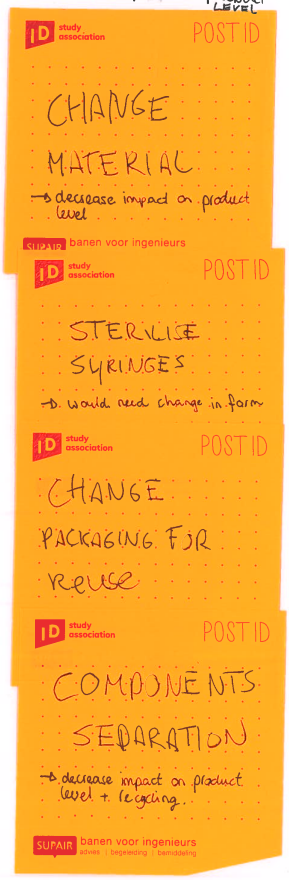
Appendix H ideation phase

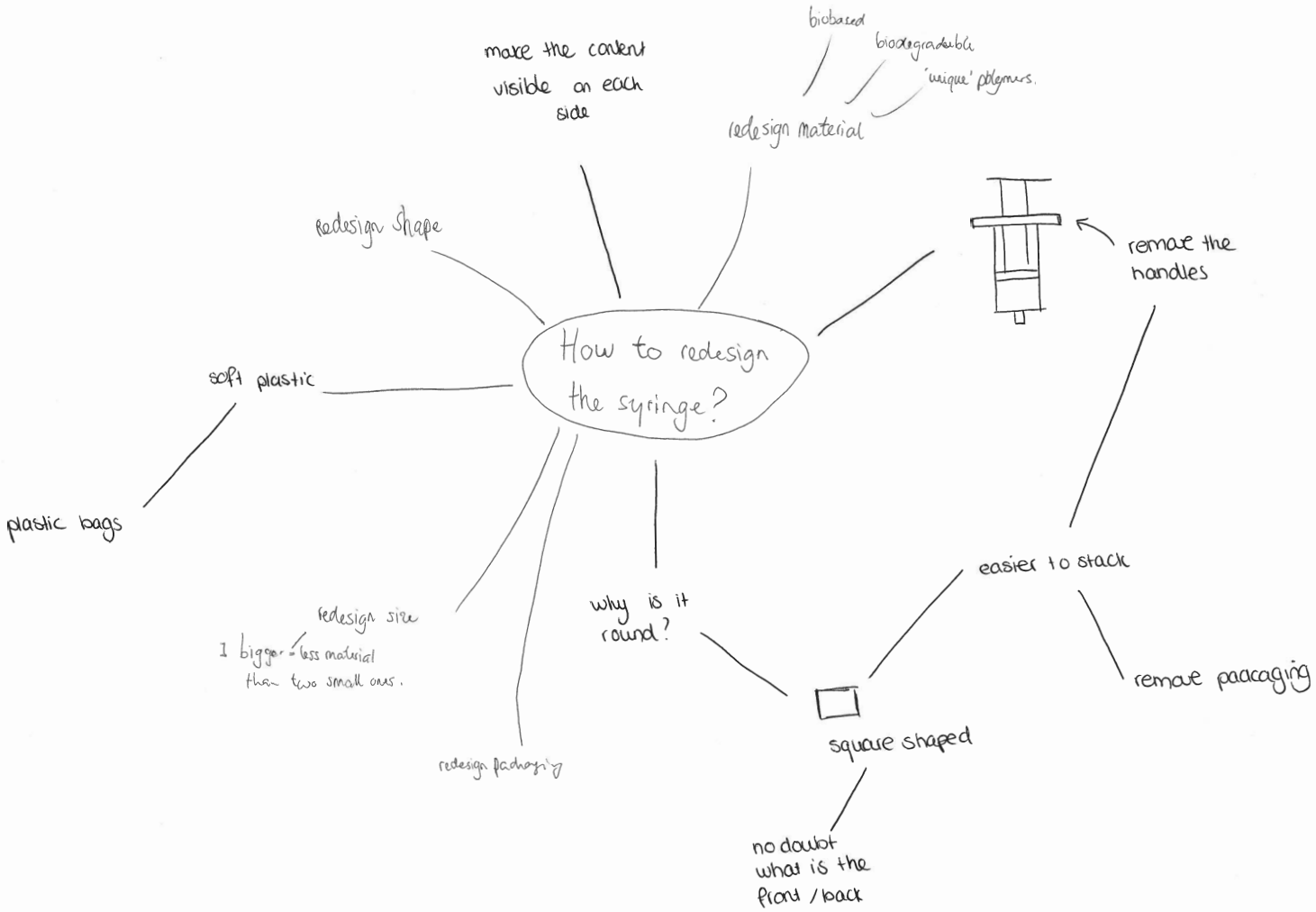
REGULATION IN HOSPITAL

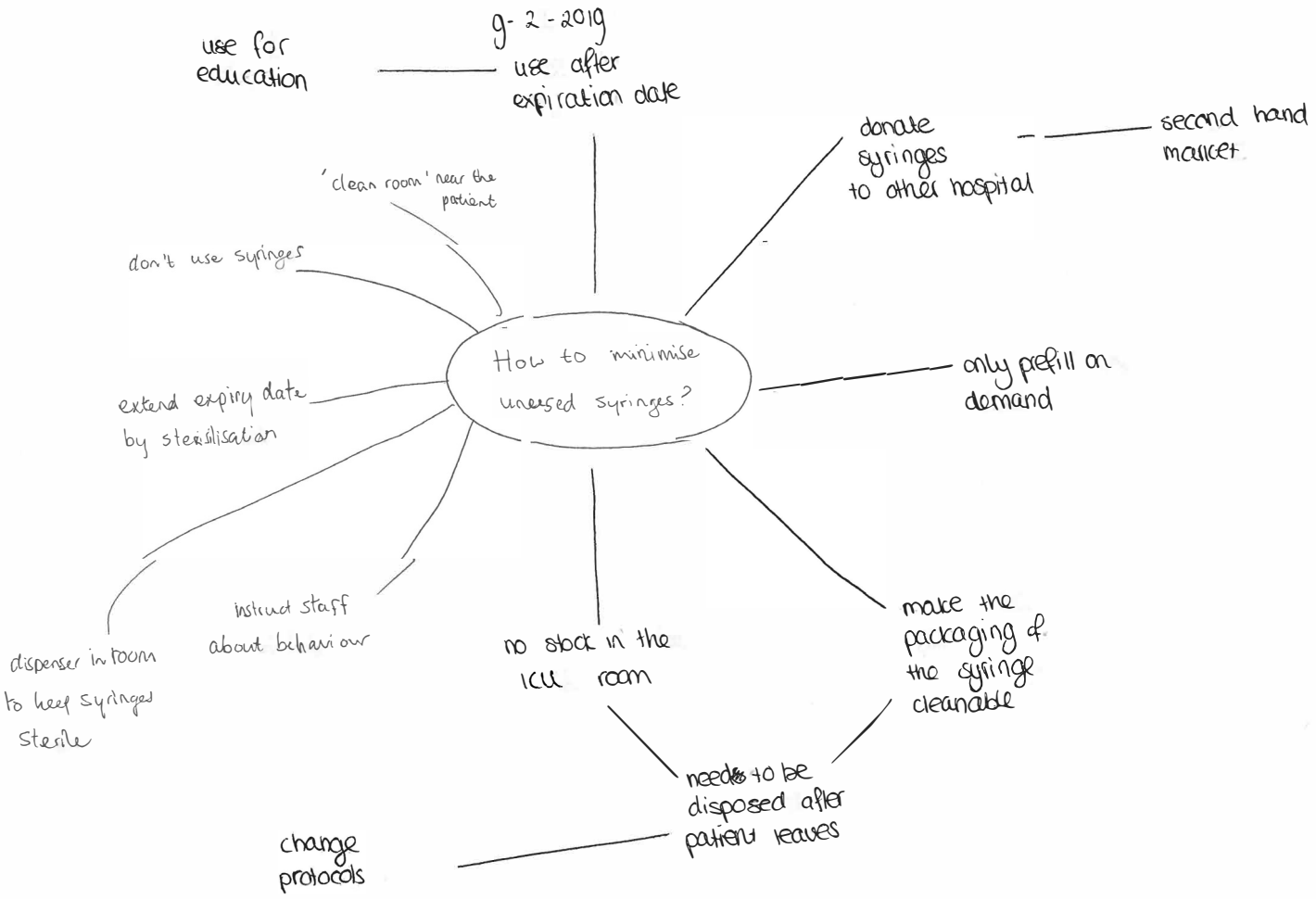
BEHAVIOUR CHANGE

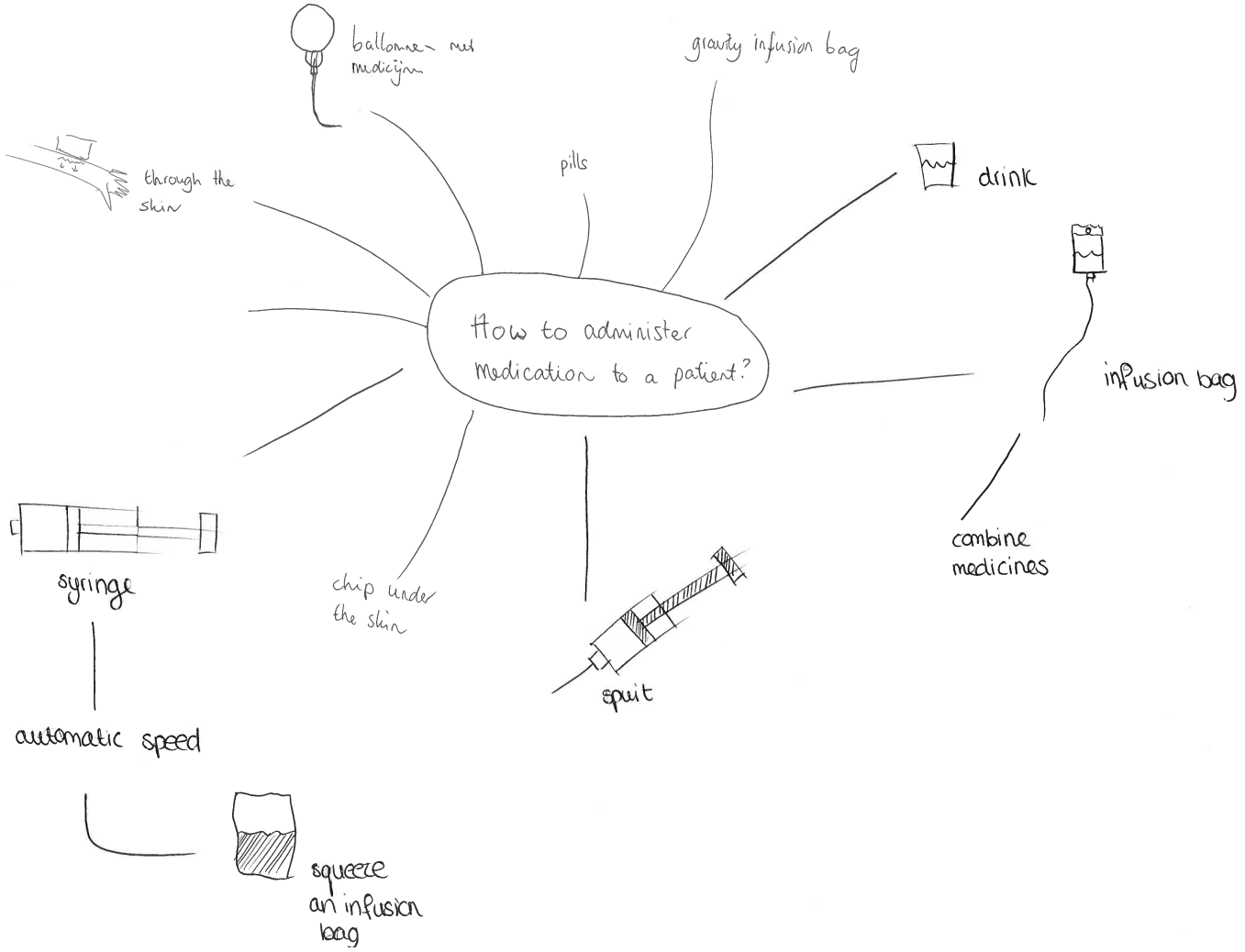
SCALE UP FILLING PROCESS

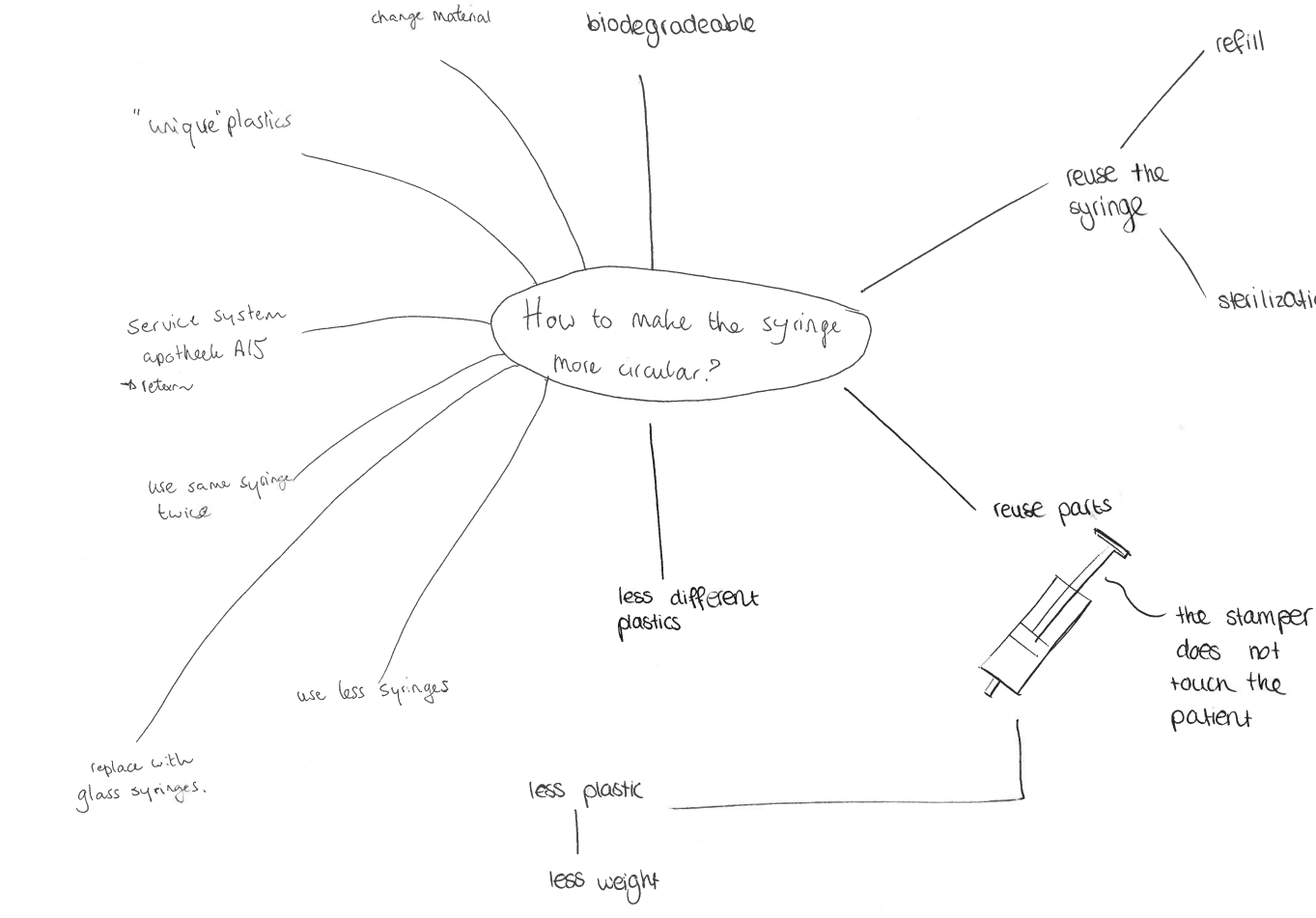
DECREASE IMPACT ON PRODUCT LEVEL

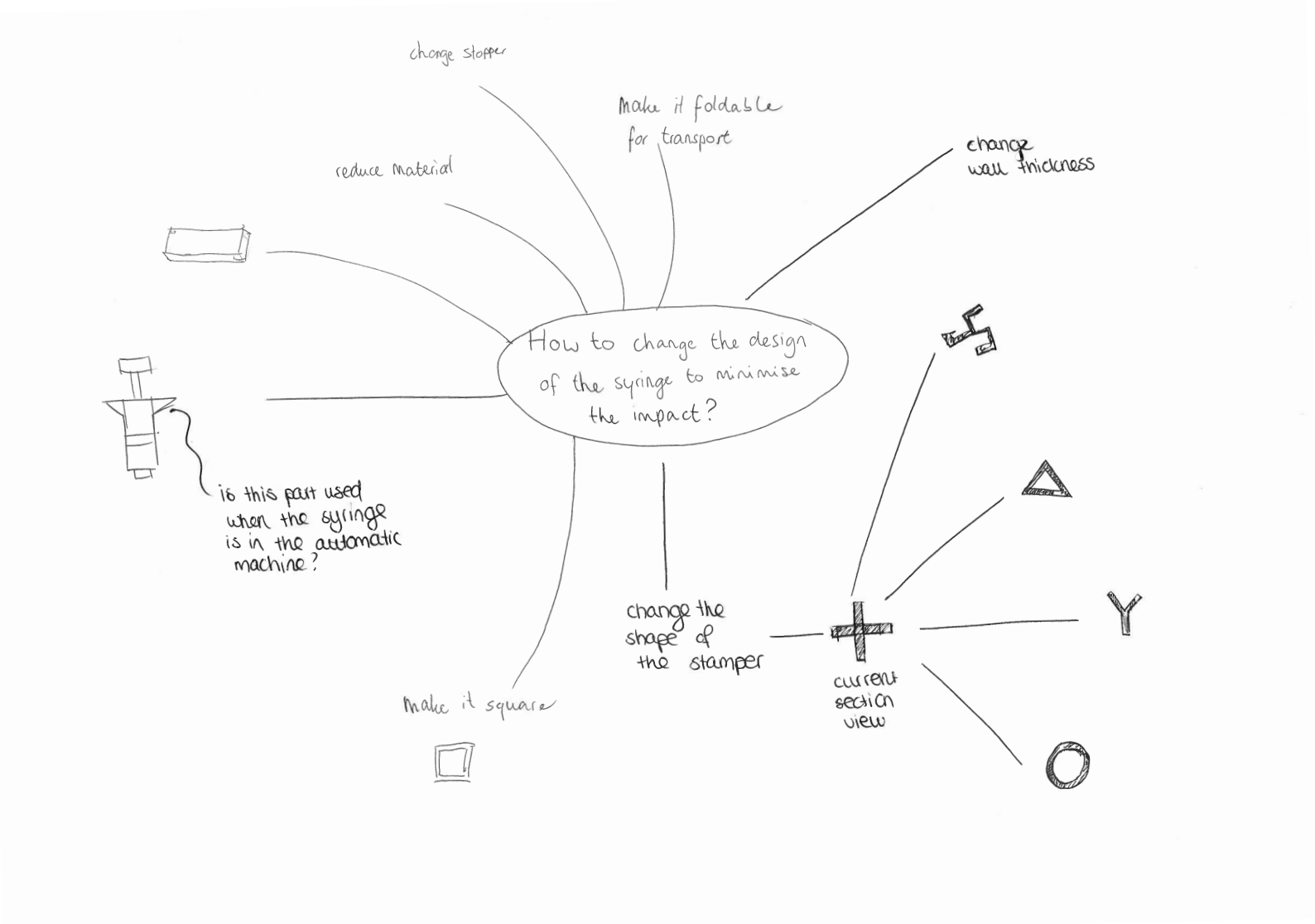


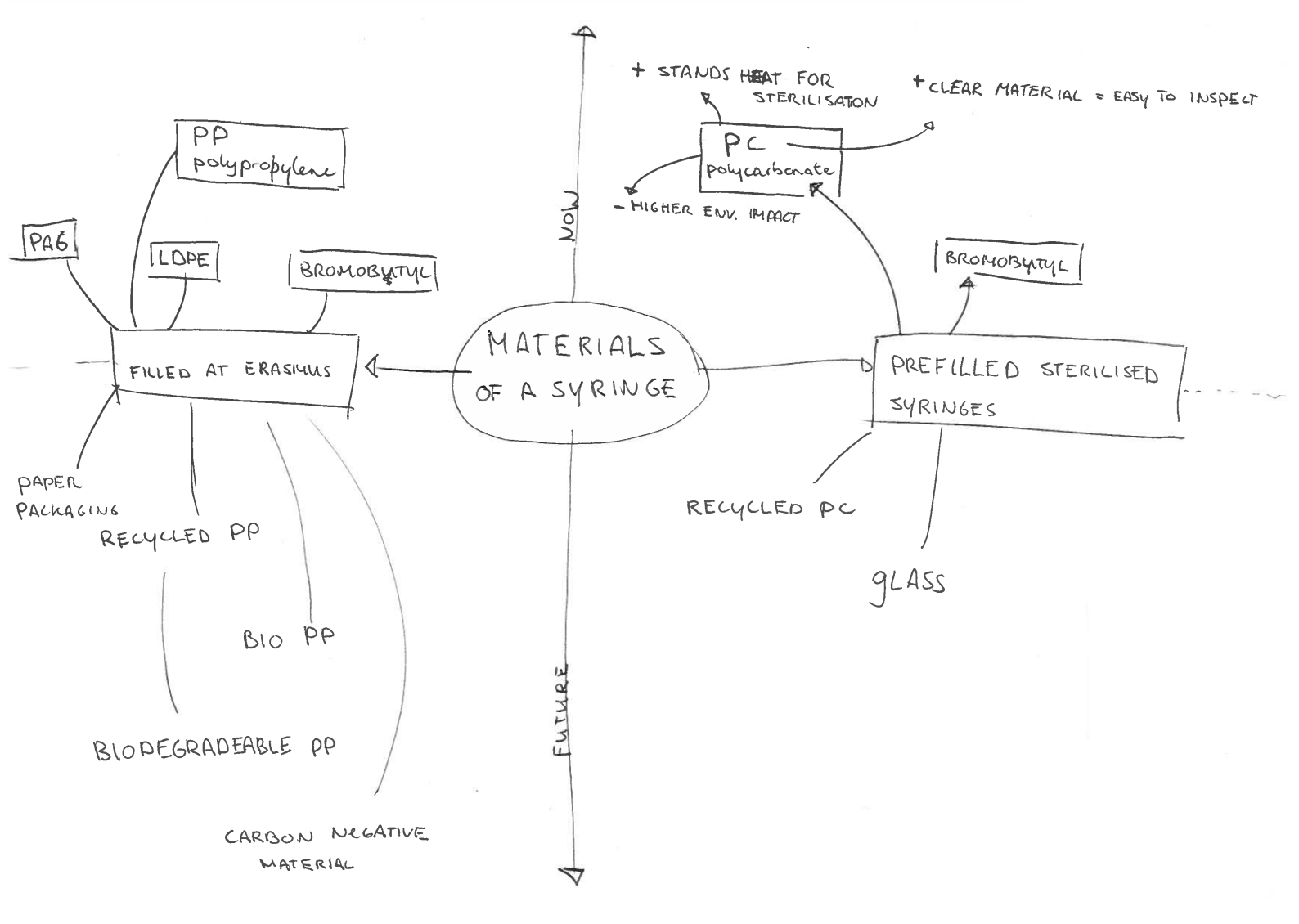

How to redesign the syringe?
make the content visible on each side
biobased
biodegradable
'unique' polymers.
redesign material
redesign shape
remove the handles
soft plastic
plastic bags
redesign size
1 bigger = less material than two small ones.
redesign packaging
why is it round?
easier to stack
remove packaging
square shaped
no doubt what is the front / back


How to minimise unused syringes?
use for education
9-2-2019 use after expiration date
donate syringes to other hospital
second hand market
'clean room' near the patient
don't use syringes
only prefill on demand
extend expiry date by sterilisation
dispenser in room to keep syringes sterile
instruct staff about behaviour
no stock in the ICU room
make the packaging of the syringe cleanable
needs to be disposed after patient leaves
change protocols


How to administer medication to a patient?
balloon- met medicijn
gravity infusion bag
pills
drink
through the skin
infusion bag
combine medicines
syringe
chip under the skin
spuit
automatic speed
squeeze an infusion bag


How to make the syringe more circular?
change material
biodegradeable
"unique" plastics
refill
reuse the syringe
sterilization
service system apotheek A15
return
use same syringe twice
reuse parts
the stamper does not touch the patient
less different plastics
use less syringes
replace with glass syringes.
less plastic
less weight

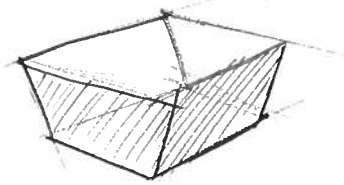

change stopper
Make it foldable for transport
reduce material
change wall thickness
How to change the design of the syringe to minimise the impact?
is this part used when the syringe is in the automatic machine?
change the shape of the stamper
current section view
Make it square


MATERIALS OF A SYRINGE
NOW
FUTURE
+ STANDS HEAT FOR STERILISATION
+ CLEAR MATERIAL = EASY TO INSPECT
PC polycarbonate
- HIGHER ENV. IMPACT
PP polypropylene
PA6
LDPE
BROMOBUTYL
FILLED AT ERASMUS
PAPER PACKAGING
RECYCLED PP
BIO PP
BIODEGRADEABLE PP
CARBON NEGATIVE MATERIAL
BROMOBUTYL
PREFILLED STERILISED SYRINGES
RECYCLED PC
GLASS

1.

USE THE "USED" WHITE BOXES FOR OTHER PURPOSES

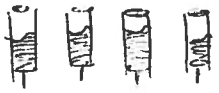
NEEDLE BOX



REDESIGN THE WHITE BOX

REUSE THE WHITE BOX

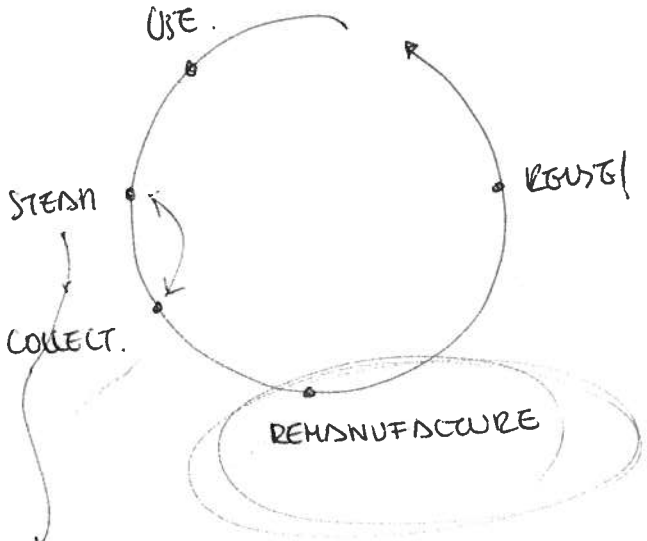
DISINFECT.

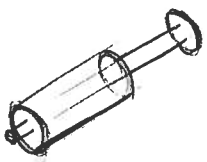


FILL MORE SYRINGES WHEN MED IS LEFT

REDESIGN THE PROCESS

REDESI

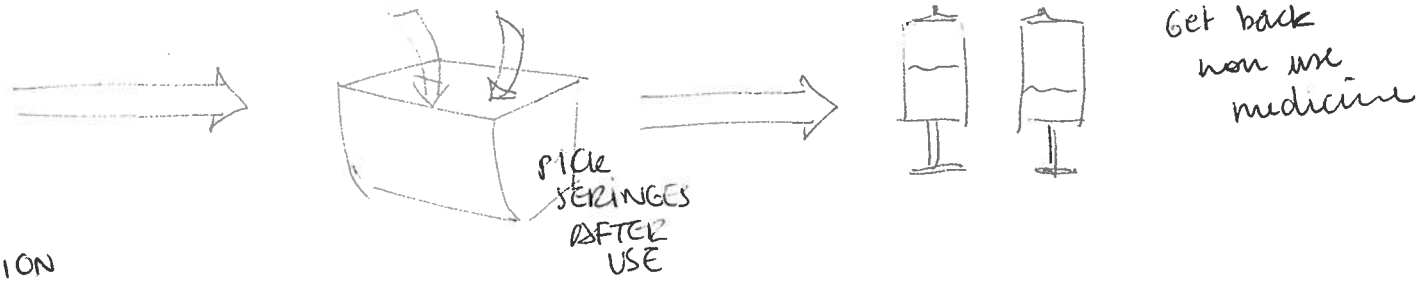




REDESIGN THE PLUNGER

CROSS SECTIONS

MA
WITH
ST

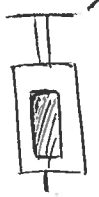


DICATION

better calculation quantity medicine to be prepared? EXACT QUANTITY.

HAVE STOCK READY OUTSIDE THE ROOM FOR WHEN EXTRA IS NEEDED

RECYCLE



REMOVE PRIVACY INFORMATION FROM THE PRODUCT

GN THE PRODUCT

steam out!?

ATERIAL REACTS
H INFECTIOUS
UFF
CHANGE IN
COLOR

REMOVE THE HANDLE

DESIGN AS A NEW CONTAINER

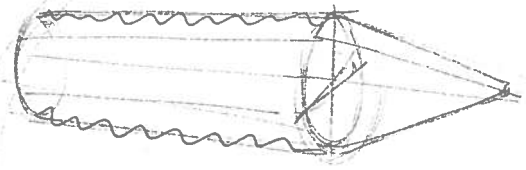
PRODUCT.

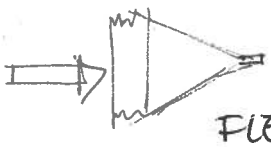
MONOMATERIAL. → RECYCLE EASILY.

ONLY TUBE.

whole system in ICU itself.

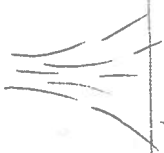
CARTRIDGE SYSTEM



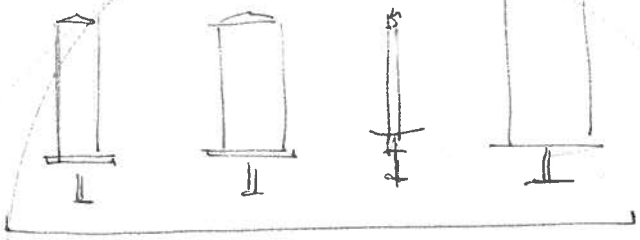


FLEXIBLE ?

NOT TOU
THE SY



~~PROCESS~~



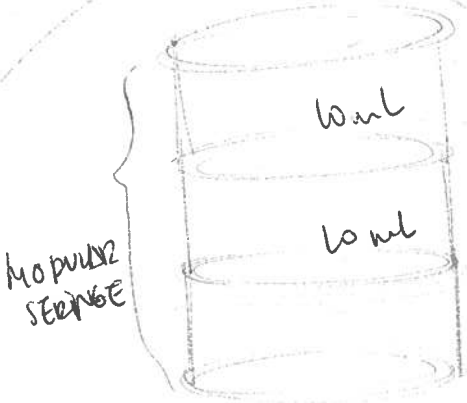
LOTS OF DIFFERENT SIZES

↓

FILL EXACT QUANTITY.

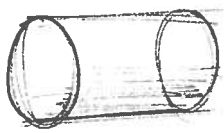
↓

AVOID MEDICINE TO BE THROWN AWAY



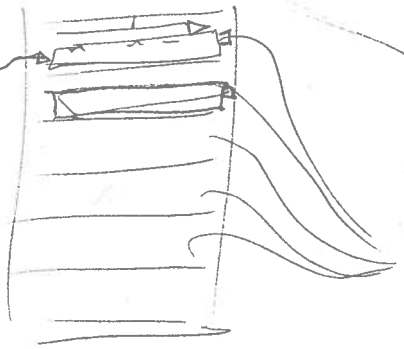
← charge per patient.

CHING
RINGE



USE AIR PRESSURE INSTEAD OF A PLUNGER

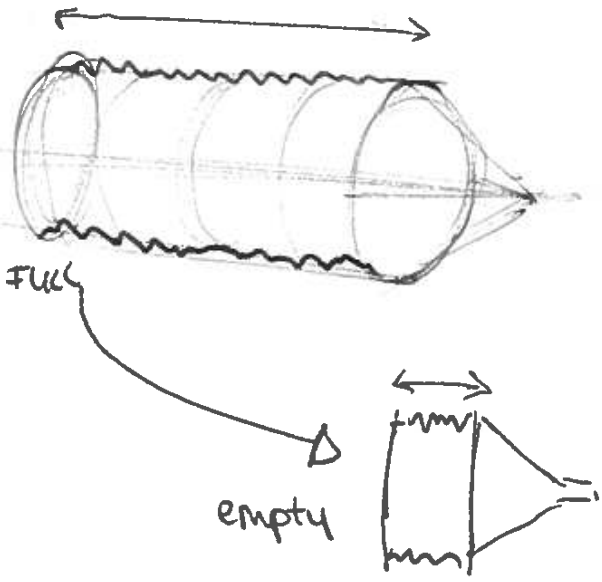
USE ONLY A TUBE OR CONTAINER IN THE PUMP TO MADE OF ONE COMPONENT



IDEAS

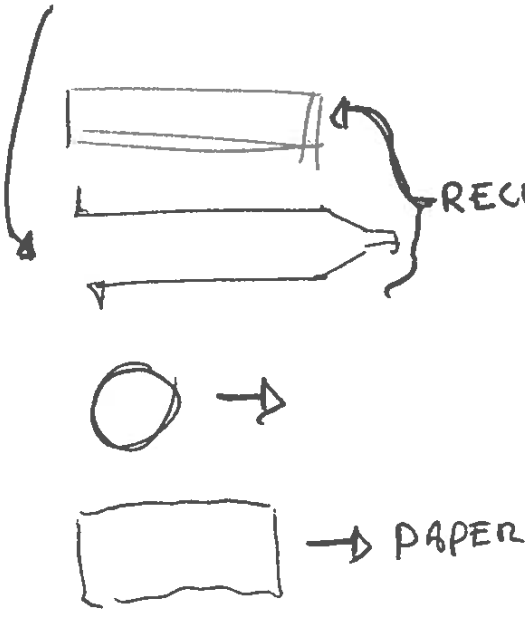
PRODUCT BASED

1. FOLDABLE SYRINGE

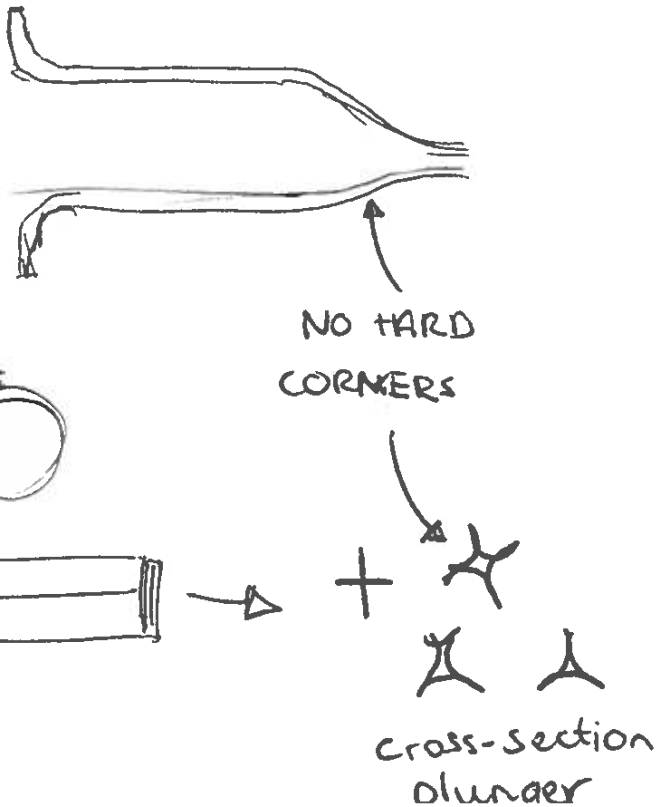


2. CAR

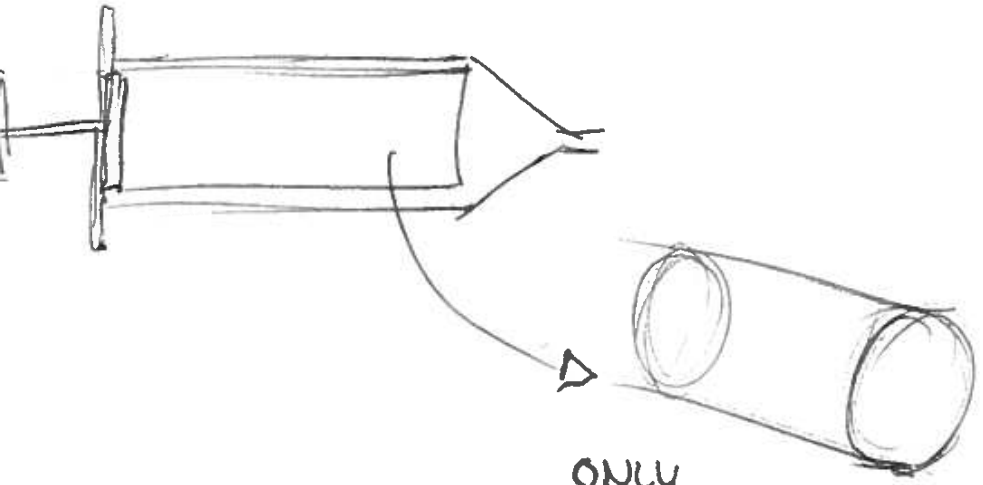
4. PLUNGER AND BARREL IN ONE MATERIAL



5. MAKE STERILISABLE

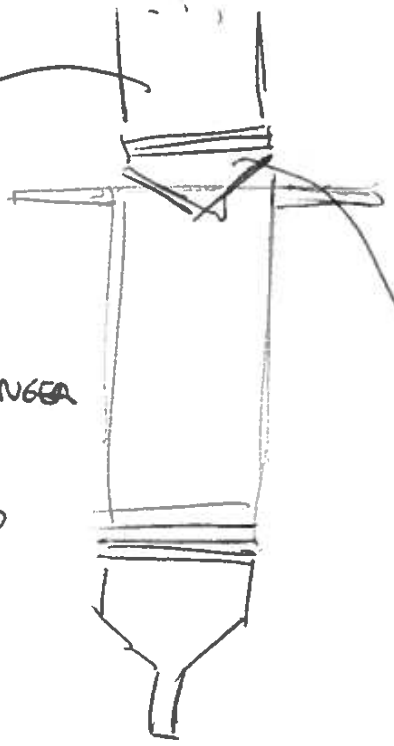


RTRIDGE SYSTEM



ONLY
REPLACE TUBE WITH MEDICATION

3. MODULAR SYRINGE



→ SEPARATE ALL COMPONENTS AT END OF LIFE

SCREWABLE STOPPER

REUSE PLUNGER

↓

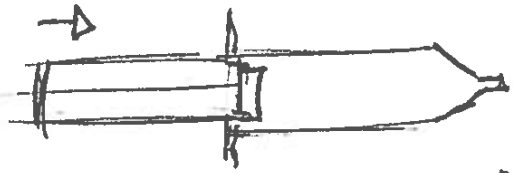
SCREW ONTO STOPPER

YCLE

PACKAGING

1. USE PREFILLED STERILISED SYRINGES

→ WITH PLUNGER



= takes more space + material but ready to administer (RT

→ WITHOUT PLUNGER

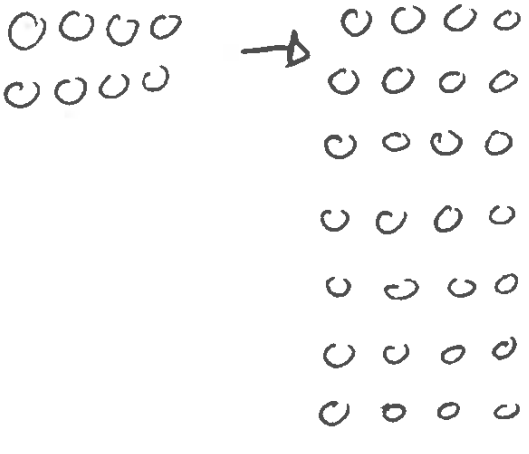
= less space needed + less material but nurse needs to screw on the plunger

IDEAS

SYSTEM / PROCE

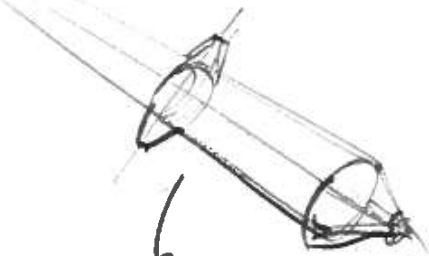
5. PRODUCE IN LARGE BATCH

→ less waste + costs



STERILISE WASTE FOR RECYCLING

4. RECYCLE



RECYCLE CLE

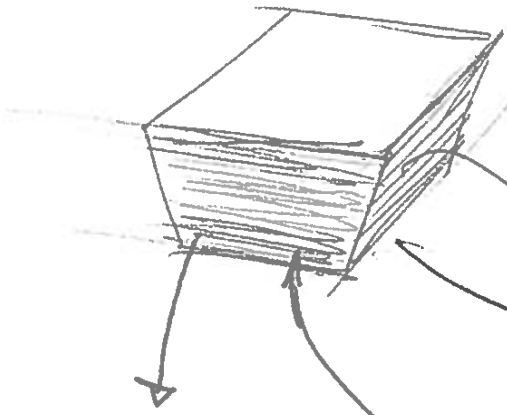
PARTS :

→ INFECTED

INDICATED

→ SORT PER

2. REPURPOSE PACKAGING OF PFSS

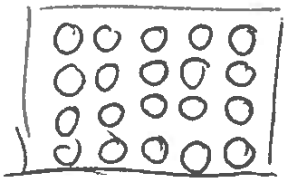


NEEDLE BOX

INFECTIOUS WASTE BOX

SEND BACK TO BD
↳ STERILISE + REUSE

USE TO TRANSPORT PFSS TO HOSPITALS



BOX DOES NOT NEED TO BE STERILE

3. COLLECT USED SYRINGES

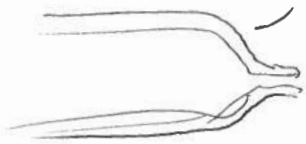
NOT EMPTY:
COLLECT LEFT OVER MEDICINE TO PUT IN FILTER

EMPTY:
SEPARATE PLUNGER TO REUSE/RECYCLE

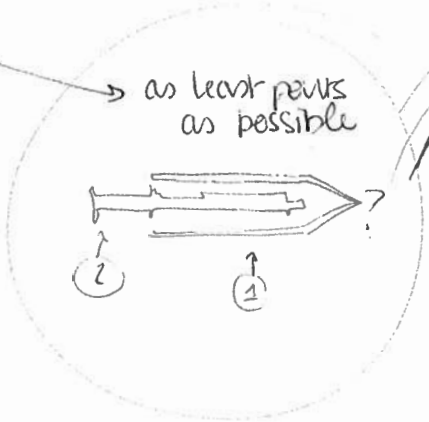
COLLECT SYRINGES TO STERILISE AND REUSE AT APOTHEEK AIS

PRODUCT BASED IDEAS

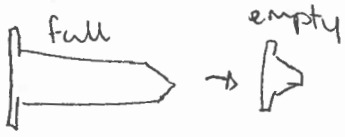
REDESIGN FORM FOR STERILISATION



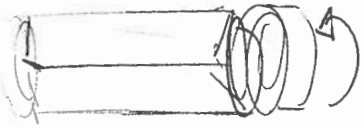
ORGANIC SHAPE



FOLDABLE



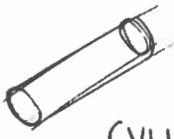
SEPARATE STOPPER AND PLUNGER by rotation

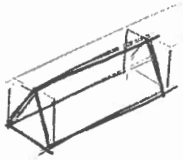


reusable plungers

"click system" or "kinderbeveiligingssysteem"

CYLINDER PLUNGE:
less edges impraves the sterilisation





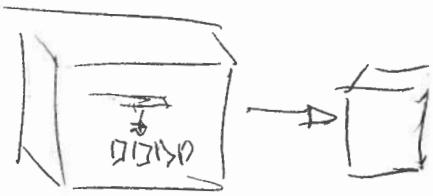
TRIANGLE SHAPE WITH ROUNDED EDGES

SYSTEM

COLLECT USED SYRINGES SEPARATELY TO REMANUFACTURE

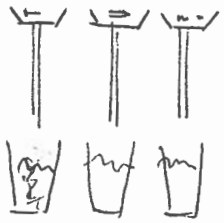
- steam out patient info
- keep packaging! → vanguards.de.

USE PREFILLED STERILISED SYRINGES by machine



DISPOSE FOR RECYCLING ⇒ separate per material

- monomaterial

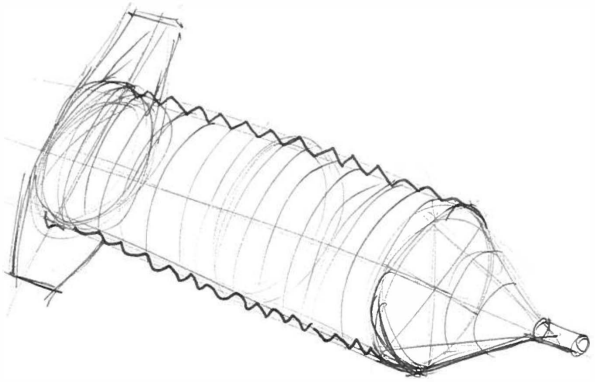


USE EXPIRED SYRINGES FOR EDUCATION

- thrift market

1] Foldable syringe

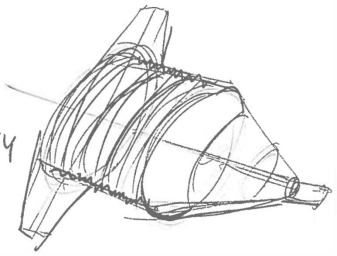
ADVANTAGE
+ waste takes up less space



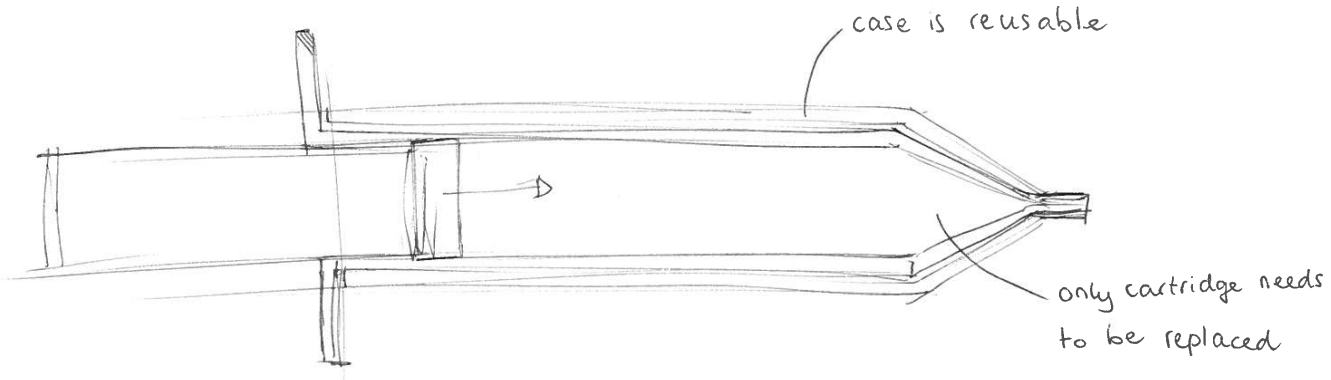
FULL

DISADVANTAGE
- B-braun pump needs to be calibrated again
-

EMPTY

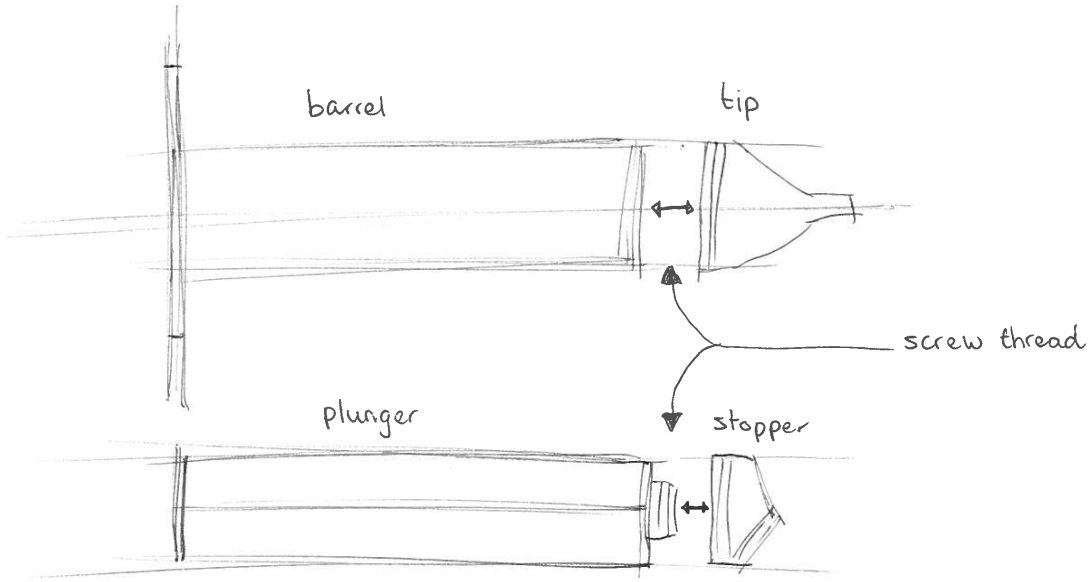


2] Cartridge system



+ cartridge is placed in holder, holder can be reused
+ ~~holder is~~ cartridge is infectious waste, rest is not
- extra work

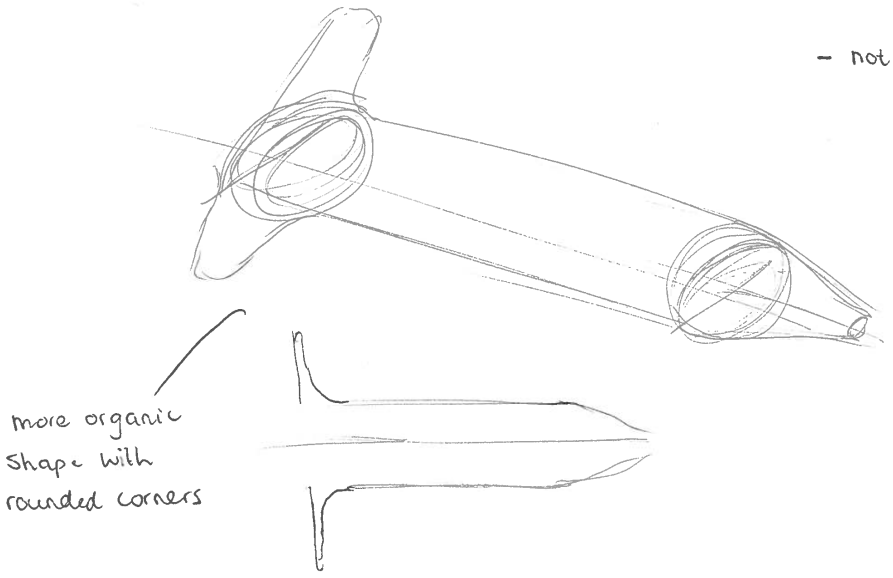
3| Modular syringe



+ easy to separate at end of life
+ reuse plunger
+ sterilise barrel
+ dispose tip

4| Sterilisable shape

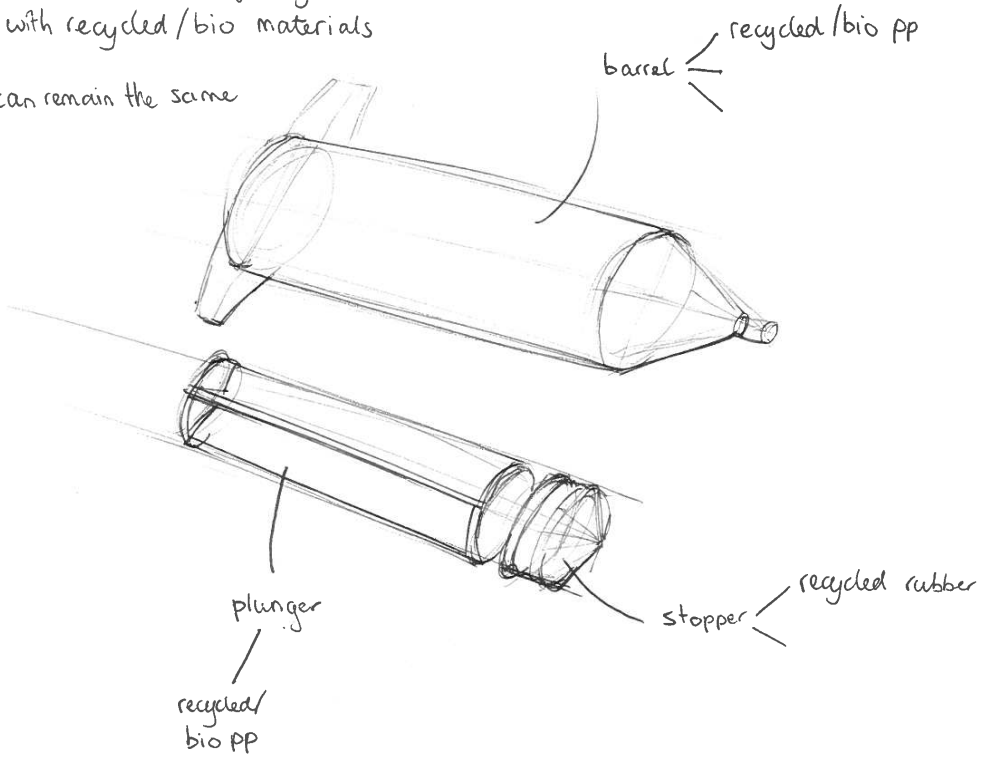
+ easier to clean
- not compatible with pump



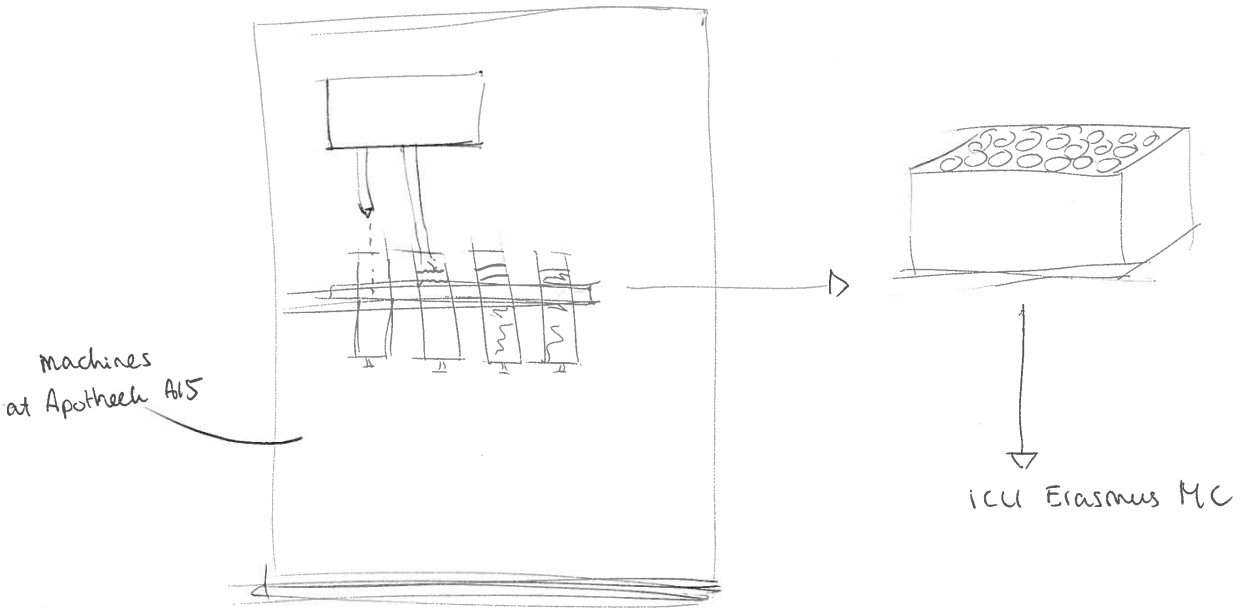
5| Circular materials

+ decrease impact by replacing virgin materials with recycled / bio materials

+ geometry can remain the same

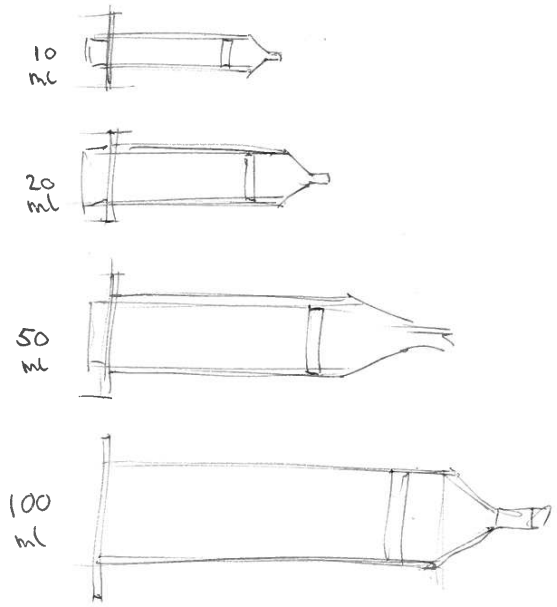


6| Machine filled+sterilised syringes



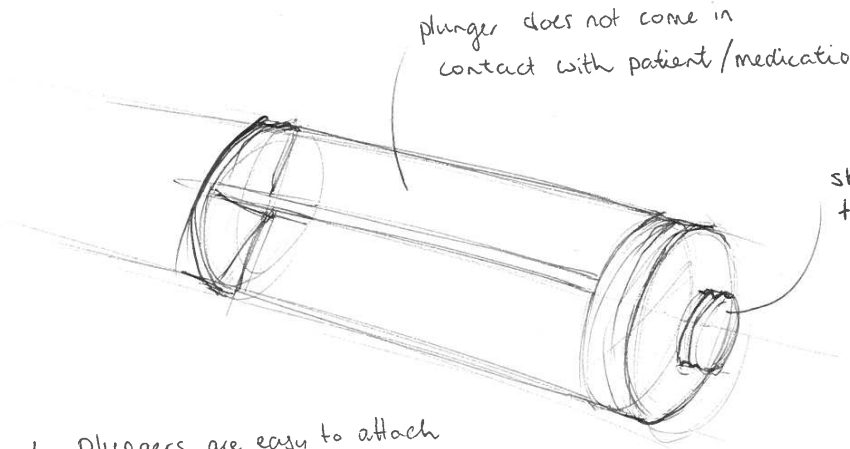
+ Limit products needed by mass production / large batches
+ Longer shelf life (up to 2 years)
+ Takes off workload of nurses / pharmacists
- Increased difficulty of logistics
- Energy intensive process (machines, autoclave)

7| Optimise size of syringes



USE LOTS OF DIFFERENT SIZES
→ FILL EXACT QUANTITY
TO MINIMISE LOSS OF MEDICATION
AND TO MINIMISE REPLACEMENT OF
SYRINGES

8| Reuse plungers



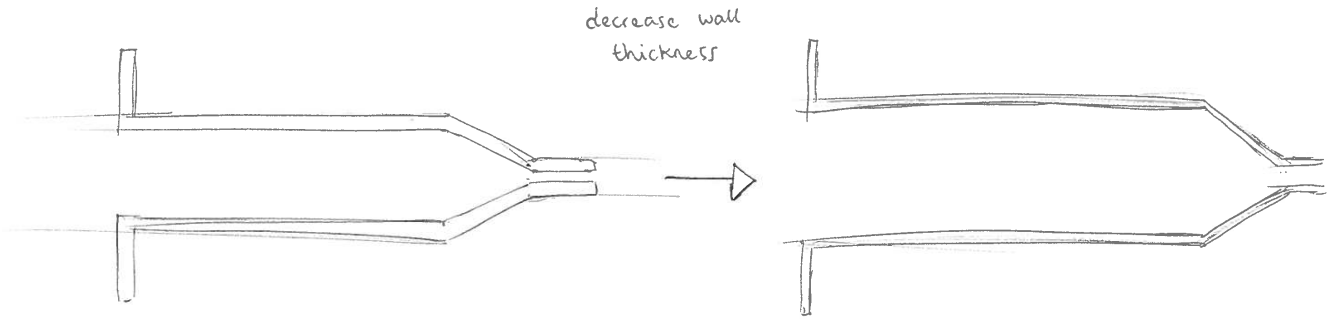
\+ plungers are easy to attach by screwthread

\+ saves materials used per syringe

\- not approved by rules and regulation

collecting plungers separately enables recycling ⇒ more non-infectious waste

9/ Thin walls



+ less material needed = less impact

- decreased stiffness


C-bo
prefill on demand
Make out of one component
change wall thickness
thinner walls
extend expiration date
separate waste for recycling
materials
difficult to implement
HOW?
air pressure through skin
Chip under the skin for syringe
foldable syringe
material changes color when it has been in contact with infections
glass syringes
repurpose packaging as needle container
eliminate flange
original
use infusion bags
large batches
100 cc syringes
collect used syringes and extract leftover medicine
sterile syringe dispenser in the room
NOW
optimise size of syringes
sterilise waste for recycling
machine filled
make it square for easy stacking
repurpose overdue syringes for
WOW!
collect syringes for remanufacture
easy to implement
original

refill empty syringes

sterilisable shape

sercice system apotheek AIS

change shape of plunger

redesign shape plunger

recycle plunger

reuse plungers

make packaging easy to clean

decrease stock in the rooms

adapt infection prevention protocol

change behaviour of staff

modular syringe

separate ~~materials~~ components for recycling

cartridge system

Appendix I demonstrator

Demonstrator: Repurpose packaging boxes as needle containers

Intervention 7 is elaborated on further in this section. This is done to show the stakeholders how an intervention could be developed into a practical solution.

Steps of how to design the box as a sharps container

The goal is to design the packaging box into a sharps container that can be used in the hospital. The following steps are executed to do this:

1. Determine the use of the product (how is it used, what are the user's needs?)
2. Determine requirements for the product in terms of feasibility, viability, desirability
3. Ideate
4. Conceptualise + embodiment design (size, material, dimensions, human factors)
5. Prototype and test
6. Iterate on the design
7. Final design

Use

The box is used to dispose of sharp waste in the hospital by the staff in the ICU. Needles of syringes, scalpels, insulin pen needles etc. are disposed of in this box. The staff must be able to use the box safely, to prevent them to touch the sharp and possible contaminated waste. The lid of the box cannot come off once assembled, and the opening of the lid also has a final closure mode. This is to ensure that the box does not open when handling it at the disposal phase, to ensure the safety of people working with the boxes.

Figure I1: Packaging and needle container

Use scenario:

1. A needle is used on a syringe and needs to be disposed of.
2. The nurse opens the opening of the sharps container, which is located in the room of the patient.
3. The needle is placed in the designated opening to disconnect the needle from the syringe.
4. The needle falls in the box and the nurse can dispose of the syringe without a needle in the other waste bin in the room.
5. The lid of the box is half-closed since the container is not full yet.
6. Once the container is filled upon the line indicating the maximum filling height, the lid can be fully closed by the user, and it cannot be opened anymore.
7. The closed box is collected in a cardboard box with the other full sharps containers from the ICU.
8. The cleaning department collects the boxes and disposes of them as specific hospital waste.
9. The closed box is incinerated.

Requirements for the box

From the use analysis, requirements are derived. Other requirements come from rules and regulations from the hospital and medical norms (Medbis, n.d.).

Desirability

- Various "disconnect" options
    - Scalpel blades disconnection system
    - Unscrewing system for insulin pen needles
    - Disconnection system for Luer-slip needles (conical coupling)
    - Unscrewing system for Luer-lock needles (screwed needles)
    - Big hole for larger objects
    - Hole: 55 x 50 mm
- Two modes for the lid opening: temporary and final closure
- Anti-backlash safety valve.
- Sticker indicating icons of sharp contaminated waste
- Minimal space between opening and maximum filling height = 30 mm
- Leak-free in vertical condition
- Stable on a flat surface
- Handle to provide safe transport

Feasibility

- Dimensions of the lid should fit the packaging box (260 x 228 mm)
- Puncture resistant and shockproof: so a wall thickness of at least 2 mm
- Containers must comply with the common UN3291 quality mark, 2010-32 and European Standard 23907 and additional standard NFX 30 511.
- Containers must have a UN quality mark

Viability

- The lid of the sharps container must be able to be mass-produced.

Ideate

The bottom part of the sharps container is already there, namely the packaging box of the empty syringes. To turn this into a sharps container, a lid needs to be designed.

Prototype and test

A prototype can be made using a 3D printer. Then a test can be performed to analyse:

- Does it fit the box?
- Do the different holes work for different needles/sharps?
- Is the box leakproof?
- Does the lid stay on the box during use (transport, collection, falling over)?

Iterate

Iterations can be made after testing to make it better.

Final design

After a few iterations, a final design can be made to be mass-produced. For this, external companies, that do production processes such as injection moulding, should be contacted.

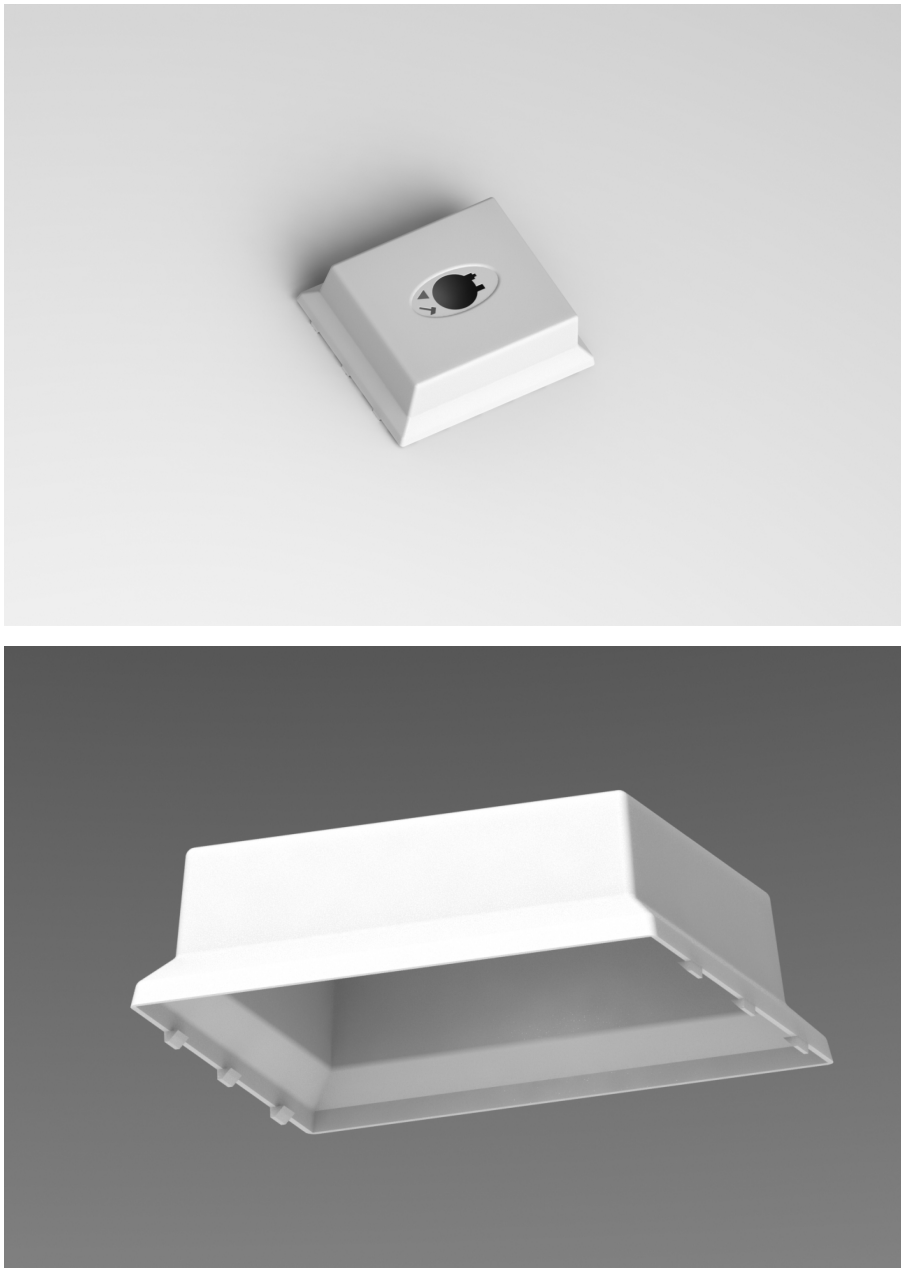


Figure I2: Design of the lid

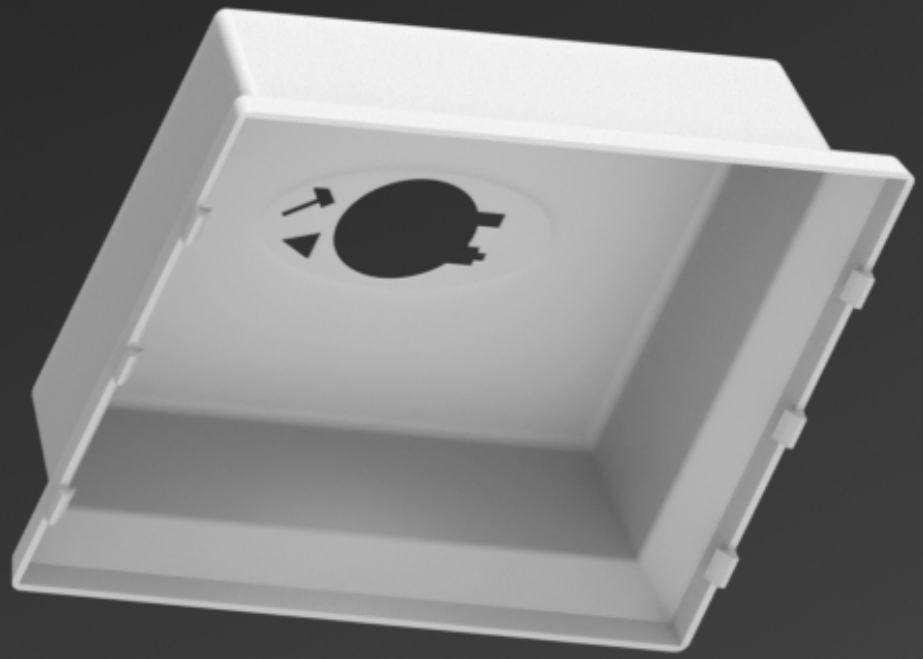


Figure 13: Design of the lid