De Zeepkist

Design of a funeral enclosure for resomation

Master thesis

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Abstract

This thesis explores the design of a funeral enclosure for resomation, utilizing PISOX – a biobased and biodegradable polymer – and soap. The research follows a three-phase framework of analysis, design and evaluation. In the analysis phase, the resomation process and its context are examined, followed by analysis of the suitability of soap and PISOX for the application of resomation and their manufacturing possibilities. Laboratory testing reveals that soap and PISOX dissolve in a KOH solution at comparable or faster rates than wool, the current market standard. The analysis concludes with a list of requirements and wishes for the design.

In the subsequent design phase, various design activities are conducted to define the design of a funeral enclosure of PISOX and soap. Various ideas are explored and a natural and calm direction is selected based on conversations with potential users. A cocoon-shaped design is created that is designed to fit within the Resomator S750. The PISOX offers the strength needed for a coffin, while the soap adds a decorative aspect. Thermoforming is selected to produce the PISOX parts, and soap is moulded directly into these parts. A stainless steel non-resomatable frame is added to enable carrying of the coffin, and rivets are used to secure the coffin. The design is created to accommodate the dimensions of a P95 human body.

The design's strength is evaluated through a combination of tensile testing and Finite Element Analysis to determine the thickness needed for the PISOX parts. This showed that a small thickness of >5 mm PISOX can realistically bear the expected loads. A 1:4 prototype was created to assess the manufacturability and to gather insight into users' opinions of the design through interviews. The interviews revealed that users have a positive attitude towards the new design, though they need time to get used to this innovative approach.

Finally, a sustainability evaluation demonstrates the environmental advantages of introducing De Zeepkist. The thesis concludes with a proof of concept for the design of De Zeepkist and ends with recommendations for future development.

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01

PROJECT INTRODUCTION

In this chapter the project will be introduced.

1.1

The need for a funeral enclosure for resomation

In past centuries, only two body disposal methods were practised in The Netherlands, which are burial and cremation. These body disposal methods have a burden on the environment, mostly considering land use, land transformation and depletion of water and minerals (Keijzer et al., 2014). As sustainability is becoming more and more important, the funeral industry is trying to innovate. In a call for a more sustainable body disposal method, the option of resomation as a new funeral technique is being considered. In a study by TNO (Keijzer et al., 2014), it has been estimated that the environmental effects in shadow prices of resomation are about 8 times lower than those of burial and cremation. Additionally, resomation saves a lot of space compared to burial.

Resomation is a body disposal method that involves the chemical process of alkaline hydrolysis, which decomposes a body in approximately 3 hours (V. Van Leest, personal communication, March 15, 2024). A limitation of this process is that only a few types of materials can be decomposed through the process, limiting the possibilities of coffin materials and clothing of the deceased. As of 2024, only wool, silk and leather are assumed to be suitable for resomation (Arnold et al., 2023), and materials such as wood cannot be decomposed through the process. This implies that resomation exempts the use of conventional funeral enclosures as most commonly practised in the Netherlands, leaving only the option of using a shroud. However, as many people feel uncomfortable saying goodbye to their loved ones in a shroud (Bokdam et al., 2021a), a new type of funeral enclosure needs to be introduced to enable the bereaved to say goodbye to their loved ones comfortably and respectfully.

1.2

Elaboration of a design concept

This thesis elaborates on research done in 2021-2022 where a design concept called ‘De Zeepkist’ is introduced (Van Andel, 2022). During this previous research, an answer was sought on how a resomation-suitable funeral enclosure could be designed. This resulted in a design concept including two resomatable materials, namely soap and PISOX as in figure 1.1. Soap is an interesting material due to its natural dissolving characteristic and its pleasant smell and decorative possibilities. PISOX is a biobased and biodegradable polymer which has similar mechanical properties to ABS (G. J. Gruter & R. J. van Putten, personal communication, Nov. 23 2021) and is also very well hydrolysable, which makes it suitable for resomation. This material lends itself well to offer the strength a coffin needs. This concept for a funeral enclosure made of soap and PISOX is the starting point of this research.

Figure 1.1: Design concept De Zeepkist 2022.

1.3

Project partners and context

De Zeepkist is developed for Eer & Volharding, a funeral service company in South-Holland in the Netherlands (Eer & Volharding, n.d.). Eer & Volharding is specialised in funeral services and assists the bereaved in everything from the moment someone passes away. This starts with picking up the deceased just after passing away until disposal of the body remains after the funeral service. Eer & Volharding aspires to offer the possibility of resomation to its clients in the near future.

The project is done in collaboration with Avantium, a research company that develops biobased polymers and has developed PISOX (Avantium, 2023).

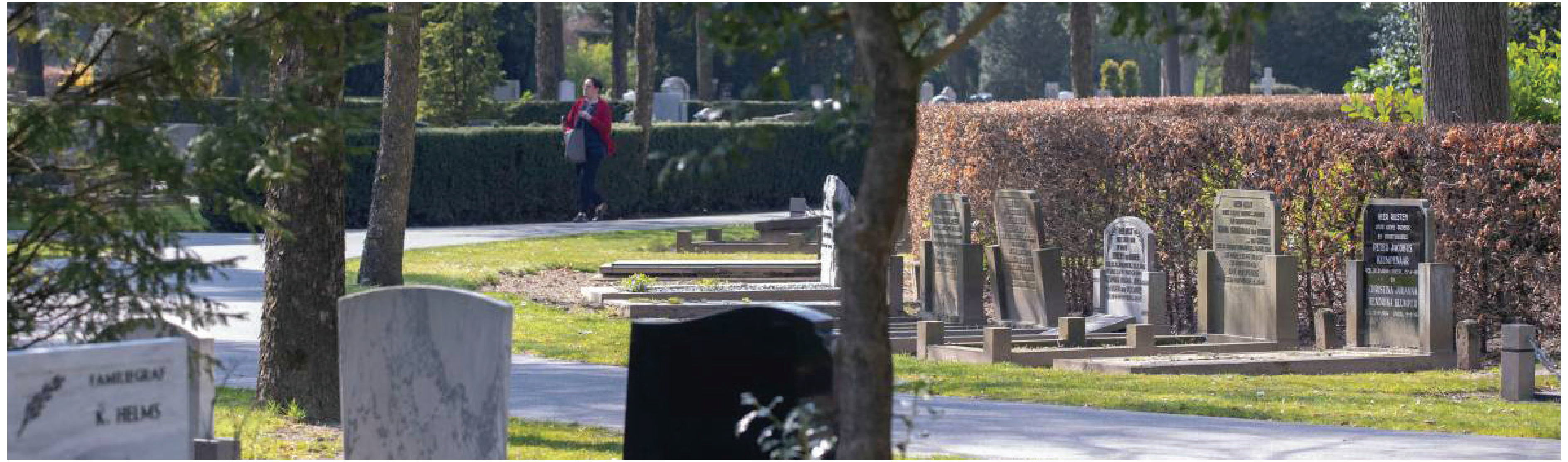
Context

De Zeepkist is designed for the Dutch funeral service practice, especially those in the area of South-Holland where Eer & Volharding is located. The design of De Zeepkist is adjusted to suit the resomator S750 as produced by Resomation ltd.. This is anno 2024 the only type of operational resomator in The Netherlands and Resomation ltd. is the main producer of alkaline hydrolysis machines on the Dutch funeral market.

At the start of this research, PISOX is not yet commercially available. Avantium is solely a research company and does not produce the plastics they have developed themselves. PISOX is fully developed and ready to be produced on an industrial scale and Avantium is currently looking for investors who want to take this next step.

Anno 2024, resomation is slowly gaining ground within the Netherlands. Researches have been done to investigate resomation's safety, sustainability, support base and operational procedures. More and more people have heard of resomation and the process of resomation is on the agenda of being adopted in the Dutch funeral law (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2020). As of March 2024, resomation is currently not yet legalised in the Netherlands, but it is expected to be so in 2024 or in a few years. Currently, there are already a few operational resomators located in the Netherlands, ready to be put into use once the law is accepted.

Figure 1.2: A cemetery in The Netherlands (Stöver, 2019).



1.4

Project scope and method

The goal of this research is to explore the possibilities of a funeral enclosure made of soap and PISOX for resomation and to prove its feasibility, desirability and viability. The concept developed in 2022 needs to be elaborated into a more tangible design. This involves aspects of technology, product experience, ergonomics, economics and implementation strategy that all need to come together. This all comes together in the following research question that is central in this report:

How can a funeral enclosure be designed to be suitable for resomation in the Netherlands in 2030, using PISOX and soap as materials?

The project is divided in three phases: analysis, design and evaluation. The analysis phase starts with collecting information about resomation, the funeral process and its context. This is followed by an analysis of PISOX and soap and include aspects such as their characteristics, their suitability for resomation and an exploration of their technical possibilities regarding production. The analysis phase is finished with a list of requirements and wishes for the design. In the design phase, a design exploration and ideation is executed to define the design of De Zeepkist. Here, aspects explored are possibilities regarding the Zeepkist's morphology, texture and colour both considering spatial or technical constraints and user's experience. This phase ends with introducing a final design. In the last phase, the design is evaluated on its experience for users and its sustainability. This is followed by conclusions and recommendations to take De Zeepkist further.

Research and design activies

The process follows an iterative approach to explore the different aspects related to the design and to find and integrate solutions. During the development of De Zeepkist, the IDEO's DVF framework (Cristache, 2021) is considered to ensure that the design meets feasibility, desirability and viability demands.

A combination of research and design activities is used to elaborate De Zeepkist. Research activities include literature research, interviews with experts and company representatives, company visits, conducting surveys and lastly lab tests to evaluate the resomatability of materials and their strength. Design activities include brainstorming, moodboard exploration, sketching, lo-fi prototyping, advanced prototyping and generating a 3D CAD model. Several evaluation techniques are used to evaluate the design or ideas, such as a Harris profile; interviews with prospective users to assess the user experience; calculations to assess its sustainability and finally a cost price calculation to estimate its production costs.

Part 1: Analysis

In the next chapters, the context of resomation and the materials and their properties and manufacturing possibilities will be analysed. Finally, a list of requirements and wishes for the design is discussed.

Part 1 Analysis

02

AN OVERVIEW OF RESOMATION PRACTICE

In this chapter, background information will be provided on which the design will be based. First, the resomation process is described, followed by an introduction of the resomator S750. Then, the funeral process is explained, followed by the stakeholders involved in the process. Subsequently, the target group is defined and lastly an explanation is given on what is already on the market considering resomation-products.

2.1

The resomation process

2.1.1 The process of resomation

Resomation is a body disposal method that involves the chemical process of alkaline hydrolysis. Though this may seem rather artificial, the process is originally derived from nature (Arnold et al., 2023). During alkaline hydrolysis, a body is being decomposed acceleratedly (Robinson, 2021). The practical process of resomation can be seen in figure 2.1. Other names for resomation are aquamation or water cremation.

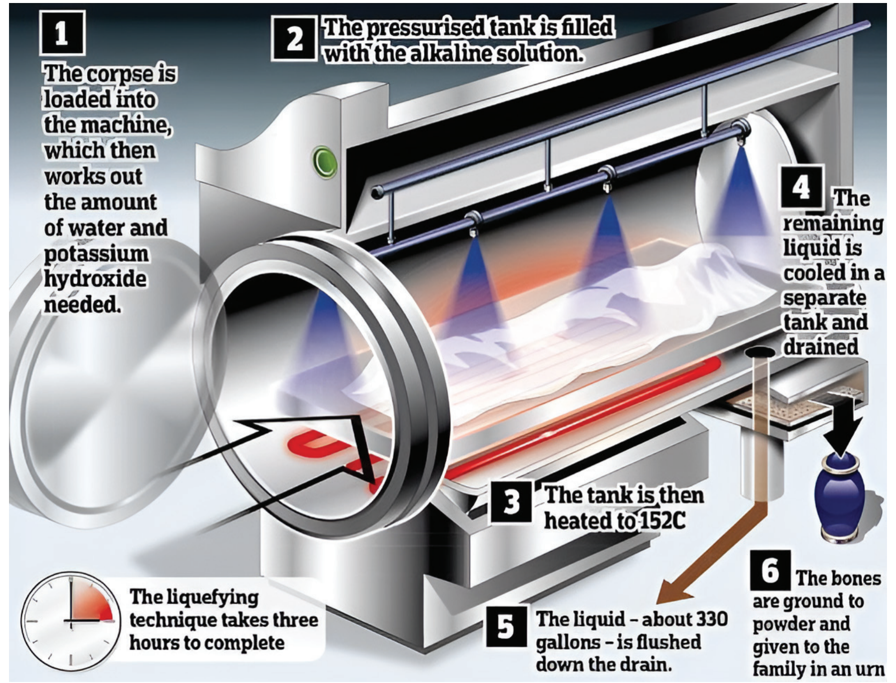


Figure 2.1: The resomation process in practice (Funeral Celebrant | Resomation | an Overview, 2019).

2.1.1.1 Design considerations

An important aspect of the resomation process is the time it takes to decompose a body. A big amount of materials can be decomposed if given enough time, water and alkali, yet increasing the time and/or water and alkali used means increasing the energy needed and increasing the environmental impact of the process. It is therefore important that a funeral enclosure for resomation dissolves in a matter of a few minutes or allow for the alkaline liquid to seep into the enclosure and reach the body quickly, so that the body starts decomposing right after starting the process. Ideally, the enclosure would already break down while the filling process of the resomator is still taking place (V. Van Leest, personal communication, March 15, 2024). This would also help avoiding the side effect that when the funeral enclosure is watertight and it is not yet dissolved, there will be an air bubble within the enclosure, which can 'implode' once the enclosure wall is broken through (V. Van Leest, personal communication, March 15, 2024).

2.1.2 Decomposing matter with resomation

In resomation, matter is decomposed by means of alkaline hydrolysis. Hydrolysis is a chemical reaction in which a chemical bond is broken down by a reaction with water (The Editors of Encyclopaedia Britannica, 1998). To speed up this process, potassium hydroxide (KOH) is added as a catalysator. KOH is an inorganic compound and a strong base, derived by electrolysis of potassium chloride (PubChem, n.d.). Due to the placing of the body in a resomator and the remainders of the bones, resomation seems process-wise most similar to cremation for bereaved. Technically speaking, the process is more similar to burial, as the way in which the body is decomposed in burial and resomation is similar, only it happens much faster in resomation due to the presence of KOH and the elevated temperature and pressure (Robinson, 2021).

Materials that can be decomposed using alkaline hydrolysis are limited. Generally speaking, it is assumed that only protein-based materials can be decomposed through the process, leaving only materials such as wool, silk and leather (Arnold et al., 2023). Obviously, a human body as well as animal corpses can be decomposed using the process. This implies that all material components that exist within your body (except for bones) can be decomposed. This includes proteins, fats, carbohydrates, minerals and DNA (Helmenstine, 2019). Therefore, materials that are made from these chemical building blocks should be decomposable using alkaline hydrolysis. During the resomation process, DNA is destroyed and cannot be identified in the effluent (Pickard, 2020).

As mentioned before, bones cannot be decomposed by alkaline hydrolysis and will remain at the end of the process, though they have become brittle (Van Leest, 2021). Additionally, the 1500L effluent remains, which is a brown-tinted liquid (Van Leest, 2021).

2.1.2.1 Foaming

When a body is being decomposed, fatty acids and glycerine are released from the body (Tsokos, 2005). These materials together with the present KOH and water are the main ingredients of the saponification process as explained in more detail in chapter 4. This means that while the body is being decomposed, a soapy substance is being made. It is important that this soapy material is not triggered to start foaming, because when high foaming levels occur, the volume of the liquid increases drastically. This might cause issues due to limited space and difficulty eliminating foam through the drainage system (V. Van Leest, personal communication, March 15, 2024). A solution could be to add a defoamer to the process to counter the forming of foam (Crucible Chemical, 2021).

2.1.3 Sustainability of resomation

The main driver of resomation and probably one of the first things you'll read about when you google resomation is its sustainability. TNO concluded that resomation's environmental effects calculated in shadow prices are about 8 times lower than those of burial and cremation, as can be seen in figure 2.2 (Keijzer et al., 2014). An additional benefit to burial is that resomation saves a lot of space. Though many people assume that a resomation process will probably cost a lot of energy and cannot be more sustainable, the TNO report proves this assumption is incorrect.

Additionally, studies on the effluent of resomation have shown that the effluent does not pose any threats to sewer systems and wastewater treatment plants and could potentially even be used to recover energy (Pikard, 2020) & (De Vries & Opdam, 2023).

Furthermore, resomation can comply with the regulations in The Netherlands with regard to occupational and environmental safety (Reinders & Spruijt, 2018). The process does therefore not pose any safety threats for the people working with resomation or the environment.

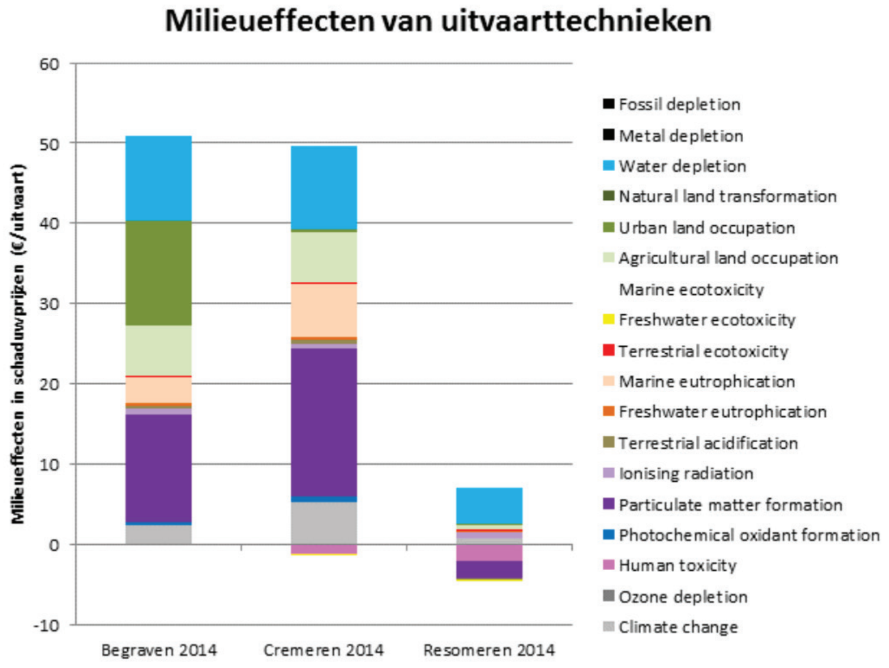


Figure 2.2: Shadow prices of environmental effects of different funeral types.

2.1.4 Resomation gaining ground

Historically speaking, alkaline hydrolysis is a long-established chemical process, yet for the application of funeral services it is relatively new (Milne, 2023). The main reason resomation is gaining popularity is because it offers a more sustainable body disposal alternative compared to burial and cremation.

Resomation is already permitted in (parts of) some countries, such as the USA, Canada, Ireland, the UK and Australia (Smith, 2024) & (Walsh, 2023). In some states of the United States of America, aquamation has already been legalised for over twenty years ("Where in the United States Is Aquamation Legal or Allowed?," 2022). Multiple other countries are interested in adopting resomation and are taking steps to legalise the process (Smith, 2024) & (Wikkelgoed, 2023).

Resomation as a funeral technique has gained some attention in the media when the public figure Desmond Tutu passed away. Tutu chose to be resomated at the end of his life, drawing attention to resomation for many (Vanhelden, 2022).

Something that contributes to the positive image of resomation, is because of the use of water instead of fire. A funeral using water is by some people perceived to be more peaceful and natural, which is one of the reasons terminal people mention to prefer resomation (E. van Zoest, personal communication, March 15, 2024). Additionally, Van Leest (personal communication, March 15, 2024) mentions that when people are asked whether they prefer to be cremated with water rather than fire, most people choose water. On the other hand, some people have associations with dissolving a body with acid as it is sometimes displayed in horror movies (Bokdam et al., 2021b). A persistent image of this is the scene in Breaking Bad (figure 2.3), a popular series in the Netherlands.

Finally, another positive aspect of resomation is its cost. The costs of resomation will likely be similar or slightly lower to those of cremation, which implies that it would be a rather affordable or even the cheapest funeral option (Robinson, 2021).

Figure 2.3: Scene in Breaking Bad where a body is dissolved in acid.

2.2

The resomator S750

De Zeepkist is designed to suit the Resomator S750 as explained in chapter 1.3. The Resomator S750 can be seen in figure 2.4 - 2.6. After loading the machine with a corpse, the resomator is filled with a concentration of water and alkali and heated up to 150 °C under 4.5 bar pressure (Van Leest, personal communication, March 15, 2024). Completing a resomation takes about 2.5 to 3 hours, after which the effluent is cooled to room temperature (V. Van Leest, personal communication, March 15, 2024). This implies that materials that are dissolved during the resomation process should not solidify once it is being cooled down again. The effluent is then neutralised using an acid so that the water can be discharged into the sewer. The dimensions of the Resomator S750 are analysed and reported in confidential appendix A.

Figure 2.4: Resomator S750 located at 't Vijfde Seizoen.

Figure 2.5: Resomator S750 located at 't Vijfde Seizoen.

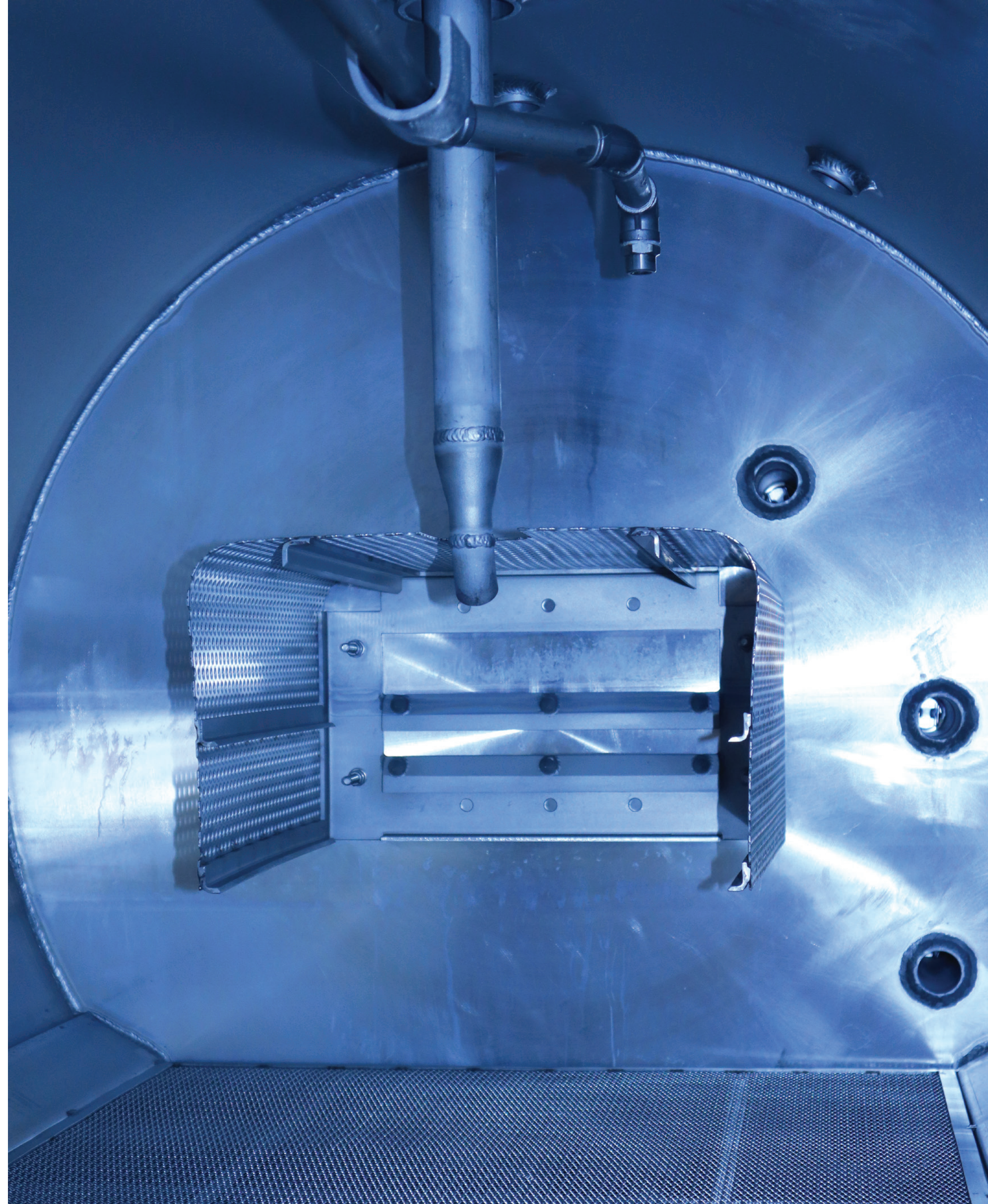


Figure 2.6: Head fixture within the resomator.

2.3

The funeral process

The funeral process involves a less or more fixed set of steps from the moment when the deceased passes away until the end of the funeral process (T. Tubée, personal communication, February 12, 2024). Small changes in the funeral process are needed when choosing for resomation. The most likely funeral process for a resomation is visualised in figure 2.7. During the funeral process, the body is always cooled using a cooling plate at -25 °C. Before the start of the funeral process, the funeral enclosure is manufactured and stored.

2.3.1 Desired funeral enclosure experience

The desired experience of the funeral enclosure was explored by Bokdam et. al. (2021a) to gain insight into how people prefer a funeral enclosure to be. Here it was found that people mostly want a funeral enclosure to be personal and honorable. Something that also showed to be of importance by the same research, is that a funeral enclosure is often preferred to already create a bit of distance to the deceased, and the enclosure is seen as a means to say goodbye. Lastly, this research showed that not only the appearance of the enclosure matters to the bereaved, also its functionality is of importance and influences the choice for a funeral enclosure.

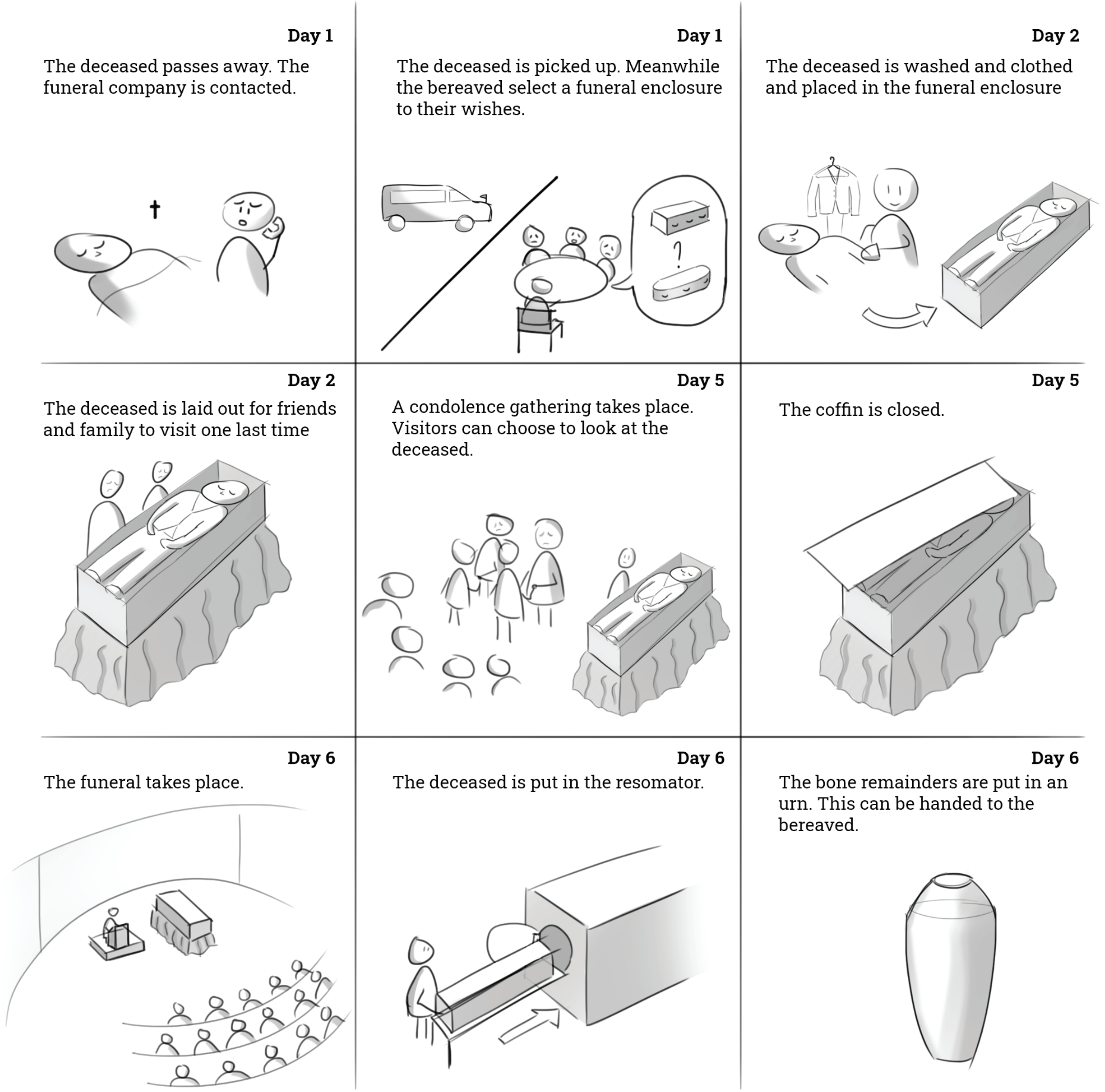


Figure 2.7: The funeral process of resomation.

2.4

Interested groups

As resomation is a new process and not yet legalised in the Netherlands, it is difficult to define the target group of De Zeepkist and their characteristics. Also, the use of the word 'target group' sounds rather unethical so the word 'interested group' will be used instead. Some conclusions on the interested group can be drawn though from participant surveys and observations of professionals in the field. However, these researches and the observations are all speculatory as they discuss hypothetical situations, so the future should prove the reality.

A survey was done to investigate people's familiarity with resomation, their image of resomation and whether they would consider resomation for their own funeral and why. The questions can be found in Appendix 1. The survey was filled in by 36 participants. From the survey, it can be concluded that the group of people that would consider resomation for their own funeral is diverse, covering different age groups and including both men and women. People that indicate that they would consider resomation for their own funeral mostly mention resomation's sustainability as the reason to choose it. A smaller group mentions that they perceive it to be more peaceful compared to cremation and find it a good alternative for cremation. People that would not consider resomation mention arguments such as a personal preference for another funeral technique, they need more time to get used to it, they need more information about the process, religious reasons or because they miss a ritual with this process. The research also confirms the assumption that people would be hesitant to choose for something they are not very familiar with, indicating that resomation first needs to gain more attention.

The results of the survey align with a support base research by I&O Research (Andringa et al., 2017), which shows that if people would consider resomation for their own funeral, one of their main considerations would be resomation's sustainability. In addition, the results also align with the image E. van Zoest shapes in a conversation about his work (E. van Zoest, personal communication, March 15, 2024). At the funeral home where van Zoest works, a resomator has been installed already and they are being contacted by people that want to be resomated. From their observations they concluded that the group of people that is interested in resomation is diverse. It was observed that regardless of people's background, educational levels or age, people are all interested in resomation. Another interesting observation is that they noticed that most people that would choose for cremation would choose for resomation instead if it were possible.

Furthermore, if resomation would be offered today, the only possibility would be to use a shroud. Many people however indicate that they feel uncomfortable saying goodbye to their loved ones in a shroud as you can see the human contours (Bokdam et al., 2021a). De Zeepkist could make it more comfortable for people to choose for resomation, and De Zeepkist could be an in-between step for people to embrace resomation.

From all of the above it can be assumed that De Zeepkist will be designed for environmentally conscious and progressive people, early adopters who have given some thought to their own funeral, yet feel too uncomfortable to choose for a shroud. Later, when more people have become familiar with resomation and De Zeepkist, De Zeepkist might appeal to a larger group of people.

Lastly, if resomation happens to become the cheapest funeral option, bereaved might start to choose for resomation because of this, but this is not assumed to be a driver during this research as most funeral companies indicate that resomation will likely have a similar price to cremation at the start.

2.4.1 Groups that are unlikely to choose resomation

Contrarily, there are groups of people for whom it would be unlikely to choose for resomation. This includes mostly religious groups such as Muslims, Jews and reformed Christians who believe they will physically resurrect from the dead one day (Bokdam et al., 2021b). Because of this, those groups have to be buried.

2.4.2 Human dimensions

The dimensions of the human body which ideally would fit in De Zeepkist have been investigated. Data on the dimensions of a human body are collected from Dined, using a data set of Dutch adults from 2004 with ages from 60+ years old and both men and women (DINED, 2020). To be able to define the coffin's length, width and height, data on stature, shoulder breadth, breadth over the elbows and chest depth is gathered. Also the head depth is collected to ensure that the head fits under the narrow structure. In addition, the weight is researched to ensure that De Zeepkist is strong enough to bear this load. The human dimensions of P95 are used for De Zeepkist, so that most people can make use of De Zeepkist, yet the design is not adapted to extreme sizes. When defining the width of the coffin, it is assumed that the breadth over the elbows can be slightly reduced by placing the arms of the deceased on top of the stomach, but dimension is included to give a general insight into the widest dimension of the human body. In table 2.1, an overview of these dimensions is shown.

The found values of the human body form a guideline for the design of De Zeepkist. When designing De Zeepkist, the maximum dimensions that can fit within the resomator should also be considered. In case of a more organic design, the shape of a human body should be considered as well.

	Stature [mm]	Shoulder breadth [mm]	Breadth over the elbows [mm]	Chest depth [mm]	Head depth [mm]	Weight [kg]
P95	1813	476	552	362	199	91

Table 2.1: Human dimensions of P95 according to (DINED, 2020).

2.5

The market offer for resomation

Resomation is rather new and only legalised in a handful of countries. For this reason, the amount of related products that are on the market is limited. Especially when considering funeral enclosures, the market offer is very limited. Since resomation is already allowed and practiced in a few countries, innovations would be expected from those countries considering coffin and clothing use. This is however not the case, which can be explained by the way funeral processes are shaped within those countries. In many other countries, including for example in America, it is not uncommon to dispose of the body before a memorial service is being held, and have only the ashes during the service (Honan Funeral Home, n.d.). Because of this, there is less need to have a coffin and usually the body is resomated without any clothing or funeral enclosure or only a wool, silk or leather shroud (Dolan, 2019).

Hence, for innovations in the field of funeral enclosures and undergarments, we are currently depending on Dutch innovations. One company that works in this field is Wikkelgoed. Wikkelgoed is a company mostly specialised in funeral shrouds and they are anticipating resomation in the products they offer. Wikkelgoed has developed and approved a fully resomatable wool shroud (figure 2.8) as well as some additional products such as body bags, undergarments and incontinence material

(R. Wijnands, personal communication, March 13, 2024). These products are made of wool or silk.

An additional product that is developed is a coffin by FAIR coffins, see figure 2.9 (Alka Eco Systems, 2024). This coffin is made of mostly cardboard and is tested to become suitable for the Alka Eco Human (Oerlemans, 2023). The Alka Eco Human is an alternative alkaline hydrolysis machine, developed by Alka Eco (Alka Eco Systems, 2024).

Figure 2.8: Shroud by Wikkelgoed (Wikkelgoed, 2024).

Figure 2.9: Coffin by FAIR coffins (Alka Eco Systems, 2024b).

03

PISOX

In this chapter, the material PISOX, its properties and its possibilities regarding manufacturing are explored.

3.1

PISOX introduction

PISOX is a biobased and biodegradable polymer developed by Avantium (Van Der Maas et al., 2024). It is a novel material that offers benefits that cannot be found in other materials, such as good mechanical properties in combination with high biodegradability (Van Den Beukel, 2024). Because of the combination of those two properties, PISOX lends itself well to be used in a funeral enclosure for resomation.

3.1.1 Synthesis

PISOX is synthesised using at least two components: isosorbide and oxalic acid (Wang et al., 2024). A third monomer could be added in the synthesis to alter the material's characteristics (Van Der Maas et al., 2024). In figure 3.1, a reaction scheme of the general polymerization is shown. Also, the properties of PISOX can be altered by changing the ratio between isosorbide content relative to the total dial used in the PISOX (Wang et al., 2024). Generally speaking, the higher the isosorbide content in the PISOX, the higher the glass transition temperature and thus strength (Wang et al., 2024). The main components used to synthesise PISOX can be derived from renewable resources: oxalic acid can be derived from CO2 (Van Den Beukel, 2024) and isosorbide can be derived from glucose (Van Der Maas et al., 2024). Depending on the co-monomer added, PISOX can be made fully from renewable resources (Van Der Maas et al., 2024).

As explained by Kevin van der Maas (personal communication, February 21, 2024) PISOX is synthesised by mixing the different ingredients together at an elevated temperature. Long strings of PISOX exit the vessel which are then cooled and chipped into small parts. This PISOX granulate can then be used for different kinds of manufacturing techniques to produce parts. The result of the synthesis is an amorphous polymer (Van Der Maas et al., 2024).

3.1.2 Material properties

PISOX' mechanical, physical and thermal properties can be seen in table 3.1 as well as those of PLA, PETG and ABS for comparison. It can be noticed that PISOX' mechanical properties are similar to PLA and PETG and its Tg is relatively high, which are favorable conditions to generate strength in a design.

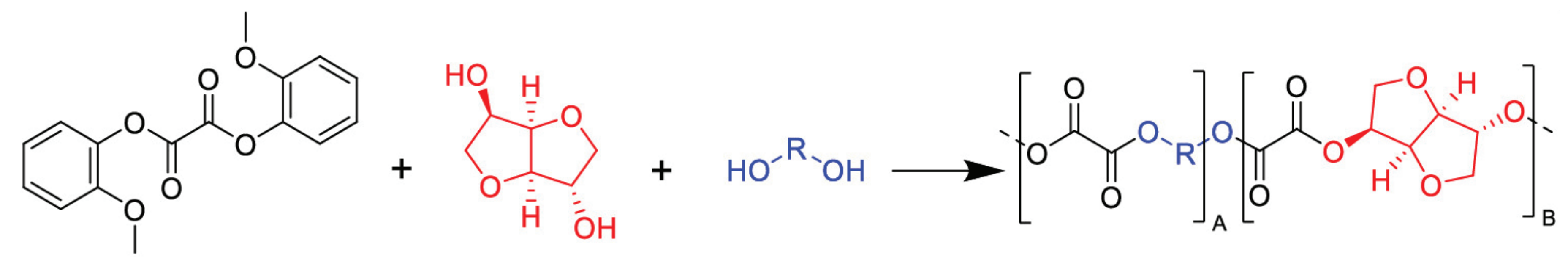


Figure 3.1: Reaction scheme of the polymerization of PISOX (Van Der Maas et al., 2024).

	Mechanical properties				Physical properties	Thermal properties
	Yield strength [MPa]	Ultimate tensile modulus [MPa]	Young's Modulus [GPa]	Elongation at break [%]	Density [g/mL]	Tg [° C]
PISOX	44.0 - 62.1	62.2 - 86.7	2.56 - 3.92	175 - 219	1.38 - 1.44	around 100
PLA	50 - 55	55 - 72	3.3 - 3.6	2.5 - 6	1.24 - 1.27	52 - 60
PETG	47.9 - 52.9	60 - 66	2.01 - 2.11	102 - 118	1.26 - 1.28	81 - 91
ABS	34.5 - 49.6	37.9 - 51.7	2.07-2.76	5 - 60	1.03 - 1.06	102 - 115

Table 3.1: Mechanical, physical and thermal properties of PISOX (K. van der Maas, personal communication, April 2, 2024) compared to those of PLA, PETG and ABS (Granta EduPack 2022 R1, 2022a), (Granta EduPack 2022 R1, 2022b), (Granta EduPack 2022 R1, 2022c).

3.1.3 Depolymerization of PISOX

In addition to PISOX's good mechanical properties, its suitability for resomation and the speed at which it can be depolymerised is the most important characteristic. An important feature of PISOX is its fast biodegradability and its sensitivity to water. PISOX' biodegradability in natural environments is remarkably good compared to other biodegradable plastics. When PISOX is in contact with water, the material quickly loses its strength and falls apart (Wang et al., 2024). Research has shown that PISOX degrades in soil within a few months under home composting conditions (Van Der Maas et al., 2024). As the oxalic acid reacts quite easily with water, the higher the oxalic acid used in the PISOX, the faster the PISOX degrades (Van Den Beukel, 2024).

During a resomation, PISOX does not experience a natural environment, but instead it undergoes the process of alkaline hydrolysis. This is a process that is also used for chemical recycling of polyesters such as PET (Gr3n Recycling, 2021). Due to their chemical structure, polyesters can be recycled chemically by means of hydrolysis (Wang, 2022). This means that during a resomation, the depolymerization of PISOX is highly sped up, making this material especially suitable for this application.

3.1.4 Availability

PISOX is a developed material, yet it is not yet commercially available. It is expected however that PISOX can be brought to the market quickly as it can be synthesised in existing production facilities used for PET production (Van Den Beukel, 2024). Due to the unavailability of PISOX commercially, during this project PISOX was not available as a material to be used for experimenting without the agreement of an Non-Disclosure Material Transfer Agreement (NDMTA). An NDMTA was not signed, hence PETG was used for experiments to resemble PISOX, since this has the most similar mechanical properties.

3.1.5 Material requirements

With good mechanical properties combined with a high sensitivity to water and good biodegradability, PISOX lends itself well to be used as a structural component in De Zeepkist. However, for PISOX to be suitable to be used in a funeral enclosure, it needs to meet a few more requirements. In addition to good mechanical properties and a fast resomatability, durability is also important. Also, the ability to function at low temperatures is relevant as the material will be placed directly on a cooling plate of -25 °C to preserve the body. The funeral enclosure should therefore function properly at temperatures in between -25 and +45 °C Celsius, which is a rather large range for plastics. Furthermore, a low density is preferred so that it is easier to carry the enclosure, as well as a low price to make sure it is affordable. A list of requirements and wishes has been drafted below.

PISOX's requirements and *wishes*:

1. The PISOX can be decomposed in max. 198 minutes.
2. The PISOX can function within a temperature range of -25 to +45 °C.
3. The PISOX has a shelf life of at least 30 days.
4. *The PISOX is as strong as possible.*
5. *The PISOX costs less than €10 per kg.*
6. *The PISOX has a low density.*

It appeared to be difficult to define the material's requirements strictly, since for many favorable properties of PISOX a trade-off applies. Important mechanical properties of PISOX for an application in a funeral enclosure are its yield strength, stiffness and Tg. For the Tg, a higher Tg is preferred as this is related to the stiffness of the material, yet a lower Tg would be preferred for faster resomation and lower energy use in production of parts. Also, a higher sensitivity to water is preferred to increase the resomation speed, yet this will lead to a shorter shelf life of the product as humidity in the air will affect the coffin's strength. Therefore, some properties are captured as wishes and it has to be researched whether a suitable funeral can be designed from the given properties. Due to the lack of PISOX available for this project, requirement 2 and 3 could not be tested during this project.

3.2

Suitability for resomation

To evaluate the resomatability of PISOX, two tests have been done. First, a dissolvement test with five variants of PISOX and wool for comparison has been done by Avantium. Secondly, a test has been done with PETG to gain insight in the degradation process.

3.2.1 Dissolvement test Avantium

A dissolvement test was done by Kevin van der Maas with different variants of PISOX and compared to wool. The full research report by Kevin including procedure, results, conclusions and discussion can be read in appendix 2. In this test, different types of PISOX have been dissolved in a 5 wt% sodium hydroxide solution using the setup as shown in figure 3.2. Wool was used as a reference material for comparison. In a solution of 8 ml, 0.5 gram wool or PISOX was added. The glass vials were heated to around 85 - 100 °C and stirred to simulate the conditions in resomation. After a while, when two types of PISOX had been fully dissolved the glass vials were switched for other types of PISOX. After this first test, another dissolvement test was done with PET, PLA, ABS and PETG for comparison, the results of all of the tests can be seen in table 3.2.

Figure 3.2: The test setup used by Kevin van der Maas for the comparative dissolvement test of wool, different variants of PISOX and PET, PLA, ABS and PETG.

Type	Time to dissolve	Weight left (g)
Wool	13 minutes	dissolved
PISOX 1	24 minutes	dissolved
PISOX 2	16 minutes	dissolved
PISOX 3	>300 minutes	Not dissolved
PISOX 4	10 minutes disintegration - Not dissolved until more water added	
PISOX 5	10 minutes disintegration - Not dissolved until more water added	
PET	>300 minutes	0.5
PLA	>300 minutes	0.15
ABS	>300 minutes	0.5
PETG	>300 minutes	0.5

Table 3.2: Results of the dissolvement study done by Kevin van der Maas.

3.2.1.1 Discussion

In table 3.2 it can be seen that the wool sample is dissolved in 13 minutes. For the PISOX samples, the dissolvement time varies significantly. For PISOX 4 and 5 five it seems that the PISOX is depolymerised after 10 minutes, but because more water needed to be added before it appeared dissolved it is difficult to say this with certainty. The conventional plastics PET, ABS and PETG do not seem to degrade within the KOH solution, while PLA does degrade in the KOH solution but at a speed that is much slower than wool and hence not a realistic alternative.

It should be noted that for this test a NaOH solution was used instead of a KOH solution which is used for resomation. Also, the test has been done at a lower temperature as is used in resomation. Nevertheless, the test lends itself well for comparison between the different materials as the conditions are the same for all material samples.

Another aspect that should be considered is the large difference in surface area between the wool sample and the PISOX samples. In this test, the samples of PISOX have a much smaller surface area than the wool sample. A larger surface area is favorable so that more molecules of a sample can react with the KOH at the same time, so the wool sample has been at an advantage during this test.

Furthermore, as the density of PISOX is much higher than that of wool, in the design of a coffin there is likely a lot more PISOX needed in terms of weight compared to wool in a shroud. Further research is needed to investigate the effect of scaling up the quantities and the time needed to dissolve a larger part of PISOX that is representative for a coffin suitable for resomation. Also, the effect of increasing the temperature to 150 °C as is common in resomation needs to be researched.

3.2.1.2 Conclusion

From the test it can be concluded that some types of PISOX depolymerise in a similar time as wool, and significantly faster than conventional plastics. The use of PISOX for resomation seems realistic, but more research into the dissolvement speed under the exact conditions of resomation and with more realistic samples is needed.

3.2.2 Degradation experiment PETG

To gain more insight into how the PISOX degrades over time in a KOH solution, another experiment was done. This experiment was done with PETG for the reasons as explained in 3.1.4. For this experiment, samples of 20x20x3 mm PETG were placed in a KOH solution and its weight was observed at certain time intervals.

3.2.1.2 Setup

Preparation

The dissolvement test was done in the chemical lab using the fume hood. First, five 20x20x3 mm samples were created from PETG Vivak ordered at Vink Kunststoffen (Vink Kunststoffen, n.d.), as well as five plywood samples of 20x20x3mm to serve as a reference. The plywood samples were made using laser cutting and marked using engraving. The PETG samples were cut using an industrial cutting machine and marked using embossing digits. The samples can be seen in figure 3.3.

During the test

The material samples were analysed simultaneously following these steps:

1. The material samples were weighed and noted down.
2. A 5% KOH solution was created by adding 25 g KOH to 475 ml of water in a beaker.
3. A magnetic stirring bar was added to the beaker.
4. The beaker was placed on a heating plate and the temperature was increased to 77 °C. Once this temperature is reached, the temperature is held constant by the heating plate.
5. The material samples of PETG are placed in the solution and the timer is started.
6. Every 30 minutes, the material samples are taken out of the solution using tweezers, the samples are dried using tissues and weighed. After weighing, the samples are placed back in the solution. This is done every 30 minutes for two hours. If the material is dissolved within two hours, the experiment is stopped.

After completing the steps, this procedure was repeated for five samples of plywood. The setup of the test can be seen in figure 3.4.

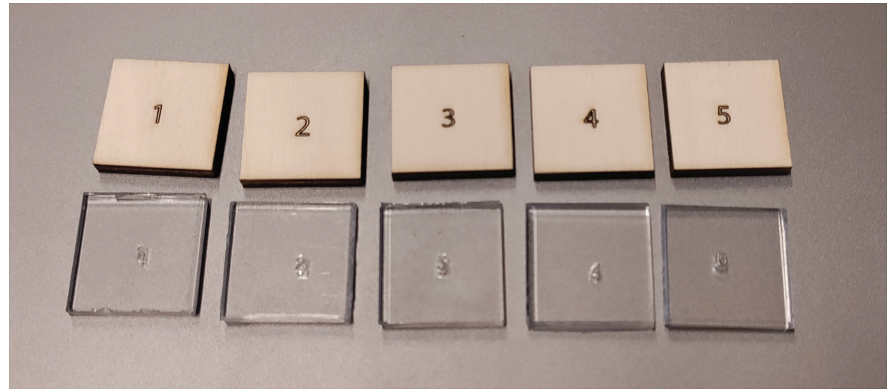


Figure 3.3: The material samples used.

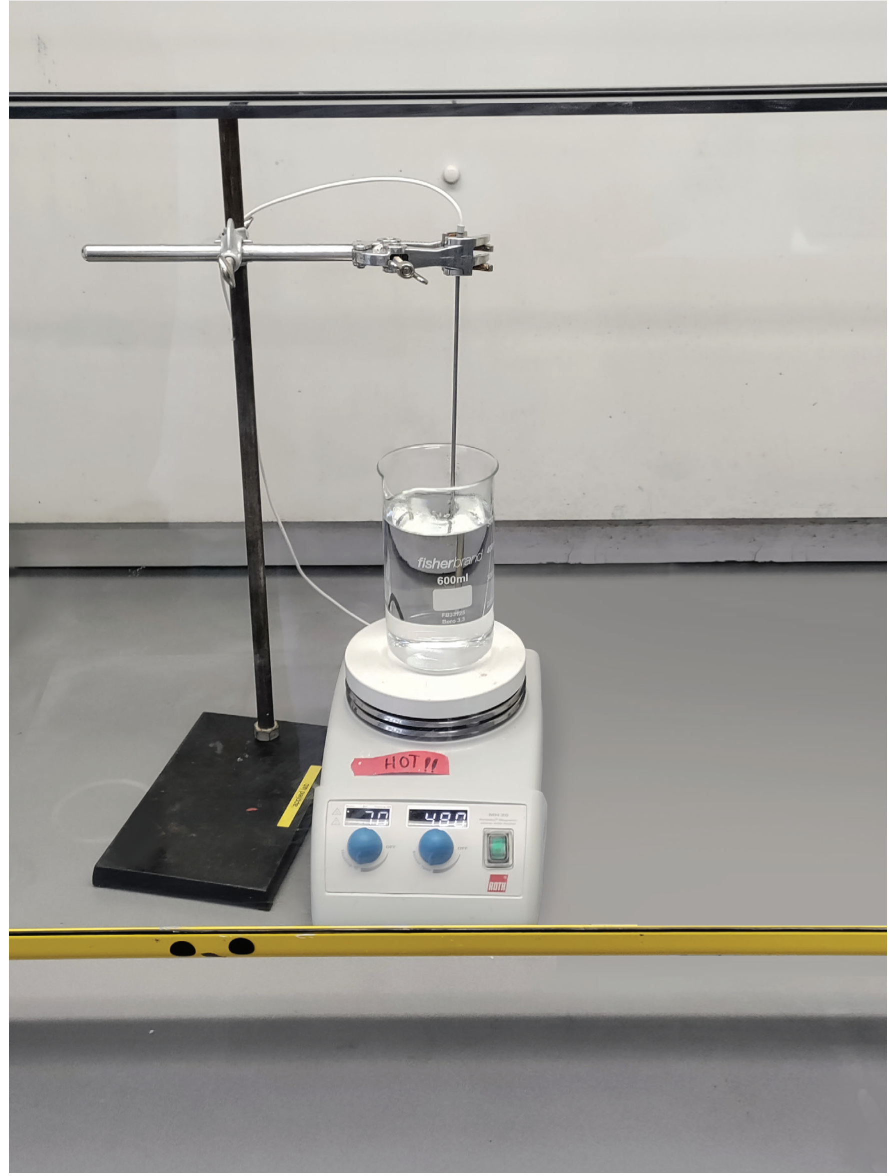


Figure 3.4: Setup of the degradation experiment.

3.2.2.2 Results

After 30 minutes, at the first measurement, the numbers that were pressed into the PETG samples had disappeared. Hence, the weight of the samples were still measured but the individual change in mass over time could not be tracked, only the average of them all. For this reason, the average of the samples was taken. The results of the average mass of the PETG and plywood samples over time while exposed to a KOH solution can be seen in figure 3.5. In figure 3.6, a more zoomed in graph of the average mass of the PETG samples is shown to be able to see the change in mass of the PETG samples. During the period of testing, ca. 75-100 ml of the solution had evaporated.

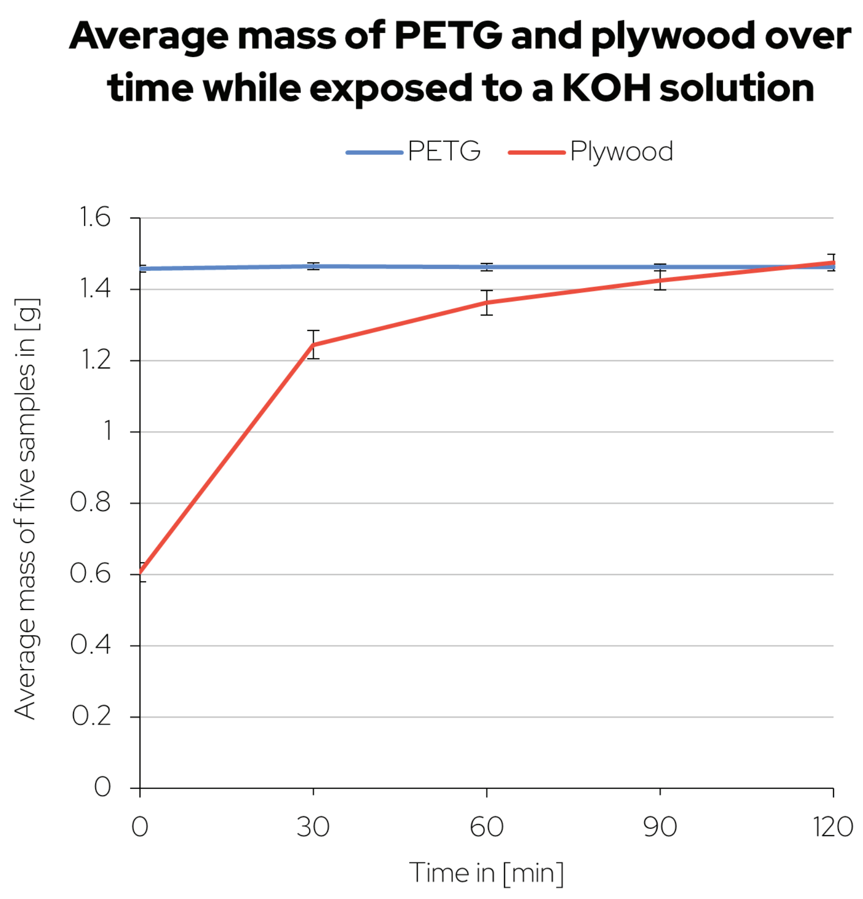


Figure 3.5: Observed mass of PETG and plywood samples over time while exposed to a KOH solution.

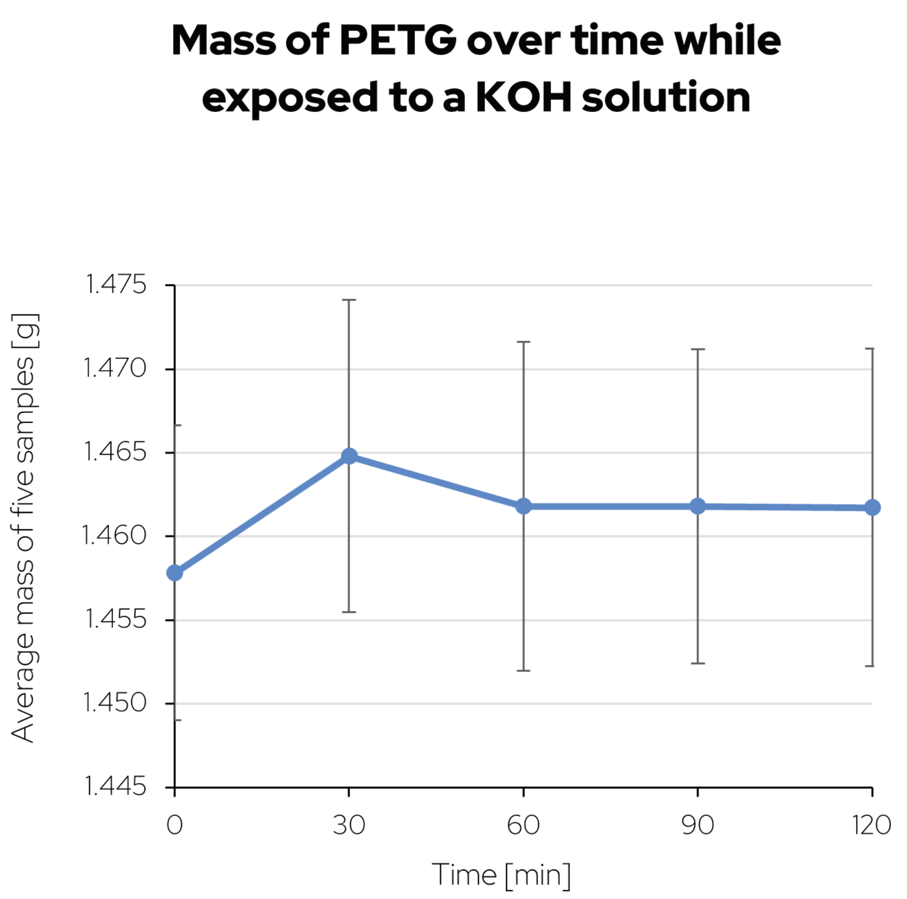


Figure 3.6: Zoomed in observation of mass of PETG samples over time while exposed to a KOH solution.

From graph 3.5, no drop in weight can be observed for both the PETG and plywood samples. For the PETG samples, a small increase phase can be noticed when looking at the zoomed-in graph 3.6, after which the mass of the samples stabilises again.

3.2.2.3 Discussion

The results show that for the plywood samples the weight increases significantly, which can probably be attributed to the absorption of water. The mass of the wood samples seem to follow a logarithmic increase, which is probably because the wood gets closer to its saturation point. For the PETG samples a small increase can be observed, however, this is both in absolute and in relative terms a very small change which makes it difficult to determine the reason for this change. The small change could be the result of a chemical reaction, but it could also be the result of not properly drying the samples at the first measurement.

3.2.2.4 Conclusion

From the graphs, it can be concluded that it seems that no loss of mass and hence degradation takes place by exposure to a KOH solution over a period of two hours. The results are in line with the expectation that wood cannot be decomposed by resomation, which is why a new coffin needs to be designed in the first place. Also, the outcome that PETG does not degrade within two hours is in line with the results of the dissolvement test done in paragraph 3.2.1.

3.3

Production possibilities

PISOX is a polymer so it is expected that it can be processed in a similar manner as other polymers. Possible processing techniques for shaping polymers in 3D organic shapes are thermoforming, 3D-printing, injection moulding or rotational moulding. These methods have been evaluated for the purpose of producing a funeral enclosure. Important characteristics for this are the possibility to shape large parts (2 meters long), the possibility to be financially viable for small batches and the form freedom with those methods. The different techniques are intuitively scored amongst those characteristics in table 3.3, where a green colour indicates a good score and red indicates a bad score.

	Large parts	**Form freedom**	**Small batch**
Injection moulding			
3D printing			
Thermoforming			
Rotational moulding			

Table 3.3: Evaluation of processing techniques for producing PISOX parts.

From the table it can be concluded that injection moulding is not suitable for creating coffin parts. The other three methods are all suitable for producing coffin parts, yet they all have their own advantages and disadvantages which are discussed next.

3D printing

Large-scale 3D-printing is nowadays possible at some places such as The New Raw. When 3D-printing larger parts, the nozzle size is usually increased to reduce the time needed to produce a product. As a result of this, a texture in the surface of the product can be perceived, for example in figure 3.7. This can be used as an advantage, for example when 3D-printing a coffin with the appearance of a willow coffin, but if this is not preferred it can leave a very distinct, undesirable texture, limiting the possibilities of other designs. Additionally, when creating shapes with large angles in the product, support might be needed to be able to produce the shape.

Figure 3.7: A design by The New Raw (The New Raw, n.d.).

Thermoforming

Thermoforming is a common technique to produce products that require a releasing mould. This is mostly done for thin and small products, though it can be used for larger products as well. A company that could perform thermoforming for the large scale of a coffin is VDL Wientjes Roden. When producing a product using thermoforming, it should be kept in mind that the end product will have an inconsistent wall thickness (Engineering Product Design, 2024).

Rotational moulding

Rotational moulding would offer another option to produce coffin parts. This technique is especially suitable for larger products, but it must be kept in mind that it produces closed off parts. Parts could be cut out of the closed off product, but this will require an extra step in production. Also, as a result of the process the product will end up with an inconsistent wall thickness. A suitable company for rotational moulding in The Netherlands is Rotomoulding.

Selection of production technique and prototyping material

From the above, any technique can be selected to produce a coffin. For the design of De Zeepkist, thermoforming has been selected as a production technique, because this is a fast process, it does not have a distinct texture such as 3D-printing and it is highly accessible for rapid prototyping.

As PISOX is still under development and not yet commercially on the market, PETG is used for prototyping to develop and evaluate De Zeepkist's plastic parts. For prototyping, a combination of small-scale 3D printing and thermoforming will be combined.

3.4

Thermoforming

Thermoforming is a well-known production technique. For this application we are focussing on heavy-gauge thermoforming. Heavy-gauge thermoforming is considered when thermoforming materials with a thickness above ca. 2.5 mm (Tempelman et al., 2014). Thermoforming is done at temperatures between Tg and Tm (Tempelman et al., 2014). It is easier to perform thermoforming when there is a wide plateau between those. Amorphous, high-molecular-weight grades of plastics tend to have a relatively long, horizontal, rubbery 'plateau' which is favorable for thermoforming (Tempelman et al., 2014). Since PISOX is an amorphous plastic with a high molecular weight, this is beneficial and hints towards good suitability for thermoforming.

3.4.1 Thermoforming guidelines

Guidelines of the thermoforming process are researched so that the design can be adjusted to the manufacturing possibilities and limitations. Most guidelines for thermoforming address the issue of a varying material thickness, material thinning or the ease of demoulding.

Releasing mould

First of all, a mould that is used for thermoforming needs to be releasing so that the product and the mould can easily be separated. There are two types of moulds that can be used for thermoforming, a female or a male mould. This can be seen in figure 3.8. The choice for a type of mould defines how the end product turns out, because of the material thinning and the variations in material thickness. The side of the material that touches the mould will turn out exactly as intended and could be given a texture. The side of the material that does not touch the mould can have small variations from the intended design due to material thinning.

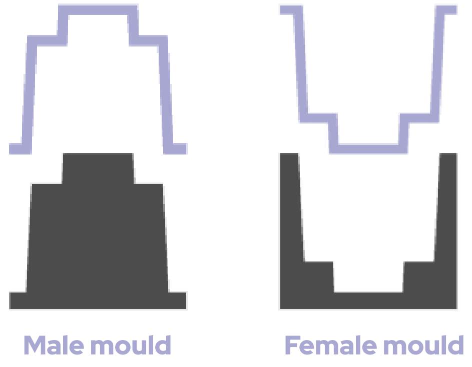


Figure 3.8: Male and female mould example.

Cavities

Cavities can be added to a product, but there are some things to consider when designing cavities. First of all, there are limitations in their depth. In general, a cavity can only be as deep as two thirds of its width, to prevent excessive material thinning (Mayku, 2023) (figure 3.9). Secondly, indents always need to be wider than the sheet thickness, otherwise the material will not form properly into the recess (Tempelman et al., 2014).

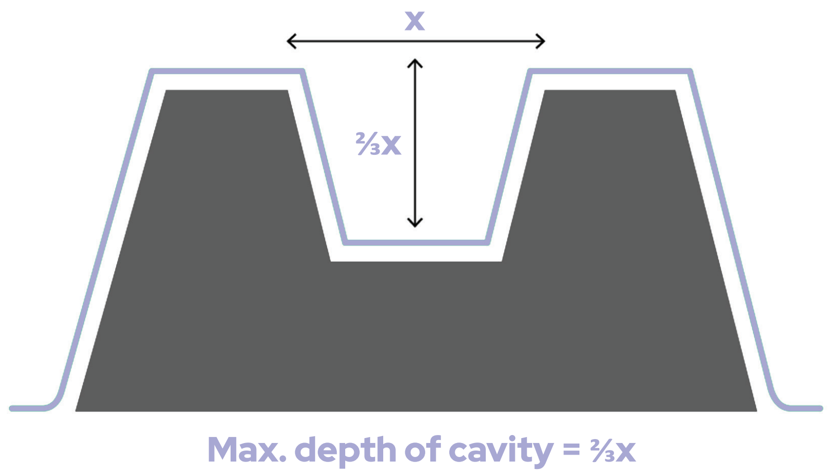


Figure 3.9: Visual representation of the maximum cavity depth.

Corner radius

Sharp corners are best to be avoided with thermoforming. When using a female mould, sharp corners lead to material thinning as displayed in figure 3.10. In male moulds, having sharp corners in the product (figure 3.11) can lead to webbing (Mayku, 2023).

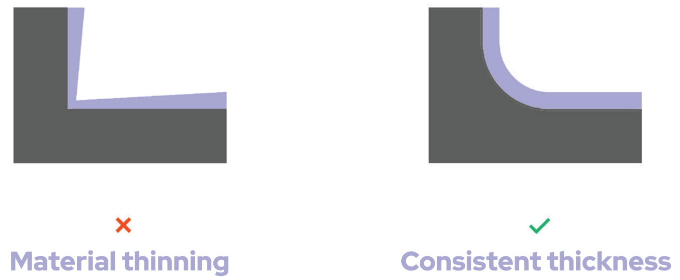


Figure 3.10: Visual representation of material thinning due to sharp corners using a female mould.

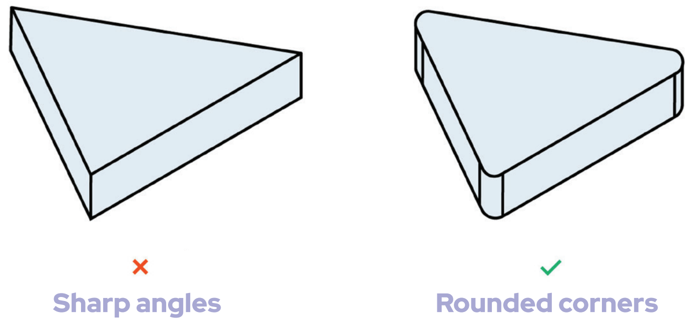


Figure 3.11: Visual representation of undesired sharp corners in male moulds.

Air vents

For the material to form well around the mould, air vents need to be added to create cavities. The location of the air vents is of importance and should be placed close to edges of cavities or indents (Mayku, 2023). The effect of the location of air vents is displayed in figure 3.12.

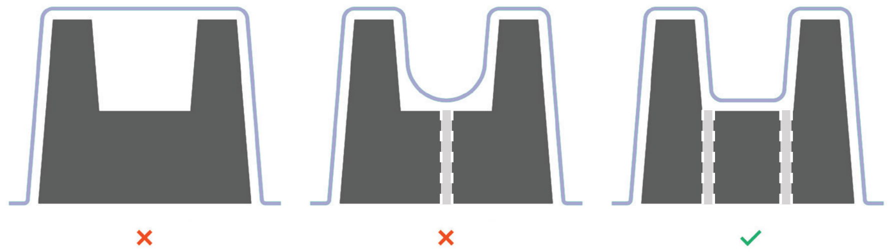


Figure 3.12: The effect of the location of air vents to the thermoformed product.

Shrinkage

After the material has been formed and when it is cooling down, the material shrinks. Using a releasing mould is therefore of importance so that the product is easy to demould (figure 3.14).

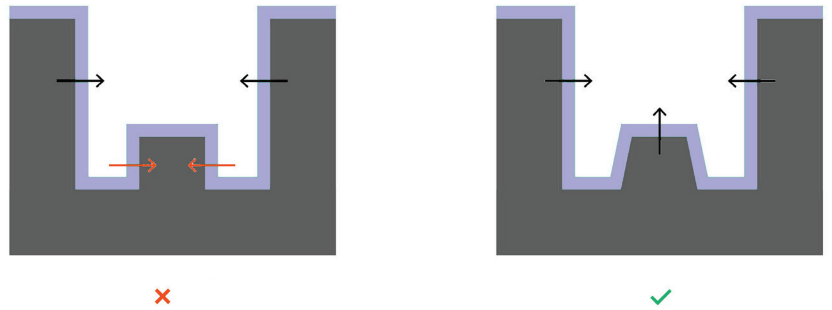


Figure 3.14: Visual representation of shrinkage after thermoforming.

All of the above guidelines need to be considered when preparing De Zeepkist for thermoforming.

04

SOAP

In this chapter, the desired characteristics of soap are defined and a suitable soap is selected for the design of De Zeepkist. With the selected soap, tests are done to evaluate the soap's characteristics and suitability for use in De Zeepkist.

4.1

Soap introduction

Soap is a commonly known product that people use everyday to ensure hygiene. There are many different types of soap, such as liquid soap, hand soap, body bars, shampoo bars, etc.. All these types of soap can have their own colour, fragrance and texture, offering endless possibilities to personalise soap. There are also multiple ways in which soap can be made, of which many are very easy to do on a DIY scale at home (Anderson, 2024). In the design of de Zeepkist, soap will fulfil mostly a decorative function. The soap should therefore mostly offer an aesthetic look and feel and contain a pleasant fragrance. Ideally, the soap could be personalised to a colour & fragrance of choice. Furthermore, the soap should meet some functional requirements regarding resomation time, strength and price, and ideally the soap has a low density to lower the overall weight of the enclosure. Lastly, it is important that the negative impacts of the soap on the environment are minimised.

In the upcoming paragraphs, it is discussed how soap is made and what parameters of this process could be tweaked to alter the soap's characteristics, followed by research into the sustainability of soap. This is followed by a list of requirements and wishes to which the soap must comply and based on this a soap is selected to be used in a prototype of De Zeepkist. After the soap selection, a test is done to evaluate the unknown characteristics including the resomatability of the selected soap.

4.1.1 Soap ingredients

Soap is a product that is made by the process of saponification (Coiffard & Couteau, 2020). Saponification is the reaction of a base with an oil or fat (Coiffard & Couteau, 2020). The term 'fatty acids' is often used to refer to the oil and/or fat. Generally, water is the third base ingredient to create the soap. Additives can be added to those base ingredients to alter the soaps properties. This is mostly done to colour the soap and to give the soap a pleasant fragrance. Also the base ingredients - water, lye and fats/oils - can be customised to a certain extent. Various fats/oils or combinations of different types can be used (Tyburski, 2024). For the lye, NaOH is used to create a solid soap (HSCG, n.d.). As a result of the base that is used in saponification, a bar of soap can have a high pH of 11 or 12 (Coiffard & Couteau, 2020). As a soap with a pH of 10 or above can irritate the skin (Wholesale Supplies Plus, 2017), it is important that the soap used for De Zeepkist should be safe for bereaved to touch. As soap is such a common material and so easy to DIY, there are dozens of blogs and recipes online for creating soap. It is difficult however to find scientific information about what happens to a soap when you change one of the ingredients, and large soap-companies are reluctant to share information on how they make soap. It seems like scientific information about soap is limited because it is so easy to make it yourself and it is probably faster to just try out making some soap yourself.

4.1.2 Soap production

There are four main production techniques to produce solid soap, these are hot processing, cold processing, the melt & pour technique and soap extrusion (Fisher, 2022), (Thomas, 2024). The hot processing and cold processing soap are essentially the same, only there is a difference in heat applied. In these two processes, the main ingredients are mixed together and then poured into a mould (Bramble Berry, 2024). During the hot processing, the ingredients are heated to ca. 50-100 °C during mixing, whereas cold processing happens at low temperatures such as 30-50 °C (School of Natural Skincare, 2023). A drawback of cold processing is that the soap needs to rest for four to six weeks after putting it in the mould, to ensure that the saponification is completed and there are no traces of lye in the soap anymore ("Cold Process Vs Hot Process Soap: Benefits & More!", 2024). A benefit however is that the soap is rather liquid when pouring it in the mould, allowing for a smooth finish and large shape freedom (Bramble Berry, 2024). Those two characteristics are exactly the opposite for the hot processions soap. Hot processed soap can be used directly after it is poured into a mould and hardened after a few hours, and it has a naturally thicker texture, making it difficult to make smooth and thin soaps (Bramble Berry, 2024).

The melt and pour technique combines the best of those two techniques and makes creating soap even easier. In the melt and pour technique you make use of a pre-created soap base (Soap Queen, 2022). There are many different soap bases available, but generally speaking they contain the three main ingredients (water, lye and fats and/or oils) and some additives. The benefit of a soap base is that the saponification process has already taken place (Soap Queen, 2022). The soap can be made by melting the soap base in the microwave or au bain-marie (Bramble Berry, 2021). Once it is melted, additives such as fragrance and colour can be added. After a little bit of mixing, the soap can be poured into a mould for it to harden. After hardening for a few hours, the soap can immediately be used, as the saponification process already took place when the soap base was created. Lastly, on an industrial scale there is the option of soap extrusion which is used to create bars. This however offers very limited form freedom to shape the soap.

Because soap is mostly produced by pouring it into a mould, this is often a finished product. The only common type of post-processing is cutting it into smaller blocks.

For prototyping of De Zeepkist, the melt and pour technique is selected as it is fast and easy and a smooth texture and possibility to create thin layers is desired. For the longer term, cold processing could be desired as this is probably cheaper and there is more flexibility regarding the use of ingredients. However, a large storage space would be necessary to pre-produce the soap needed, which could nullify the cost benefit and should therefore carefully be considered.

4.1.3 Soap customization

Soap can quite easily be customised. To customise soap, colourants and/or fragrances could be used. For De Zeepkist, both a pigment and a fragrance will be added. For both of these, it is important that the colourants and fragrance are biodegradable and preferably biobased to maintain the natural character of the product.

4.1.3.1 Colour

To add a colour to a piece of soap, either liquid colourants or pigments could be used. The options to colour a soap are virtually endless and luckily there are also plenty of natural pigments that are derived from plants, such as beetroot. Such natural pigments are ideal for the purpose of De Zeepkist.

4.1.3.2 Fragrance

Just as with colours, there are endless fragrances available. For De Zeepkist, it is preferred to use natural scents to make the experience for bereaved as natural as possible. A fragrance is often added to a soap by adding fragrance oils or perfume, generally up to 1% of the soap at maximum (Duran, 2022).

4.1.4 Soap's sustainability

When considering the sustainability of bar soap, based on a study done by Gaurav et al. (2023) it can be assumed that the production of the soap will have the highest impact on the environment. The ingredients used to produce the soap highly impact its overall sustainability. Common attempts to create more sustainable soap is by choosing ingredients made of renewable or biobased resources or by using wastestream materials for ingredients. As a result of meat production, a certain amount of animal fat remains as 'waste' at slaughterhouses. These fats are commonly used as 'waste' materials to make soap (Vlees.nl, 2023). However, as this is so commonly done, it said that no 'waste materials' remain at slaughterhouses and all animal fats are generally used (Vlees.nl, 2023), so it is questionable whether this can still be called 'waste material' and pledges for using natural ingredients instead. This is another common practice to make a bar of soap more sustainable, by selecting natural ingredients such as vegetable oils and excluding any animal fats.

Another important aspect regarding sustainability for the application of De Zeepkist, is that it is important that the soap is biodegradable so that it does not leave harmful chemicals behind once it is decomposed (Chirani et al., 2021). Since biodegradable soaps are made of natural ingredients which naturally decompose over time (Chirani et al., 2021), using only natural ingredients will add a second benefit for sustainability.

Furthermore, there are some commonly used ingredients in soap that from a sustainability perspective are better to be avoided. For example palm oil is commonly used in soaps as it is a natural material. However, palm oil production is known for causing deforestation for its production (WWF, 2022). In addition, materials triclosan and triclocarban are ingredients that are often used in soaps for their antibacterial properties, yet it has been found that these chemicals are a threat to human health and the environment (Chirani et al., 2021). Furthermore, the soap would ideally not contain any chemical additives or synthetic components, though these are ingredients that are commonly used in the soap industry (Chirani et al., 2021). Examples of such harmful synthetic additives are sulfates, parabens, silicones and phthalates or petrochemicals. Those ingredients pose a threat to human health and the environment and are therefore best to be avoided (Richardson, 2022).

4.2

Soap selection

Based on the research findings, a list of criteria for the soap is drafted. The soap should comply with the following requirements and *wishes*:

1. The soap can be used within 24 hours after moulding.
2. The soap is dissolved in resomation within 198 minutes.
3. The soap can function within a temperature range of -25 to +45 °C.
4. The soap is biodegradable.
5. The soap has a pH of max. 10 and is safe to touch.
6. The soap is opaque.
7. *The soap is made of biobased materials.*
8. *The soap is not made using petrochemical ingredients.*
9. *The soap costs less than €10 per kilo to produce.*
10. *The soap has a low density.*
11. *The soap contains no synthetic additives.*
12. *The soap does not contain palm oil.*

A melt-and-pour soap was sought to meet these requirements and as many wishes as possible. It should be noted that a compromise on one of the wishes might be needed to facilitate De Zeepkist. Some information could not be found and should be tested, such as whether these soaps meet the resomatability requirement.

A melt-and-pour soap that meets the requirements and wishes has been sought. In table 4.1, an overview of suitable soaps is displayed. A major soap producer in Europe is Stephenson. Melt-and-pour soaps sold by soap distributors in the Netherlands are generally produced at Stephenson. Hence, most potential soaps are selected from their catalog. Some information was missing and should be tested, such as whether these soaps meet the resomatability requirement.

		Crystal WST	Organic Melt and Pour soap Amphora Aromatics	Crystal natural high foam	Crystal Natural White	Crystal white no sweat	Crystal Shea
Requirements	**Resomation speed**	TBD	TBD	TBD	TBD	TBD	TBD
	Suitable from -25 to +45 °C	Melting point 50-60 °C	Unknown	Melting point 50-60 °C	Unknown	Melting point 50-60 °C	Unknown
	Biodegradable	yes	Unknown	yes	Unknown	yes	Unknown
	pH	9.5-10.5	Unknown	9.5-10.5	10	9-11	10
	Opaque soap	yes	Unknown	Translucent	yes	yes	yes
	Colour	white	Unknown	white	white	white	white
Wishes	Natural origin content	89.39%	100%	96.4%	99.9%	84.81	99.75%
	Includes petrochemical ingredients	yes: Propylene Glycol	no	no	no	yes, Propylene Glycol	no
	Price in €/kg	€13.55	€13.53	€10.75	new product, not found	€14.63	€9.98
	Density in kg/m3	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
	Synthetic additives added?	yes	no	yes	yes	yes	yes
	Includes palm oil	no	yes	no	no	no	no
	Producer	Stephenson UK	Amphora Aromatics	Stephenson UK	Stephenson UK	Stephenson UK	Stephenson UK
	Remarks	-	-	High foaming / looks almost opaque in pictures	High foaming	No sweat - advantage for humid areas	-
	Sources	(Stephenson, 2024e) price at (De Online Zeep-winkel, 2024a)	(Amphora Aromatics, 2024)	(Stephenson, 2024a) price at (YouWish, 2024b)	(Stephenson, 2024b)	(Stephenson, 2024d) price at (De Online Zeep-winkel, 2024b)	(Stephenson, 2024c) price at (DistrEbution, 2024)

Table 4.1: Characteristics of suitable soaps found.

Based on the data in this table, it can be concluded that a perfect melt-and-pour soap that meets all requirements and wishes does not exist and some crucial information about the options is missing. A choice has been made for the best option out of the options in Table 4.1. Several options can be ruled out by its characteristics. First of all, for the Crystal Natural White soap it is impossible to find a seller, so this is not a suitable option. Additionally, the high foaming is undesirable as described in chapter 2. Furthermore, the options Crystal WST and Crystal White No Sweat are ruled out because of their propylene glycol content. As the application of the soap product will be used for a sustainability purpose, using oils derived from fossil resources is unacceptable. Now three options remain, these being Organic Melt and Pour soap Amphora Aromatics, Crystal Natural High Foam and Crystal Shea. The Organic Melt and Pour soap Amphora Aromatics stands out for its sustainability, however there is very little information available and it seems like there is no possibility to scale up the order size, which makes this soap unfavorable. Lastly, Crystal Shea scores a little bit better on multiple aspects compared to Crystal Natural High Foam. It should be confirmed however whether this soap is biodegradable as well as suitable for the required temperature range as this information is missing. The Crystal Shea soap is selected to be used for De Zeepkist. In the next chapters the unknown characteristics of soap are investigated.

4.3

Soap's suitability for resomation

A couple of dissolvement tests were done to evaluate the suitability of soap for resomation. To be suitable for resomation, it is important that the soap dissolves quickly, so that the overall resomation time does not increase more than what is acceptable. A comparative test was done at a small scale to evaluate the material's suitability for resomation. This was done by dissolving similar-sized 20x20x2 mm material samples of Crystal Shea melt and pour soap and shroud wool in a 5 wt% KOH solution, and observing the time needed for complete dissolvement. For the shroud wool, material samples were taken from a wool shroud supplied by Wikkelgoed. As this is the main alternative for resomation, the relative dissolvement speed of soap compared to wool gives insight in its suitability for resomation. Additionally, the dissolvement speed of soap with and without the presence of KOH was analysed to see whether the presence of KOH influences the dissolvement speed of soap. This was done using bigger samples of 30x30x30 mm soap due to the very fast dissolvement times of soap.

4.3.1 Setup

Preparation

A setup is created as shown in figure 4.1. A heating plate is placed within a fume hood. Using a stand, a thermometer is placed above the heating plate to measure the temperature of the solution. A camera is placed to record the dissolvement of the samples. A scale is placed next to the heating plate to measure the weight in grams with four decimals and to create the KOH solution.

Three material samples of Crystal Shea melt and pour soap ordered from Stephenson were cut into samples of 20x20x2 mm, as well as six samples sized 30x30x30 mm. Also, three samples of wool were prepared by cutting samples of 20x20x2 mm from the provided fabric from Wikkelgoed using scissors.

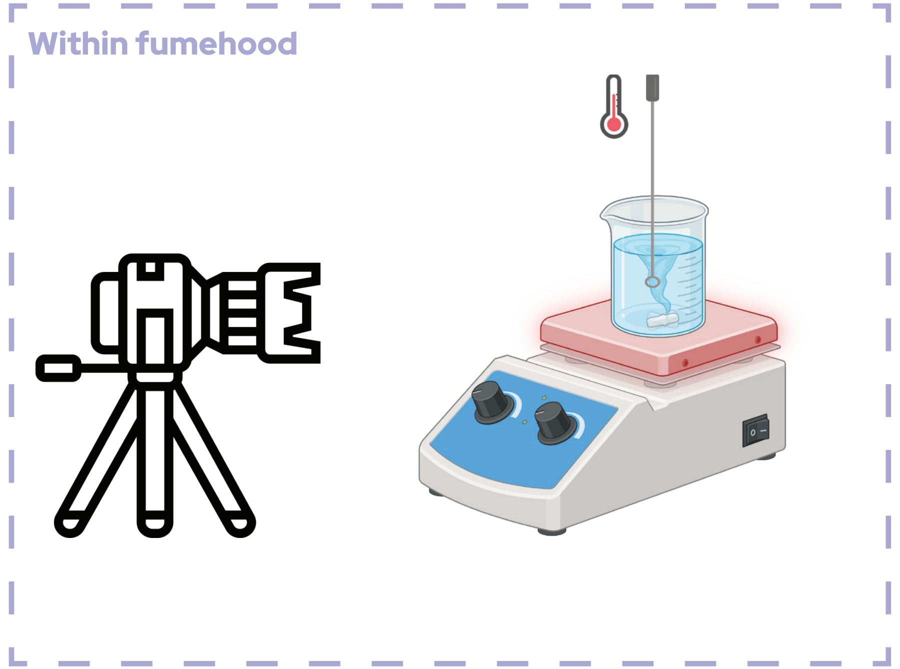


Figure 4.1: Test setup.

During the experiment

The following steps were repeated for three material samples of 20x20x2 soap as well as three samples of 20x20x2 wool, one by one:

1. The material sample is weighted.
2. A 5 wt% KOH solution is created by adding 5g KOH to 95 ml of water in a beaker.
3. A magnetic stirring bar is added to stir the solution and create flow.
4. The beaker is placed on a heating plate and the temperature is increased to 77.5 °C. The temperature is kept constant once 77.5 °C is reached.
5. A material sample is added to the beaker and the timer is started.
6. The dissolvement process is observed and the timer is stopped once the material sample is entirely dissolved.

After the 20x20x2 mm series, the steps above were repeated with three samples of Crystal Shea soap sized 30x30x30 mm. After this, the steps were repeated again using Crystal Shea soap samples sized 30x30x30 mm, only now in step 2 no KOH was added and 100 ml of water was used instead.

4.3.2 Results

The data has been collected in an excel sheet which was used for the calculations, in this chapter the results of the calculations are shown. First, the average dissolvement times for each material sample category were calculated as shown in figure 4.2. Then, a scatter plot of the mass dissolved vs. the dissolvement time of the 20x20x2 mm samples is shown in figure 4.3.

Lastly, using the initial weight and the time needed to dissolve the materials, the dissolvement speed in mg/min was calculated as shown in figure 4.4.

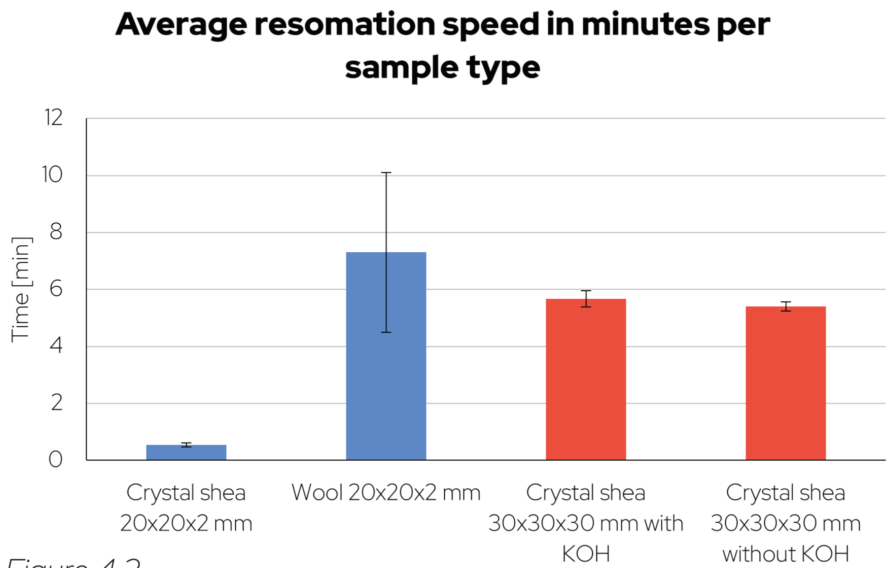


Figure 4.2.

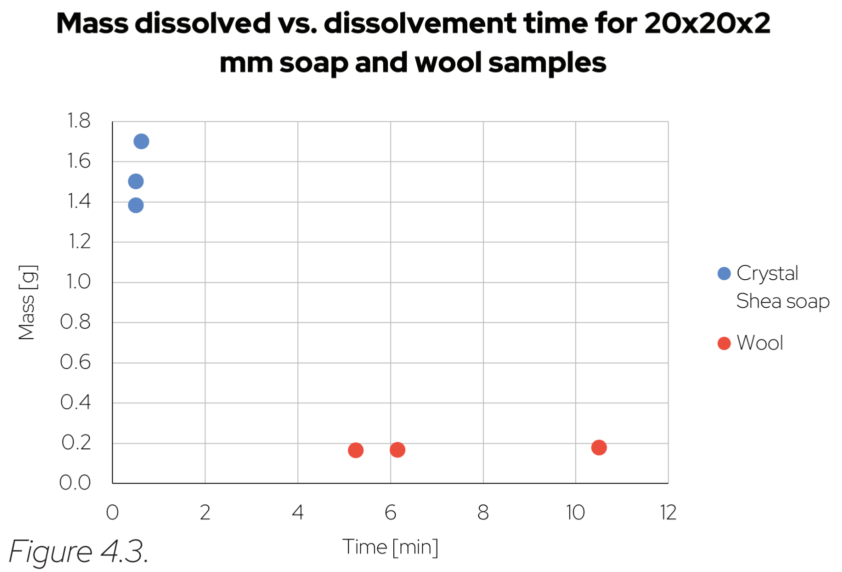


Figure 4.3.

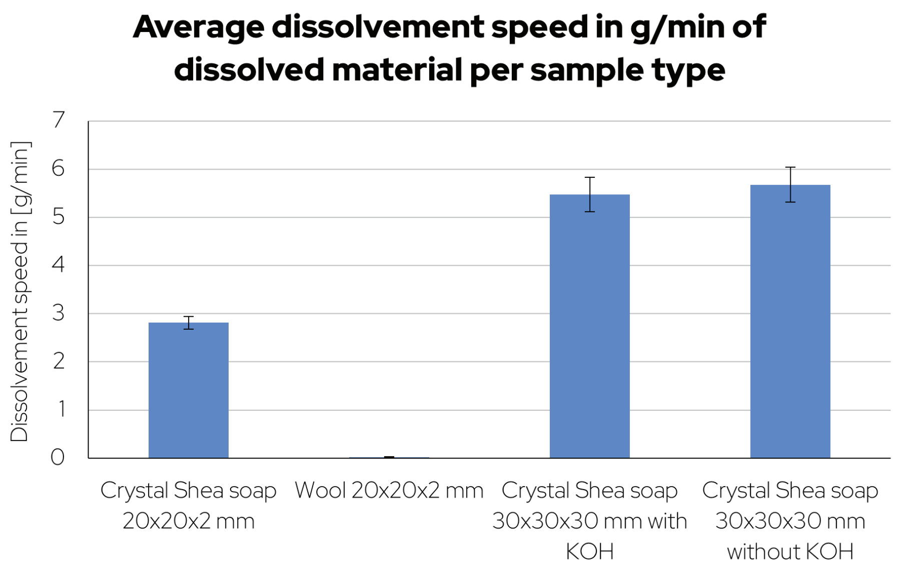


Figure 4.4.

Figure 4.2 shows that soap dissolves 13 times faster than wool when comparing similarly sized samples. In graph 4.3 it can be seen that not only the soap dissolves faster than wool, but also more mass is dissolved within a shorter time. In figure 4.2 it can also be seen that the dissolvement time of the soap with or without KOH does not differ much. In figure 4.4, it can be seen that the dissolvement speed in g/min of soap is higher than that of wool, and increases when a larger amount of soap is being dissolved.

4.3.3 Discussion

The results provide valuable insights in the dissolving capacities of the materials. First of all, it shows that soap dissolves relatively fast compared to wool when a similar volume is dissolved. Even when a rather chunky block of 27 ml soap was dissolved in a relatively small amount of 100 ml water or KOH solution, the samples dissolved in only a few minutes. In the design of De Zeepkist the soap will likely be added in thin layers, which will increase the surface area of soap that will be in contact with water, which will likely be beneficial to reduce the time needed to dissolve the soap.

Furthermore, the similar dissolvement time for soap with and without KOH in the solution suggests that KOH does not react with the soap, rather the soap dissolves in water. This is not surprising as soap is an alkali material itself, yet it is good to have this confirmed.

In addition, it is remarkable that the dissolvement speed in g/min for the differently sized soap samples are not the same. A possible explanation for this could be the larger surface area for the 30x30x30 mm samples. Because of this difference in dissolvement speed in g/min, it is difficult to predict how much time will be needed to dissolve bigger amounts of soap.

A limitation of this study is that the test has been done at a significantly lower temperature than what is common during resomation. A lower temperature was used in this test to prevent the solution from boiling. During resomation, boiling is prevented by the pressure that is applied within the resomator, however in the lab there was no such equipment available. For this reason the test was done well below the boiling point of water to prevent dangerous situations and excessive evaporation. Since it seems that the materials dissolve in different ways, increasing the temperature might affect the dissolvement time for the different materials differently. Hence, though the results are hopeful that soap is suitable for resomation, a more accurate test needs to be done using more realistic conditions.

Additionally, during the testing it was difficult to keep the temperature constant once the temperature was reached, which might have caused small variations in the results.

Lastly, the soap dissolvement behavior might also change when additives are added to the soap for customisation. Also, it should be considered that probably more soap needs to be used in mass than wool, as soap has a much higher density. More realistic tests should therefore be done when the design is in a further stage. Nonetheless, the results show that soap as a coffin material has potential.

4.3.4 Conclusion

From the results, it can be concluded that soap dissolves 13 times faster than wool and seems highly suitable to be used for resomation. Furthermore it can be concluded that the presence of KOH does not help dissolve soap, instead the soap is simply dissolved in the water.

4.4

Soap's characteristics tested

Some properties were tested that were not available from the companies' information. First, it has been tested how the soap reacts at -25 °C and at +45 °C. Secondly, the density of the soap has been defined.

4.4.1 Temperature range

A small experiment was done to evaluate the soap's behavior at the extremes of the temperature range. This was done using a climate chamber. First, small scraps of soap were collected and weighted. After weighing, the climate chamber was set to -25 °C without humidity control and the soap was placed inside. Once the temperature was reached, the soap was left inside for a couple of minutes. Then, the soap was taken out and the materials were weighed again and inspected. This was repeated for another piece of soap at a temperature of +45 °C without humidity control.

4.4.1.1 Results

In figure 4.5 and 4.6 the soap can be seen before it was placed in the climate chamber and after. For the sample that underwent -25 °C, a weight loss of 0.1 gram from the original 4.5 g could be observed. Furthermore, the soap optically looked a bit more matte than before. Then the soap was flexed to see how it would react. It could be noticed that the soap was a bit stiff, it was a little bit more difficult to bend than at room temperature but it was still easily possible. The soap did not show any brittle behavior.

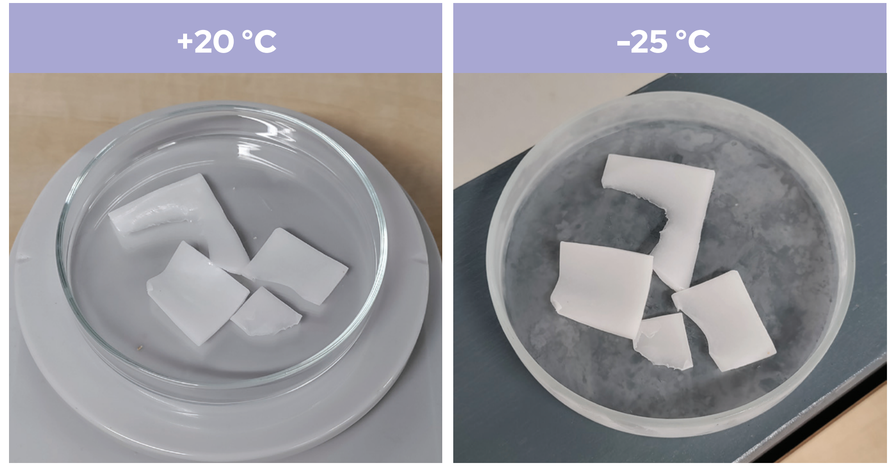


Figure 4.5: Soap scraps before and after experiencing -25 °C.

For the sample that experienced +45 °C, a weight loss of 0.25 gram from the original 4.54 gram was found. Optically, the soap looked as if it felt hot. It appears as if it is lightly sweating, but not in a manner as soap sweating can be found with drops. The soap was still flexible and unmelted, though it left some traces when it was swept on the glass.

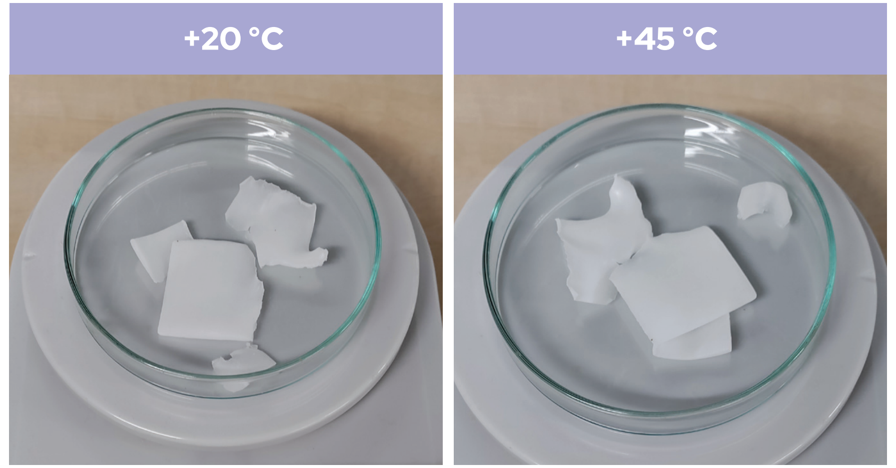


Figure 4.6: Soap scraps before and after experiencing +45 °C.

Another remarkable finding was done due to the setup of the test. Both soap samples were initially prepared and weighed at the same time, though the samples could only go into the climate chamber after each other. Just before starting the second round of soap, around 0.17 gram of soap had evaporated without the soap undergoing any temperature differences.
A little bit of soap was then added to reach 4.5 g soap again directly before starting the second test.

4.4.1.2 Conclusion

The optics of soap changed a little bit due to the temperature differences, but this stayed within an acceptable range. Also, the soap did not become brittle nor melt, which is a good result. Finally, soap loses a bit of weight due to evaporation, both at low temperatures, room temperature and hot temperatures. One possible explanation for this could be that the soap was used directly out of its packaging, and maybe the production process of the soap did not allow enough time to complete full evaporation. Opening the packaging and letting it stand before using the soap could perhaps help to reduce the effect of evaporation and to limit shrinkage.

4.4.2 Density

The density of the soap was calculated using the mass of the 30x30x30 mm soap samples used in the resomation experiments as described in 4.3. The average density of these samples appeared to be 1141 kg/m3, with a standard deviation of 36.4.

05

REQUIREMENTS AND WISHES

In this chapter, requirements and wishes are summarised based on the previous analyses.

Requirements and wishes

Based on the analysis, a list of requirements and wishes was drafted. Throughout the project, the list has been adjusted based on new insights. The full list of requirements and wishes could be found in appendix 3. The most important requirements and wishes will be discussed here.

Requirements

1. The design for a funeral enclosure together with a human body can be resomated in 198 minutes.

This is of high importance: the design needs to be resomatable within a reasonable time. To quantify reasonable, here an increase of 10% compared to not using a funeral enclosure is considered acceptable.

2. The deceased does not have to be redressed or taken out of the enclosure between the ceremony and before resomation.

This is another very important aspect that addresses user-friendliness and honorability. Now, as there are no coffins that can be placed into the resomator a deceased would need to be taken from a temporary coffin or burial plate that could be used during the ceremony and placed in the resomator. This is perceived to be disrespectful for the deceased and also cumbersome and unpleasant for the funeral directors. In the design no redressing or dragging of the body is accepted.

3. The design of the enclosure is honorable and perceived to offer a comfortable final resting place.

It is very important that people are positive about the design so that they would feel comfortable to choose the design and resomation for themselves or for their relatives.

4. The enclosure fits in the Resomator S750.

As explained in chapter 1.3 and 2.2, the enclosure needs to fit within the tight dimensions of the Resomator S750.

Wishes

1. The enclosure emphasises the unique characteristics of resomation.

As there are now no coffins suitable for resomation, De Zeepkist will hugely contribute to the image of resomation. To favor resomation's unique process, the coffin should emphasise the process' unique characteristics.

2. The enclosure hides the contours of the deceased.

Many people have indicated that they feel uncomfortable being confronted with the contours of the deceased as with the use of a shroud. De Zeepkist should ideally hide the contours to appeal to a larger public.

Part 2: Design

In the following chapters, the design of De Zeepkist has been explored and defined, starting from the overall main shape and interactions, step by step elaborating on the design by moving towards practical aspects such as carrying and the closing of the coffin, finalizing in a design where all aspects of the design are integrated.

Part 2 Design

06

EXPLORATION OF THE ENCLOSURE'S DESIGN

In this chapter, a possible design of De Zeepkist was explored by means of a moodboard which was discussed with potential users and by ideation.

6.1

Moodboard

A moodboard was created to explore the possible style of De Zeepkist, see figure 6.1. The moodboard was used as a discussion tool to discuss a desired style with potential users. As inspiration for the moodboard, mostly elements of architecture were used and pictures were collected from the internet. The moodboard was created with the idea in mind that a coffin functions as a transition place from life to the hereafter. The moodboard was discussed during informal chats over coffee breaks with eight people. Those informal chats provided insight into how the participants experienced the moodboard and how they think about a style for a coffin.

From the conversations, a general consensus showed that a new design for a coffin can look white or light and this can be perceived as aesthetic, however one should be careful about the coffin looking too clinical or sterile, as if people are in a hospital or at the dentist. Overall, people did not want it to look too chilly/cold, but rather have a warm appearance to it. Furthermore, the moodboard appears quite futuristic and some people mentioned to have a feeling of an ufo or experienced a 'larger than life' feeling. One participant mentioned that the moodboard is quite dynamic, which was found inappropriate because life at that moment just stops. Most people did not appreciate the coffin as a transition place from life to a hereafter.

When discussing what the coffin should feel and look like, participants mentioned that it should be warm, gentle, 'gezellig' and it should be somehow recognizable or familiar, however it does not necessarily have to be a squared box, it can be something new and a little bit less formal. From the conversations with the participants it also became clear that people prefer a somewhat minimalistic style, including neutral colours and preferably no texture. Most people felt drawn to the image of a wooden sculpture on the left.

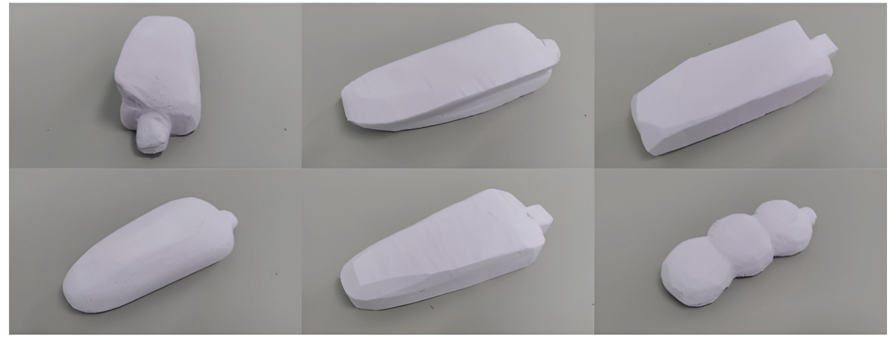
Figure 6.1: Moodboard.

6.2

Ideation

To explore what the design of De Zeepkist could look like, some exploratory sketching as well as simple 3D models were made inspired by the moodboard (figure 6.2 and 6.3). In this stage, mostly the overall shape and impression was explored.

Figure 6.2: Exploration of fully fitting shapes.



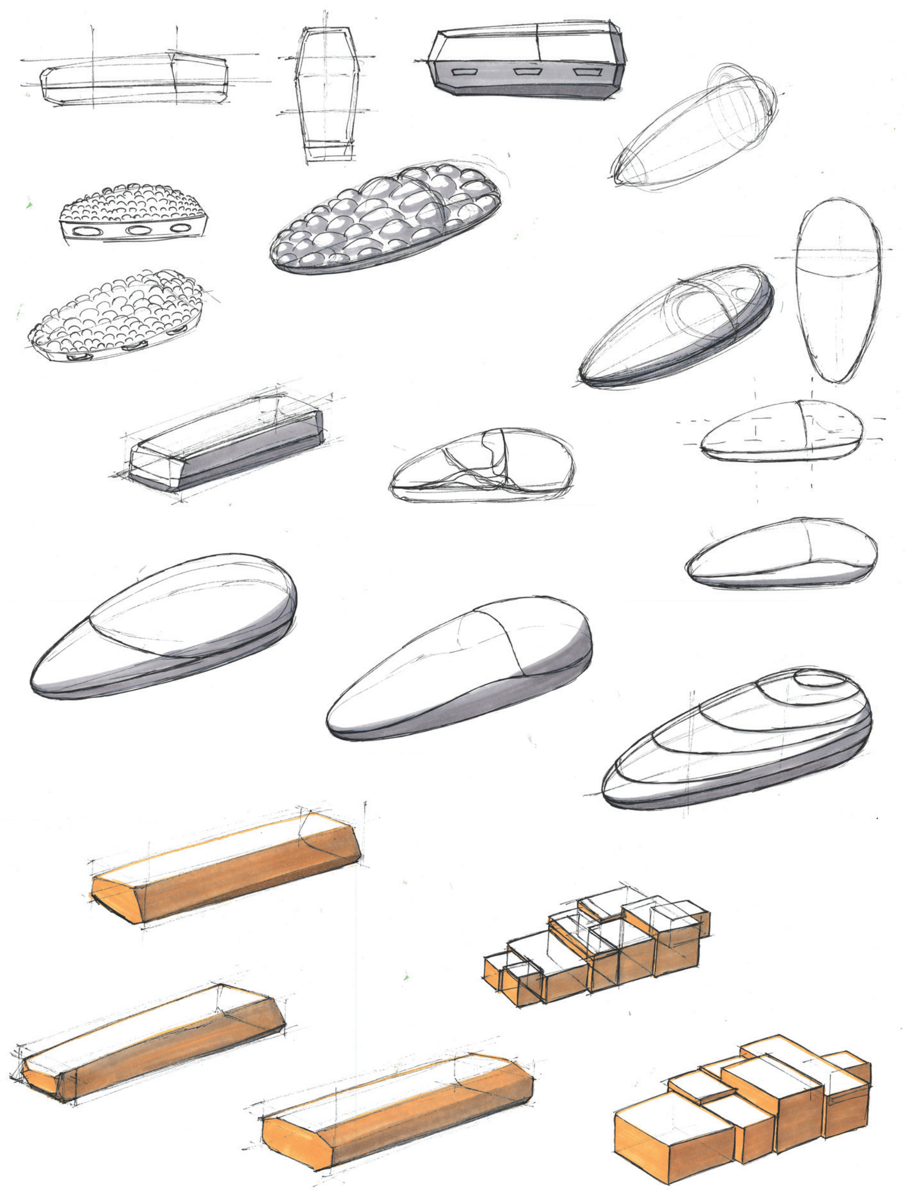


Figure 6.3: Exploratory sketching.

07

IDEA DIRECTIONS AND SELECTION

Based on the exploration in chapter 6, five interesting idea directions with a distinct style and interaction were found. In this chapter these directions are discussed and one of them is selected using a Harris profile.

7.1

Interesting idea directions

A couple of ideas were generated that could be a possible direction for a funeral enclosure for resomation.

7.1.1 To fit as a whole or to adapt

Based on the shape exploration (figure 6.2) of a coffin that fits the resomator, it can be concluded that it is difficult to create an enclosure that has a natural appearance and fits within the resomation's head fixture. One idea was explored that could fit the resomator as a whole and can be seen in figure 7.1. This idea adopts a cubist style which would make the smaller part needed to fit the head less obvious. Alternative ideas all included an additional cover for the head so that the coffin could be transitioned from an aesthetic model that could be used during the ceremony into a functional model that could fit into the resomator. This modular system can be seen in figure 7.2. Prior to resomation, the aesthetic cover on the head-side of the coffin would need to be taken away to make the coffin fit within the resomator. A functional cover would appear underneath so that the deceased will not be seen at this moment anymore.

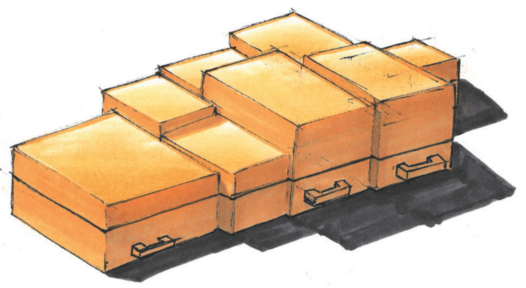


Figure 7.1: Fully fitting, cubist design idea.

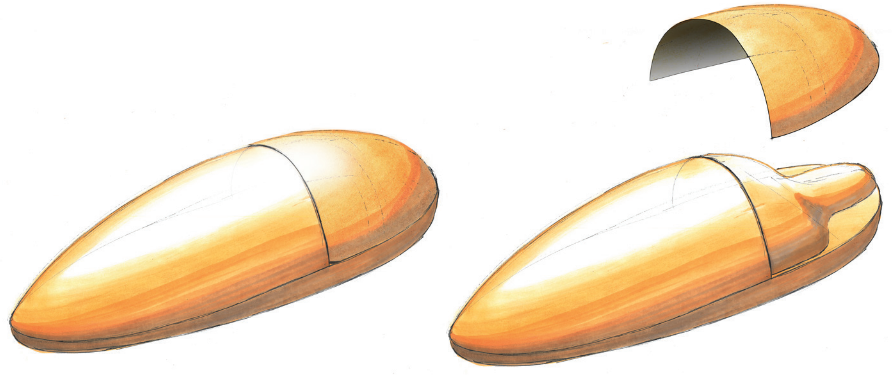
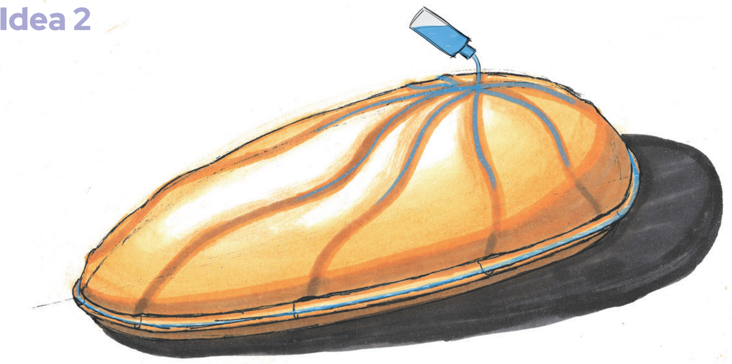


Figure 7.2: A modular design to offer both an aesthetic version as well as a fitting version.

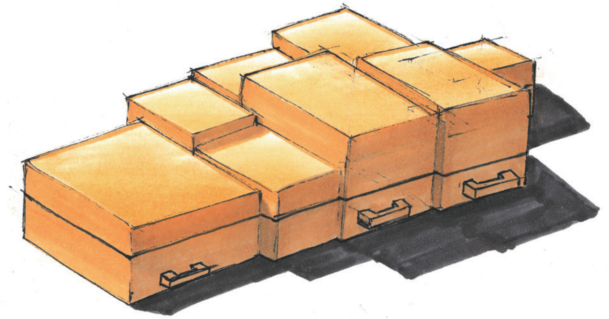
7.1.2 Interaction ideas

A couple of ideas were generated that offer different interactions or aesthetics, these can be seen in figure 7.3. The first idea is a simple design that appears calm and natural. An organic shape is used. In the second idea, a ritual with water is added to the coffin. Here the top is shaped with little gullies in the soap. Just before the resomation, water can be poured onto the top to flow down the gullies, and will end up in a gutter that is also used as a handle to carry the coffin. The third idea explored a more modern shaped enclosure, where the coffin would be perceived as a transition place to the hereafter. A fourth idea adopts a calm style, similar to the first direction, but invites the bereaved for interaction with the cover. By having a small relief in the cover, which could be created with soap, people are invited to touch the coffin.

Idea 2



Idea 3



Idea 1

Idea 4

Figure 7.3: Interaction ideas.

7.2

Idea selection

The five ideas were evaluated using a Harris profile. The following criteria were used to evaluate the idea directions:

1. Clarity: is it clear that it is a coffin, where the head is located and what interaction with the coffin is intended without any explanation?
2. Uniqueness: is the design unique?
3. Calmness: is the design calm?
4. Natural entering experience: does the entering experience of the coffin into the resomator feel natural or are additional steps needed?
5. Expected personal barriers: is the design of the idea neutral and acceptable for a large group of people or is acceptance of the idea depending a lot on personal style?

Prior to the evaluation, the ideas were discussed with potential users in informal chats. With the insights from these conversations and using the criteria, the ideas were intuitively scored amongst each other (figure 7.4). From the assessment, it can be concluded that the idea of the calm and natural design scored the most positively. This idea was selected for further development.

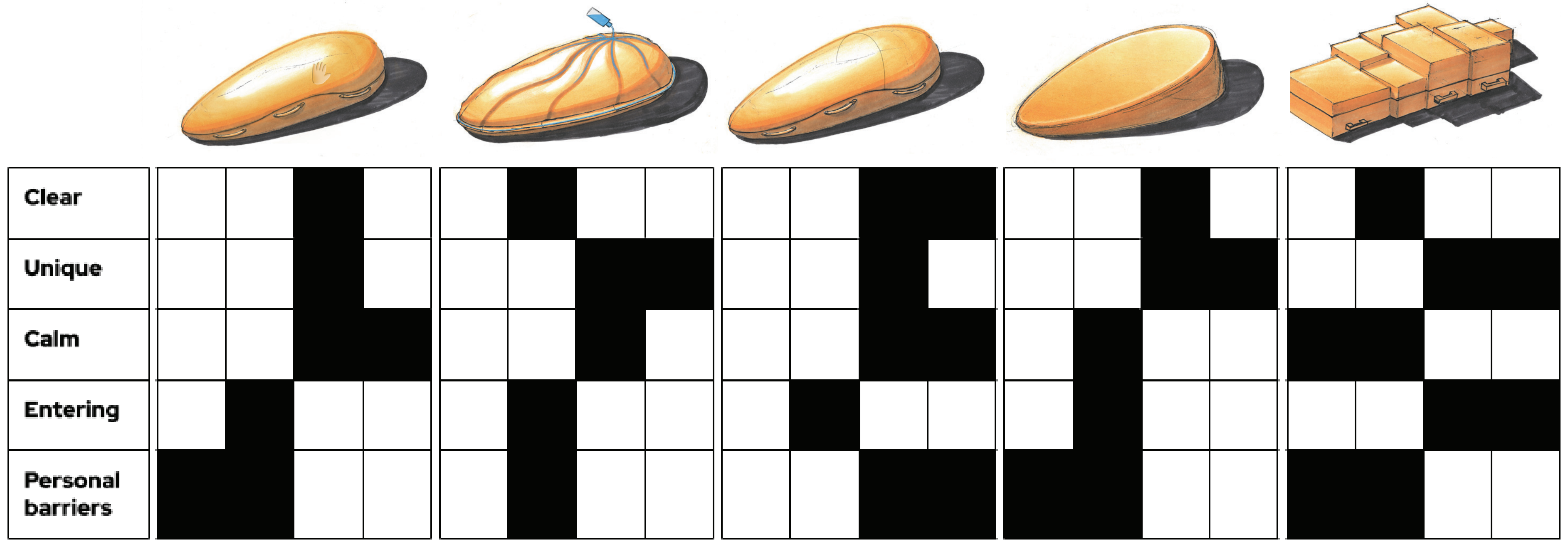


Figure 7.4: Evaluation of idea directions by means of a Harris profile.

08

EXPLORATION OF THE SOAP-PISOX INTERACTION

In this chapter, it is explored how soap and PISOX can be combined.

8.1

Style exploration

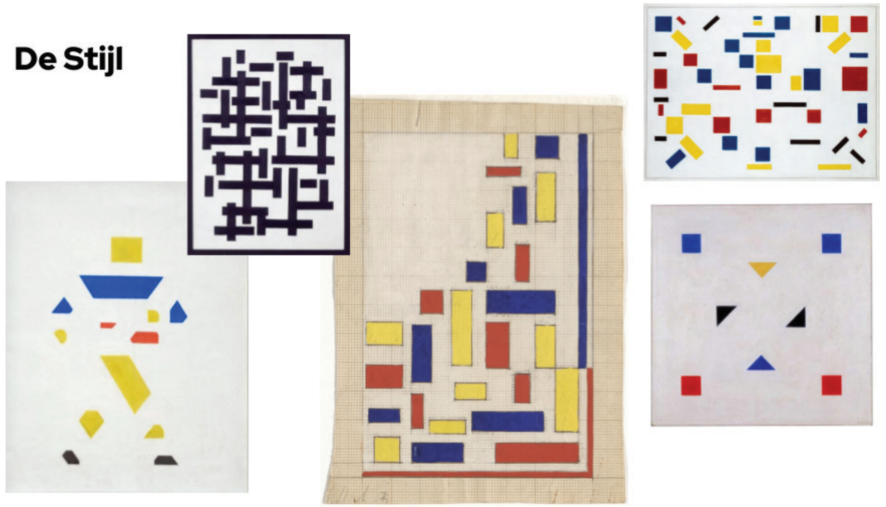


Figure 8.1: Possible style exploration for De Zeepkist.

After selecting an idea for the interaction and how the enclosure could fit the resomator, the possibilities of how soap and PISOX could be combined were further explored. Ideas were explored that would improve the strength of the top by adding ribs or indents in the PISOX, which could be covered up by adding soap as decorative elements.

At first, inspiration was taken from De Stijl (figure 8.1) and a possible idea was explored (figure 8.2). This direction was soon discarded due to its cold/chilly appearance. New inspiration that appears warmer and more gentle was found in stained glass, paintings and mosaic pebbles. This resulted in two possible directions for inspiration of the soap (figure 8.3 and 8.4).

Figure 8.2: Idea for the design.

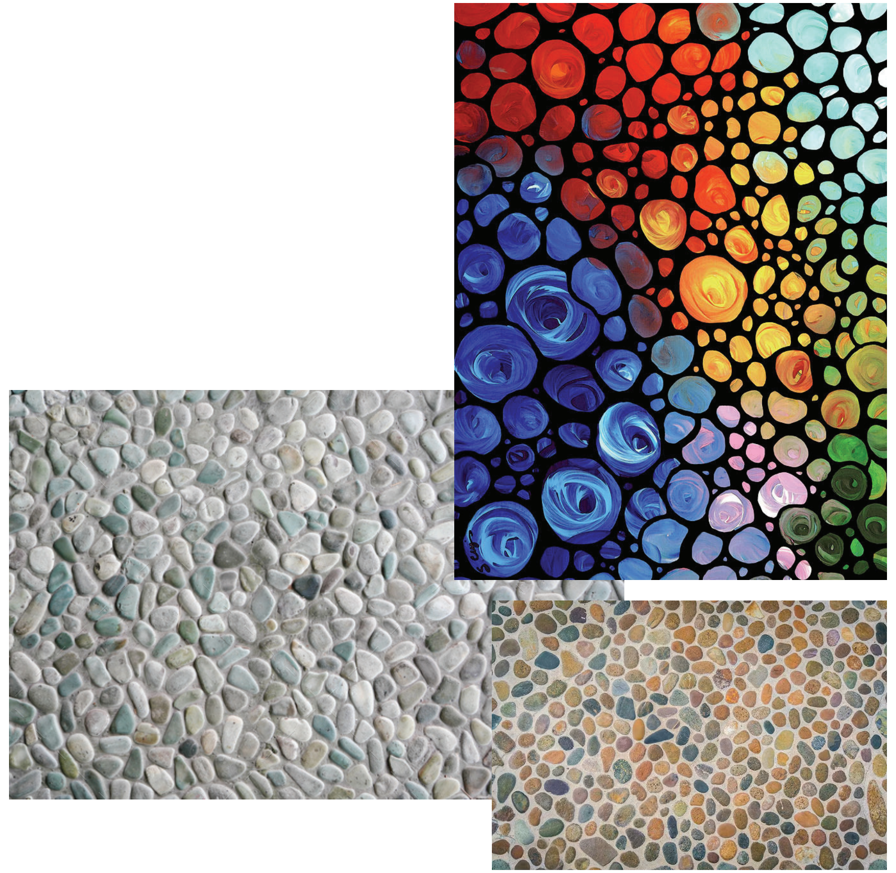


Figure 8.3: Design inspiration 1.

The first direction is inspired by mosaic pebble-floors and a painting by Cummings (2010). The second direction is inspired by stained glass. The second direction would probably be ideal to add ribs and thus optimise the strength of the top part. Also, the larger and lesser parts of soap will likely simplify the process of moulding the soap. The first direction however was selected because of the more gentle and warmer appearance, which

Figure 8.4: Design inspiration 2.

is crucial in order for people to accept resomation as this was mentioned by people in chapter 6 to be of importance for a funeral enclosure. New ideas were explored according to this design direction (figure 8.5). Several indents were added to the top of De Zeepkist to hold space for soap. The indents were added in the shape of pebbles, following a path that would resemble stepping stones as illustrated in figure 8.6.

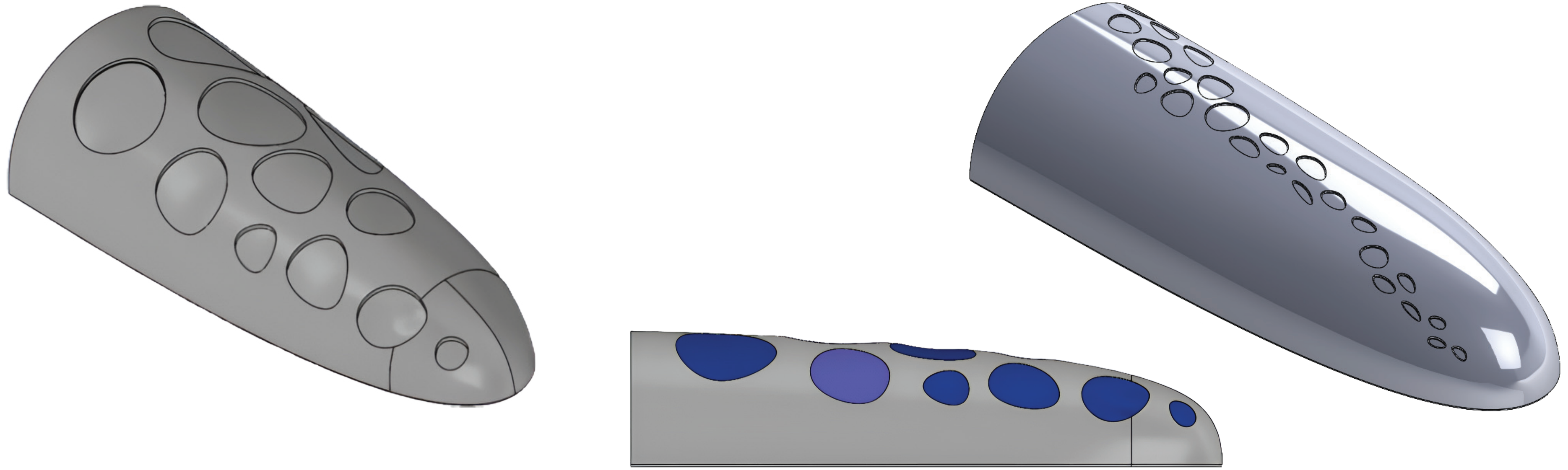


Figure 8.5: Exploration of the top design.

Figure 8.6: Stepping stones inspiration.

8.2

Soap moulding in a PISOX-cavity experiment

Options to combine soap and PISOX practically were explored. Soap is generally a product that stands on its own, since it is mostly a functional product. Sometimes, soap has a more decorative purpose, but even then soap comes as a stand-alone product, so it is uncommon that soap is combined with other materials other than packaging.

A small experiment was done to see if soap would stick sufficiently to its mould when it is produced, to see if the PISOX parts could function both as a mould and final destination for the soap. A PLA mould was 3D-printed, which was then filled with a melt-and-pour (transparent) soap, see figure 8.7 for the results.

The soap appeared to stick well to the PLA mould, so it will likely be possible to mould the soap directly on the PISOX parts. Drawbacks of this is that the soap needs to be poured neatly into a designated hole and will end up in a horizontal surface, and if poured in the open air it might not result in an incredibly flat surface.

Alternatively, the PISOX and soap parts could possibly be produced separately and assembled after. A possible option to fixate the soap parts on the PISOX is by melting a little bit of soap into the cavity where the soap will be fixated, and while still liquid place the pre-produced soap onto this. The soap will then be fixated to the PISOX by using melted soap as glue. This could be an option to simplify and better control the soap-moulding process, however this will increase the production steps.

Figure 8.7: PLA soap experiment.

09

CONCEPT DEVELOPMENT

In this chapter, the design of De Zeepkist is further elaborated. First, the main shape of De Zeepkist is fully defined. Furthermore, attention is given to how the coffin can be carried as well as how it can be closed properly.

9.1

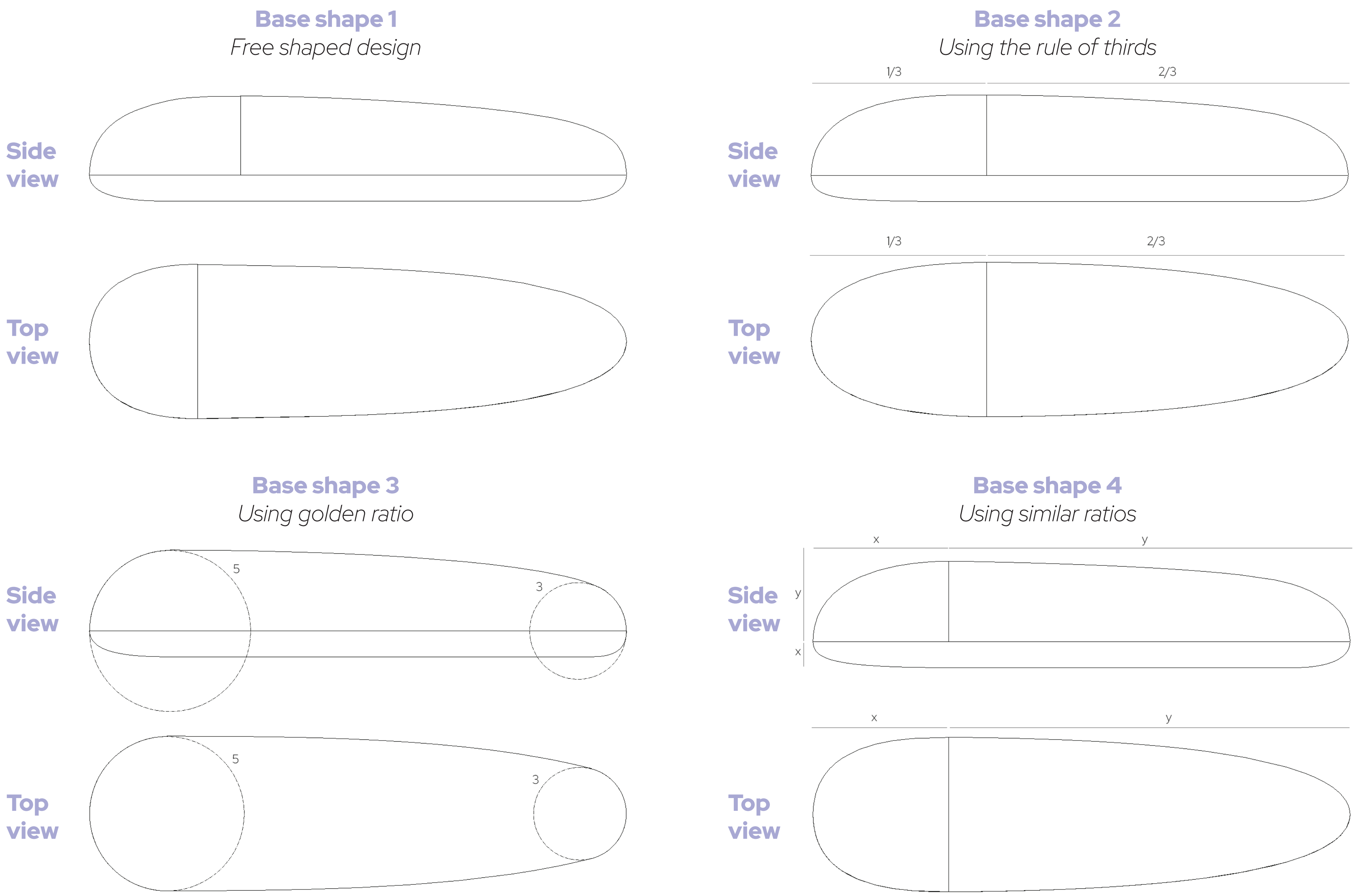
Base shape definition

Figure 9.1: Exploration of several base shapes.

Different base shapes were created and evaluated, see figure 9.1. Different ratios were explored for the base shapes as can be seen in the side and top views in figure 9.2. Rounded shapes were explored because of limitations due to the resomator's dimensions. For example a flat bottom could only be 515 mm wide, which would exclude ca. 23% of the Dutch population as their elbow width would be too wide (DINED, 2020). By rounding the bottom shape, the design allows for a wider width, enabling more people to fit within the resomator.

The base shapes were discussed with potential users and base shape 2 and 4 were judged to be the most aesthetic. Base shape 4 has been selected for De Zeepkist, because this fits better to the human body and leaves more space for the shoulders to fit. A more extensive evaluation was done next to assess whether the deceased would fit within the shape.

Figure 9.2: Ratios explored for the different base shapes. ▸



9.1.1 Fitting the human body

To fully define the main shape, it has been investigated whether the dimensions fit with the dimensions of P95 as described in paragraph 2.4.2. Since we are dealing with an organic shape, the dimensions have been evaluated using a 3D model. From the dataset used in paragraph 2.4.2 there was no 3D representation available. Therefore, a mannequin was created using a dataset of Dutch adults, males and females from 18-66 years, for P95. The dimensions of this mannequin can be seen and compared to the dimensions found earlier in table 9.1. These dimensions vary from the dimensions mentioned in paragraph 2.4.2 and are therefore used as an indication rather than a strict minimum. A standing mannequin was used as shown in figure 9.3.

	P95 60+	P95 18-66
Stature [mm]	1813	1915
Shoulder breadth [mm]	476	508
Breadth over the elbows [mm]	552	Not available
Chest depth [mm]	362	Not available
Head depth [mm]	199	207

Table 9.1: Human dimensions of P95 for 18-66 year olds compared to 60+ year olds according to (DINED, 2020).

The mannequin was positioned in the base shape and gives a rough indication of how the body will fit within the coffin, the results can be seen in figure 9.4 and 9.5. It should be mentioned that the 3D body model is not an exact representation of a deceased body, given that the mannequin is a posture of a standing body. In reality, the body will sag into the enclosure, the legs will be positioned neatly next to each other and the arms will be placed along the body. Because of this, the mannequin was positioned under an angle in figure 9.5 to evaluate how the feet would fit.

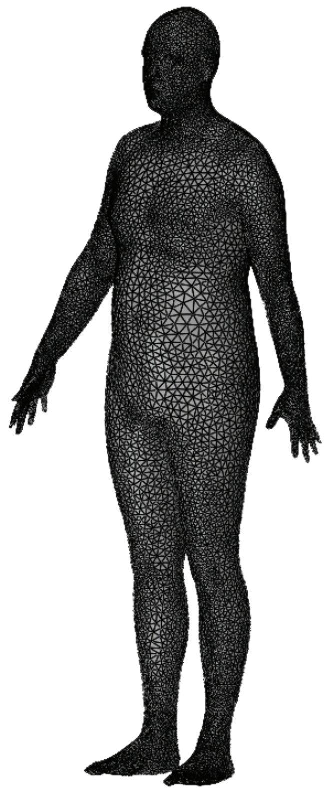


Figure 9.3: Mannequin of P95 18-66 years old, female and male.

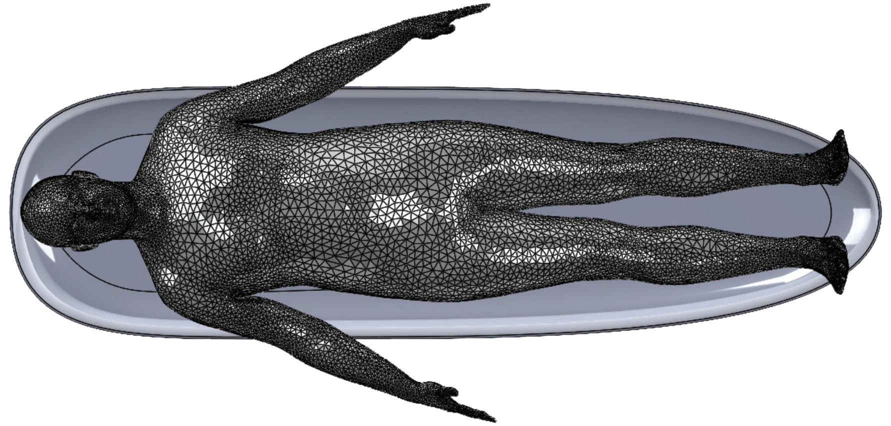


Figure 9.4: Mannequin lying in the coffin seen from a top view.

Figure 9.5: Mannequin lying in the base shape seen from the side, legs are positioned flat.

When positioning the mannequin in the base shape, from figure 9.5 it immediately is clear that the space for feet is too limited and needs to be increased. According to T. Tubée (personal communication, August 16, 2024), the feet of a deceased usually end up with an angle that is around 45 °C to the ground. In image 9.5 there would be insufficient space to stretch out the feet under an angle, but it should be considered that the 60+ people are 10 cm shorter than the mannequin used in the evaluation. Keeping all of this in mind, the rounding at the top of the feet has been increased slightly to fit feet more easily.

Regarding the length, width and height of the design, it seems that the enclosure will fit most people, especially considering that the mannequin used is larger than the people who will likely use the product in the end.

9.2

Carrying

One of the more practical functions of a coffin is that it can be carried for easy transportation. First, a brainstorm was done to different carrying types, the results can be shown in figure 9.6. The ideas of adding handles or a non-resomatable frame have been further explored visually and can be seen in figure 9.7.

A benefit of using PISOX handles is that de Zeepkist can be resomated as a whole. A drawback of this however is that the material needs to be thicker to be strong enough to carry a body, which would increase the resomation time. Also, adding handles to the coffin will increase the assembly steps. Using a non-resomatable frame, the material thickness in the bottom

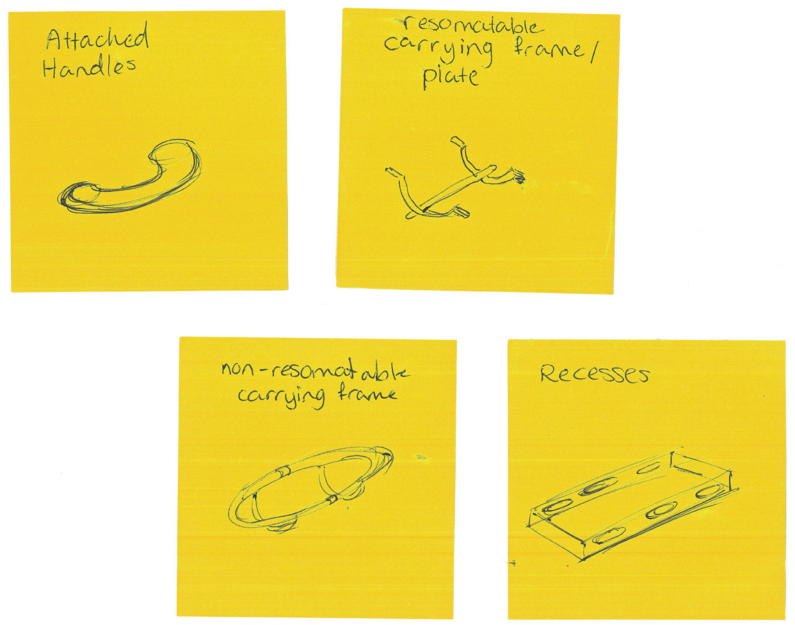


Figure 9.6: Brainstorm results.

can likely be reduced as the biggest load is carried by the frame. The frame could go together with indents in the PISOX bottom as shown in the drawing in figure 9.7 to generate even more strength. This is beneficial from both a financial and sustainability point of view as the time needed for resomation is reduced and the frame is reused. A drawback of using a frame is that logistics around the frame needs to be put into place. The indents could be covered up with a layer of soap so that the deceased can lie comfortably on a flat surface. After evaluation of the different options within the available space of the Resomator, it was found that a frame with perpendicular handles will not fit, so this idea was discarded.

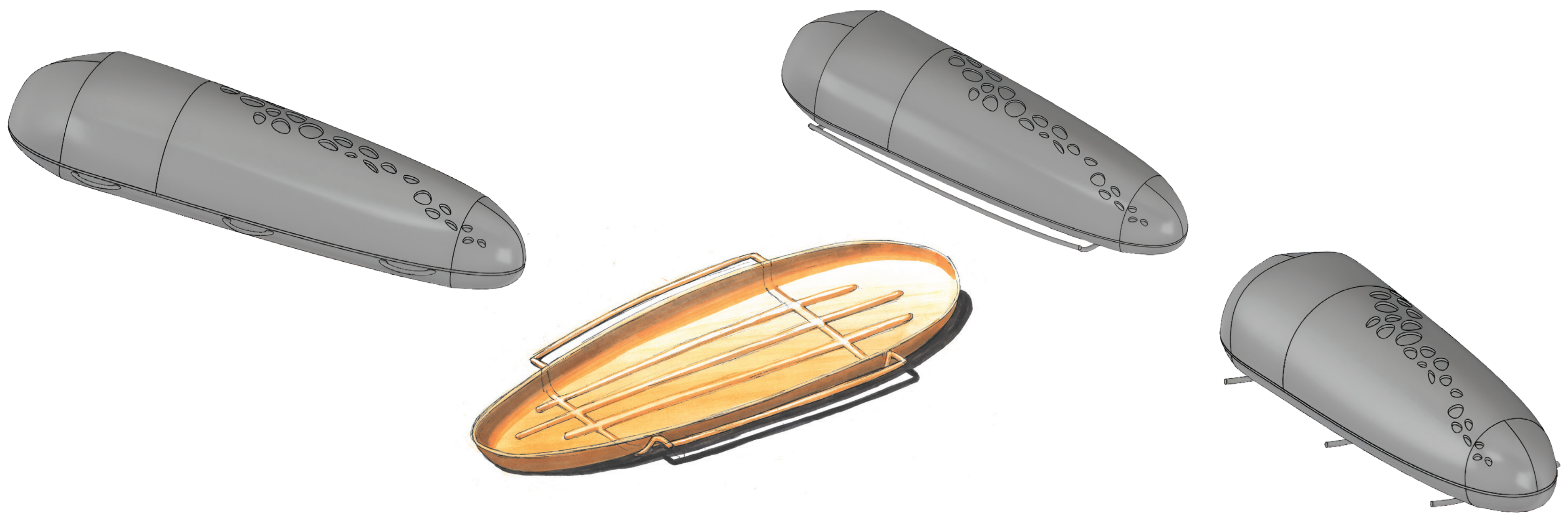


Figure 9.7: Exploration of handles and a non-resomatable frame.

Finally, a choice was made to use a non-resomatable carrying frame since this would require the PISOX parts to be less strong, enabling the material thickness to be reduced. As a benefit of this, the resomation time can be shorter which saves energy and thus money. In the next paragraph the frame is further elaborated.

9.2.1 Elaboration of the carrying frame

There are a couple of things to take into account while designing the frame, such as its shape, strength, the ergonomics of carrying and the materials and production. These aspects will now be defined.

9.2.1.1 Material and strength

Since the frame will go in the resomator, it is important that the material is resistant to the KOH solution. For this reason, stainless steel 316 was selected as this has excellent chemical resistance to KOH (Graco, 2013). This is also a strong material and has a widespread availability of tubes.

9.2.1.2 Defining the shape

The shape of the frame is mostly defined by the availability of tube sizes and the dimensions of the resomator. Furthermore, it should be taken into account that the flow within the resomator cannot be obstructed significantly so that the resomation process will not be hindered. This asks for an open frame which especially does not obstruct the flow around the head.

To ensure comfort for the people that carry de Zeepkist, the dimensions of an average hand was investigated and can be seen in table 9.2. Here, the dimensions were taken of a dataset of Dutch adults from 20-30 years, males and females (DINED, 2020). To ensure that the carrying is comfortable, it is ensured that the handles and the bottom are spaced at least 34 mm + 5 mm as a margin so that for 95% of people it is possible to comfortably place the hand in between the frame and the bottom. Furthermore, the average grip circumference of 129 was strived for, though this is also dependent on availability of tubes. Lastly, the frame needs to offer spaces of at least 97 mm wide to ensure most people have enough space to grip the frame.

	Dimensions in [mm]	Statistics used
Hand width (without thumb	1.62 GPa	P95
Hand thickness	34	P95
Grip circumference	129	P50

Table 9.2: Dimensions of a hand of 20-30 year olds male and female, P50.

Another aspect that limits the dimensions of the frame is that the frame cannot be too thick, because this would lift the bottom and this would leave too little space for the head of the deceased to fit. For this reason, a flat oval tube as shown in figure 9.8 was used to generate more strength while keeping the thickness low (ISI Stainless, 2024). A version with outer dimensions of 23x12 mm was selected.

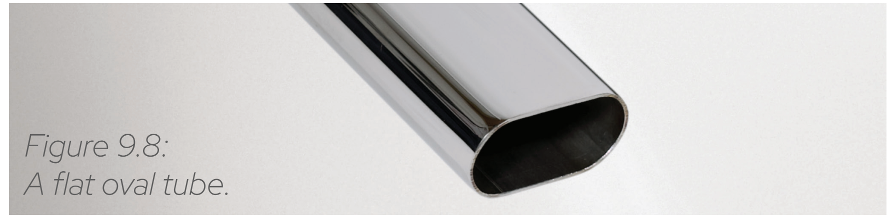


Figure 9.8: A flat oval tube.

A frame was designed originally using circular tubes for the grip, yet this showed to be too wide to fit in the resomator, as shown in figure 9.9. An oval tube was then implemented to be able to have a smaller overall width while keeping a comfortable gripping circumference. An oval tube with dimensions of 24.5x49 mm and a circumference of 119 mm was selected (Oval Tubes (UK) Limited, 2024). The circumference is a little bit on the lower side but still expected to be acceptable. Using this for the side rails the frame still appeared a bit too wide, so it was decided to optimise the width of the bottom with a few mm to fit the frame in the resomator.

In chapter 10, the strength of the frame was analysed and the required thickness of the tubes is defined. The PISOX bottom is not fixed to the frame, it is expected that due to the indents in the PISOX bottom which fall around the frame and the pressure of the deceased on the frame that together it will be stable.

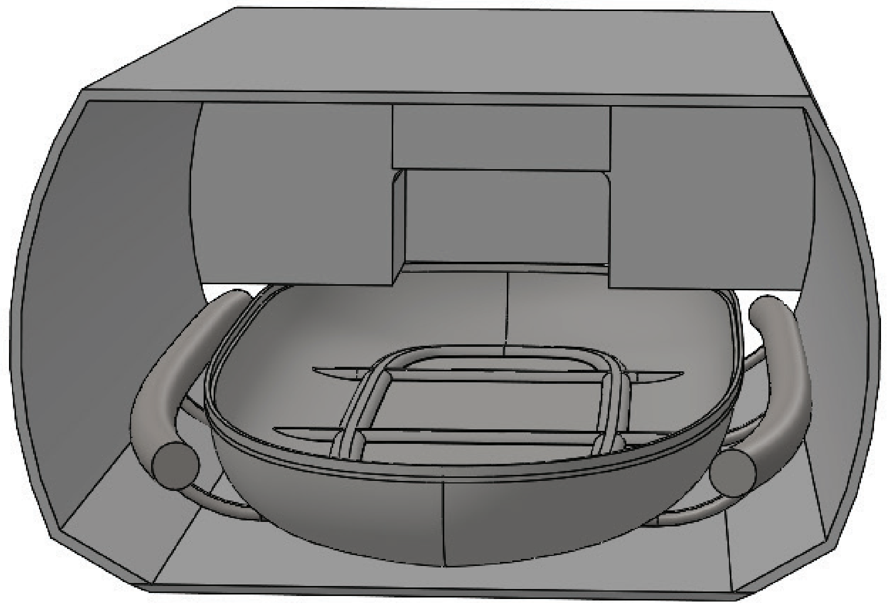


Figure 9.9: The not-fitting frame.

9.3

Closing

Another aspect of a coffin is that it can be closed. This has both a functional aspect as well as an emotional aspect. Practically, closing the coffin prevents smells from spreading or hides the body when it is not in a presentable state anymore. Emotionally, closing the coffin is a common ritual where the bereaved take a first step in saying goodbye to their loved one. Once the coffin is closed it is usually not opened again. Most of all, it does not have to be fixated tightly, it mostly has to be closed symbolically (T. Tubéé, personal communication, August 16, 2024). A brainstorm was done to explore possibilities for closing the enclosure, see figure 9.10. Secondly, it was investigated how the different parts could fit together, shown in figure 9.11.

Figure 9.10: Possible ways to close the enclosure.

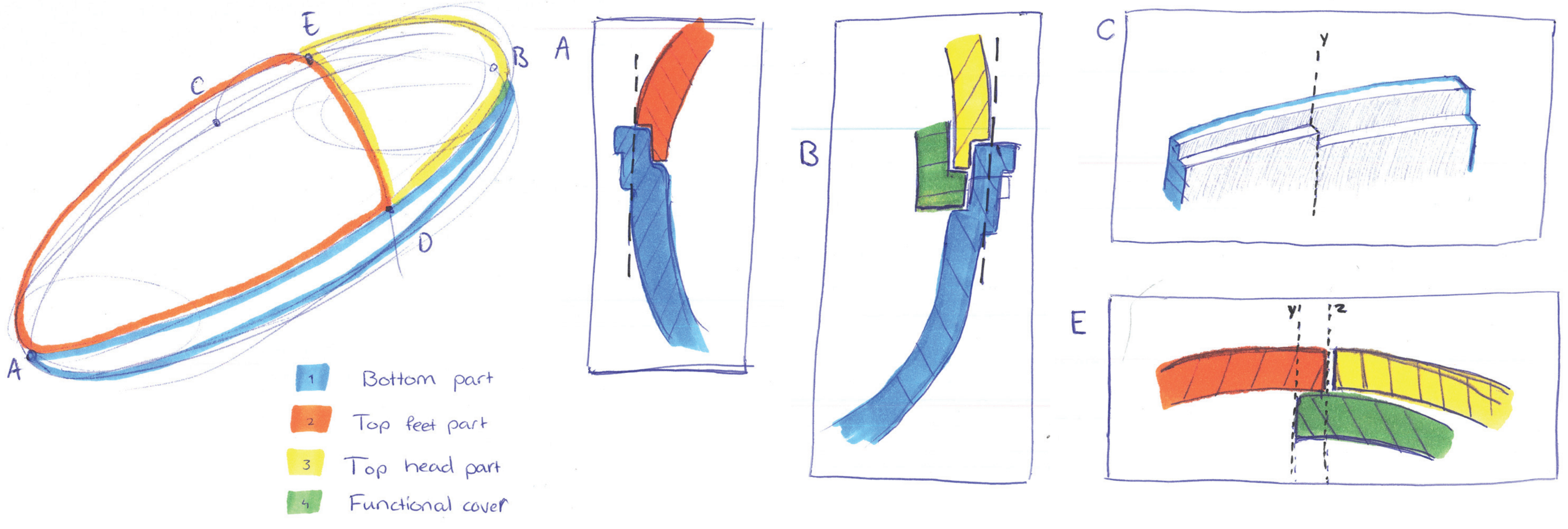


Figure 9.11: Exploration of how the different parts can fit together.

A choice was made to use push rivets made of PISOX. This would keep the symbolic moment of closing the coffin and requires the least amount of thickness or space needed to enable this type of connection, which is beneficial given the limited space available. This method also does not require complicated production steps for the PISOX parts that are to be connected. PISOX will be used for the rivets to fit more naturally in the design.

The parts are designed to fit together as in figure 9.11. The parts can be made to fit seamlessly by using CNC milling. Later this was discarded and because of the limited thickness of the PISOX parts. The bottom edge was then broadened so that the top parts could fit in the bottom. It is essential that the top fits in the bottom rather than over, as this would make the separate top parts fall off the bottom to the sides.

9.4

CAD model

A CAD model was created using SolidWorks to visualise and integrate the design aspects discussed before. Images of the model can be seen in figure 9.12-9.15. In the next chapter, this CAD model was used to evaluate the strength of De Zeepkist and to define its thickness.

Figure 9.12-9.14 from top to down: Pre-resomation variant of De Zeepkist; Bottom indents; Bottom with soap.

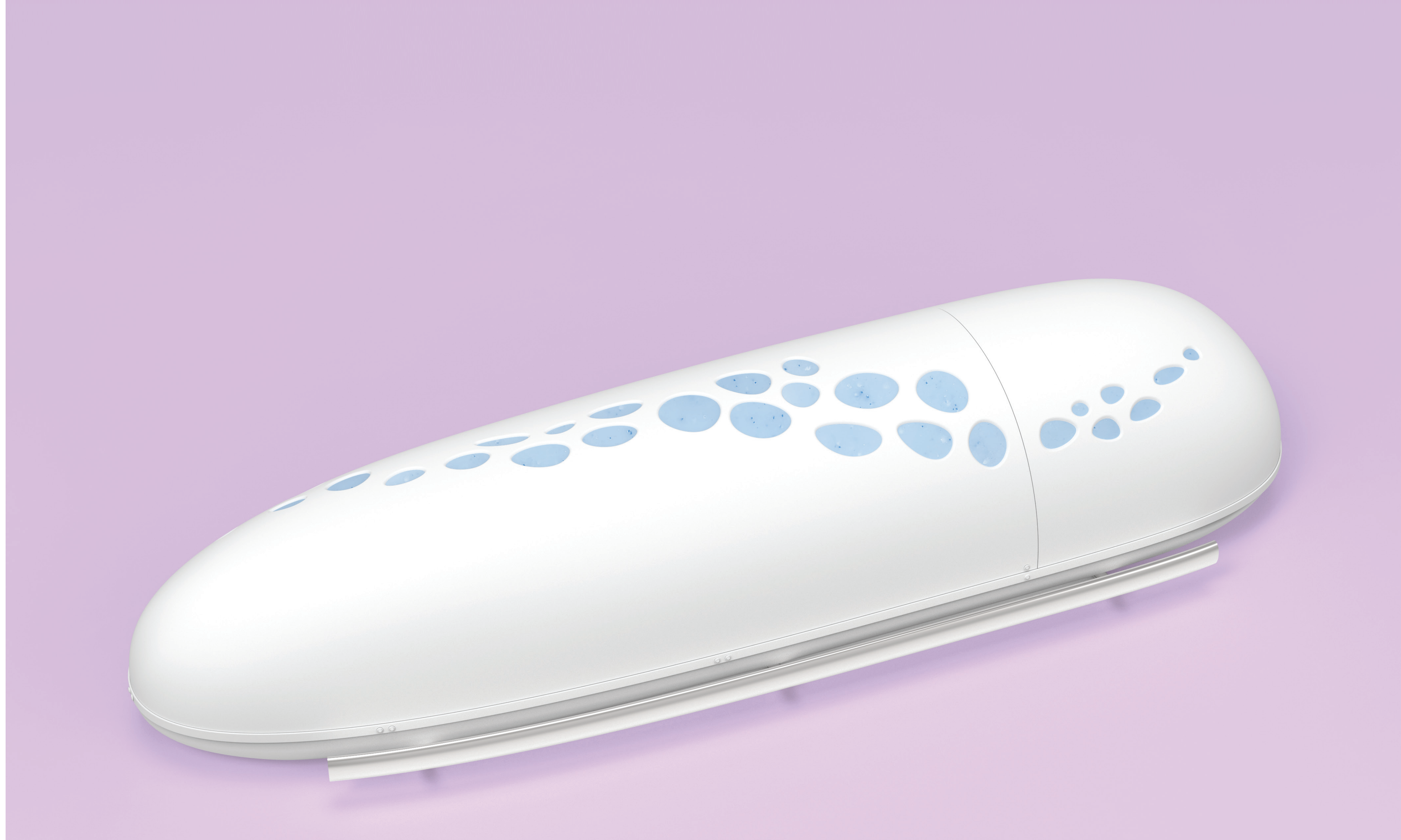


Figure 9.15: Integrated design of De Zeepkist.

10

STRENGTH ANALYSIS

To evaluate the strength of De Zeepkist, a combination of tensile tests and strength simulations are performed. First, tensile tests are done to obtain the mechanical properties of PETG after processing. This was followed by simulations using SolidWorks to evaluate the strength of the design and to define the necessary thickness of the parts.

10.1

Tensile tests PETG

Tensile tests were done to examine the mechanical properties of thermoformed PETG samples.

10.1.1 Setup

Tensile tests were performed using a Zwick Z010 machine with a 10kN load cell according to ASTM norm D882 – 18 (ASTM Compass, 2018). PETG samples were obtained from a small-scale thermoformed PETG product, see figure 10.1. The PETG material was ordered from Vink Kunststoffen (Vink Kunststoffen, n.d.). Four samples were cut in strips of 15x182 mm along the length of the product. Due to the thermoforming process, the thickness varied over the length and width of the strip. The cutting was done by hand using a box cutted, a sliding caliper to define the dimensions and a ruler to guide a straight cut. A weight was used to flatten the curved PETG part as much as possible during the cutting. After the cutting, the samples were measured using a sliding caliper. This was done at three points along each sample's length to compensate for the varying thickness and potential cutting inaccuracies. An initial grip separation of 125 mm was used with an according test speed of 12.5 mm/min. The output of the tests include a graph of the standard force that is applied to the standard travel of the grips. The samples were clamped using grips, and the strips were wrapped in small pieces of paper to protect the samples from damage due to the clamping. The testing was installed to stop once an 80% drop in force applied was measured. The tests were performed at room temperature.

Figure 10.1: Thermoformed PETG product from which the material samples were cut.

10.1.2 Results

Of the four test samples, the data of the second sample was lost, leaving three samples as results. The average dimensions of the samples and the original gripping distance can be seen in table 10.1.

Stress-strain curves were calculated from the standard force and the standard travel, using the formulas $\sigma = F / A$ and $\varepsilon = \Delta x/x$. The results of the stress-strain calculations can be seen in figure 10.2, including the average of the three tests.

The average ultimate tensile strength was found to be 46.4 MPa. The average elongation at break was found to be around 4%, which includes a compensation for the toe area.

	Sample 1	Sample 3	Sample 4
Length [mm]	181	182	181
Average thickness [mm]	0.797	0.686	0.750
Average width [mm]	14.163	14.483	14.137
Cross section [mm²]	11.28	9.90	10.62
Original gripping distance [mm]	124.042	122.702	125.795

Table 10.1: Dimensions of the material samples.

To define the average Young's modulus, the slopes of the stress-strain curves for the different samples in between 0.005 and 0.01 strain were calculated. The result is an average Young's modulus of 1.62 GPa. This was used to define the yield strength using a 0.2% offset as can be seen in figure 10.3. The lines intersect at an average yield strength of 37.4 MPa.

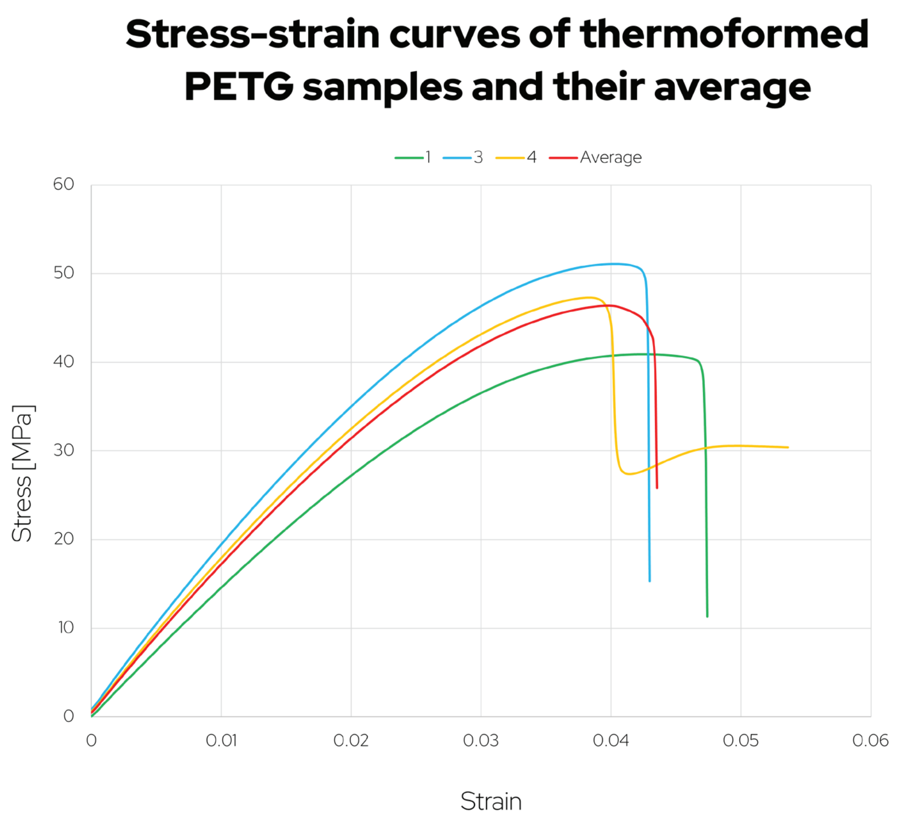


Figure 10.2: Stress-strain curves of the PETG samples and the average of the three.

The found material properties are summarised in table 10.2 and compared to the literature values from the supplier's data sheet (Exolon Group, 2022).

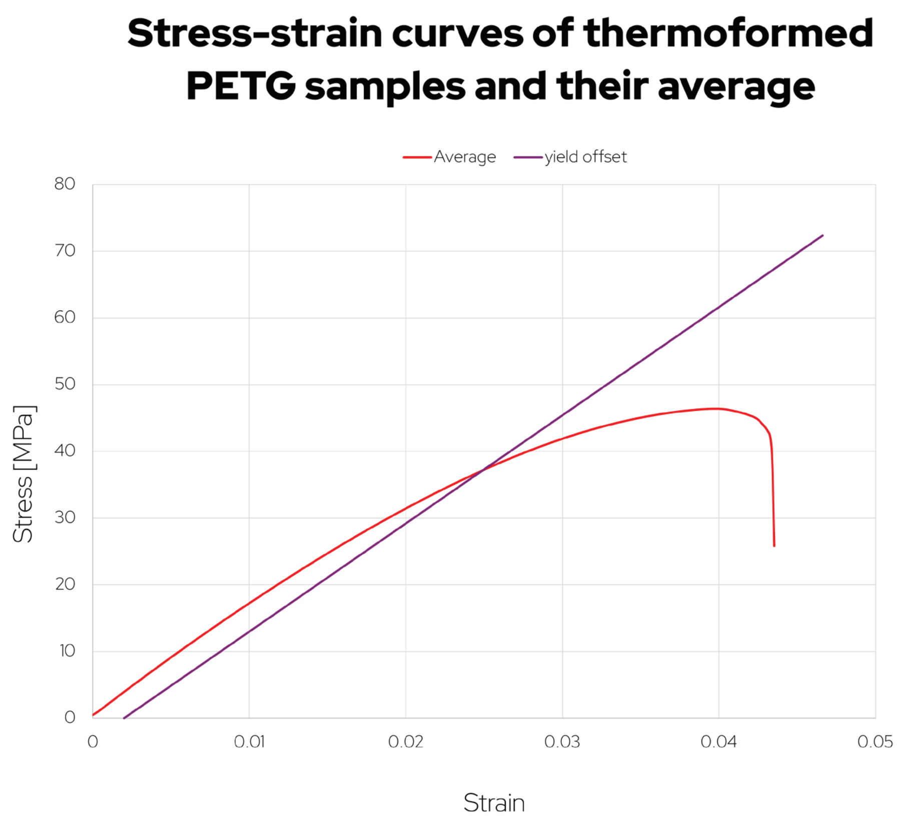


Figure 10.3: Defining the yield strength of the average of the PETG samples using a 0.2% offset.

	Tensile test results mean ± sd	Literature
Young's modulus [GPa]	1.62 ± 0.19	2.02
Yield strength [MPa]	37.4 ± 5.0	45
Ultimate tensile strength [MPa]	46.4 ± 5.1	45
Elongation at break	4 ± 0.215 %	35%

Table 10.2: Material properties found.

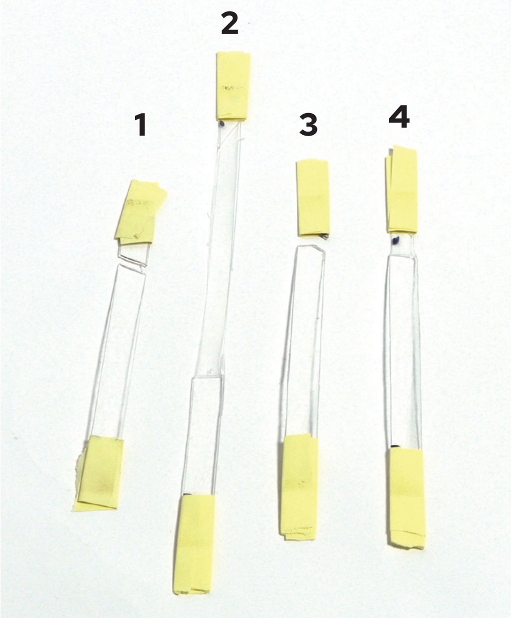


Figure 10.4: The material samples after failure.

A noticeable observation is that the samples seem to have failed for a variety of reasons as can be seen in figure 10.4. For two of the four samples, the strips seemed to have failed without a full break, after which the remaining material was stretched incredibly. This can be seen by sample 4 and also occurred by sample 2 of which the data was lost. Sample 1 seems to be broken by shear, while sample 3 is broken at the grip.

10.1.3 Discussion

As shown in graph 10.2, stress-strain curves of the different samples show a quite similar curve. The Young's modulus and yield strength are approximately 20-25% lower than the literature values and the ultimate tensile strength was found to be similar to the literature value. What is most surprising is the low elongation at break for the PETG samples compared to the literature. Also, it is remarkable that the material samples seem to have failed for different reasons.

A possible explanation for the difference between the found values and the literature values could be the inconsistent thickness of the PETG samples and the curves within the samples. Since the samples were cut out of a curved shape, the samples are not perfectly rectangular as they are supposed to be. This could have influenced the way in which the samples have failed. Additionally, small burrs resulted from the cutting by hand which could be another possible factor to add to any deviations from the literature.

In a research done by Staderini et al. (2024) to the effect of thermoforming on PETG's properties, no significant difference between the thermoformed samples and the control group samples was found. This would imply that either the PETG used from the start was of low quality considering mechanical properties, or the results are influenced by the way of cutting by hand.

10.1.4 Conclusion

Tensile testing of PETG samples found a Young's modulus of 1.62 GPa, a yield strength of 37.4 MPa, an ultimate tensile strength of 46.4 MPa and an elongation at break of 4%.

10.2

Strength analysis using FEA

To evaluate the strength of the design, three scenarios are analysed using a finite element analysis. First of all, the scenario of carrying needs to be considered for the PISOX bottom part. The coffin needs to be able to carry at least 91 kg of a body. Secondly, the scenario of leaning on the coffin by the bereaved is analysed to make sure the design doesn't fail as a result of the bereaved leaning. Finally, the strength of the frame is analysed to make sure it is strong enough and to define the thickness needed for the tubes.

The requirements regarding the strength and the design are as follows:

1. De Zeepkist can carry at least 91 kg of bodily weight using an additional factor of safety of 1.25, on top of its own weight.
2. De Zeepkist can withstand the bereaved leaning on the coffin with half of their weight (45 kg) using an additional safety factor of 1.25.
3. Deflections are elastic and at maximum 5 mm.
4. Stresses due to carrying/transportation are only applied at the PISOX and steel parts and do not exceed the material's yield strength.
5. Strains experienced in the materials do not exceed their elongation at break.

10.2.1 Setup

A static study was done in SolidWorks to estimate the behavior of the materials under both scenarios. For analyzing the PISOX parts, the obtained mechanical properties of thermoformed PETG were used. The data about the density and poisson's ratio for PETG were taken from literature (Granta EduPack 2022 R1, 2022b). A value of 0.411 was found in literature, here the worst case value was taken from a range. For analyzing the frame, stainless steel 1.4401 was selected from SolidWorks' database, only the elongation at break was found in Granta (Granta EduPack 2022 R1, 2022d). The material properties that were used can be seen in table 10.3. Here, the values marked with a * are taken from Granta.

	PETG test results	Stainless steel
Young's modulus [GPa]	1.62 GPa	200 GPa
Yield strength [MPa]	37.4 MPa	400 MPa
Ultimate tensile strength [MPa]	46.4 MPa	600 MPa
Elongation at break	4%	30%*
Density [kg/m³]	1.27*	8.0
Poisson's ratio	0.411*	0.28

Table 10.3: Material properties used in the strength analysis.

10.2.1.1 Scenario 1 - Bottom strength

First, the strength of the PISOX bottom is analysed for the scenario of a 91 kg body being carried using the frame. In this analysis the model is simplified by only analyzing the PISOX bottom. In reality the body will lay on a layer of soap that will transfer the weight to the PISOX bottom. In this analysis, it is assumed that the pressure of the body is placed on the flat parts of the bottom as shown in figure 10.5. This is a surface of 0.32 m2. The pressure on this surface is calculated by using the formula P = F/A. An equal force distribution of the body's weight is assumed. Including a safety factor of 1.25, the pressure on the PISOX bottoms is P = 1.25 * 91 * 9.8 / 0.32 ≈ 3500 N/m2. Furthermore, it is assumed that the bottom is fixed using a fixed geometry on the flat area of the indent in the bottom (figure 10.6), as this is where the frame supports the PISOX bottom. A

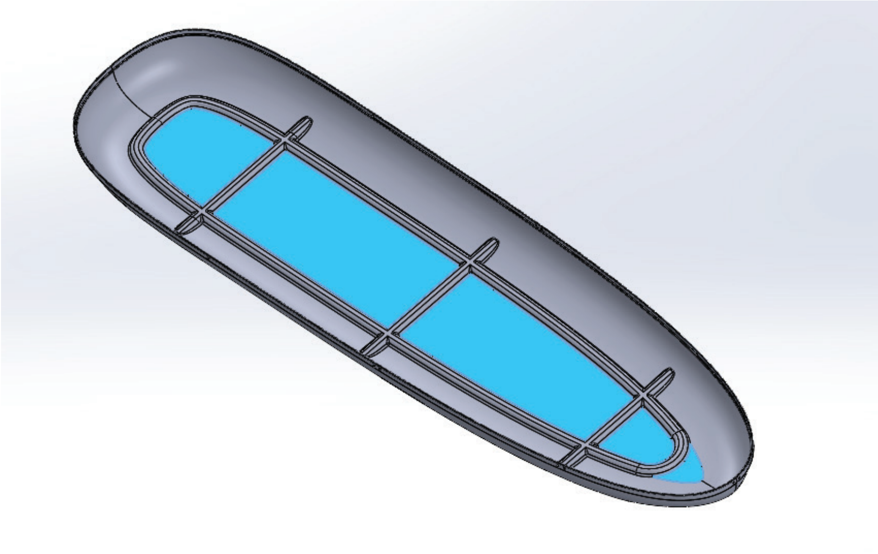


Figure 10.5: Location of the part where the pressure is applied.

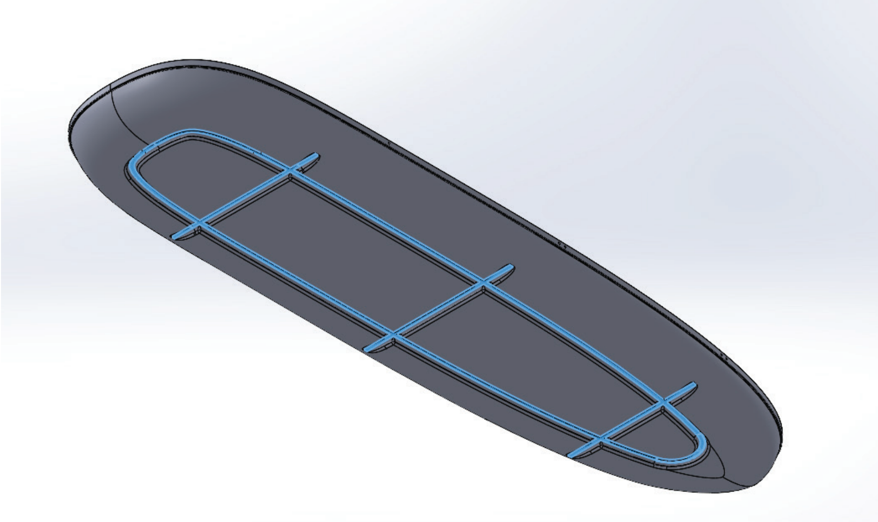


Figure 10.6: Location of the part where the pressure is applied.

mesh was created without meshing control. An initial thickness of 5 mm was used. Based on insights from the results, varying thicknesses are analysed.

10.2.1.2 Scenario 2 - Cover strength

Secondly, the strength of the PISOX top cover was analysed to check whether the top can withstand the bereaved leaning on the coffin. The top cover that covers the feet was used for this analysis. It is assumed that in a rough scenario a bereaved would lean on de Zeepkist with half of their bodily's weight (45 kg) and a safety factor of 1.25 is added. This is applied as a point load of 560N as shown in figure 10.7. Two types of fixations are added to the model (figure 10.8). First, the part is fixated at the rivet holes. Secondly, a reference geometry fixation is added at the location where the part covers the functional cover, because the functional cover prevents the part from moving down or to the sides. A mesh was created without meshing control. A thickness of 3.5 mm was analysed.

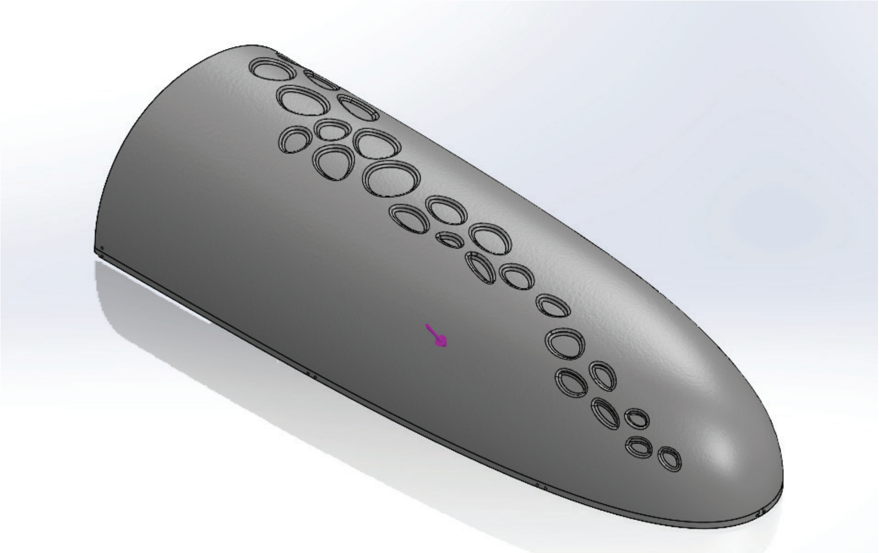


Figure 10.7: Applied load.

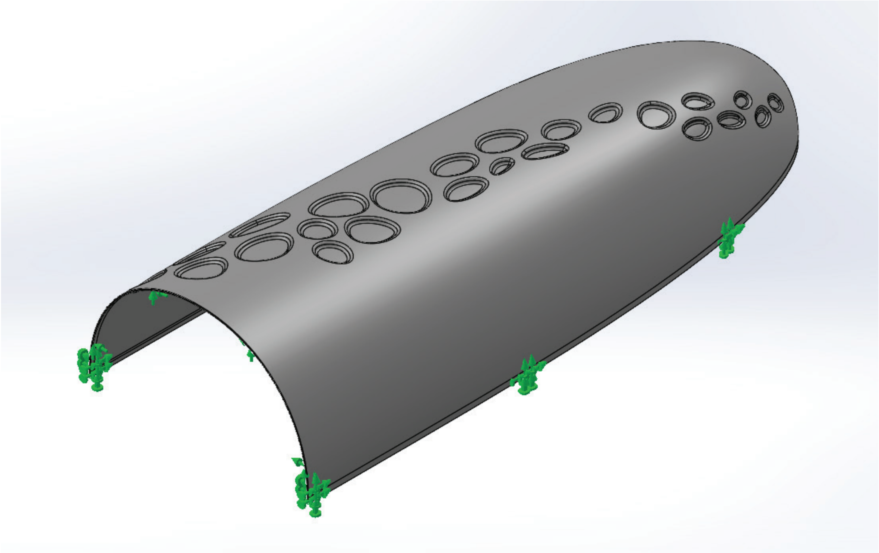


Figure 10.8: Location where the part is fixated.

10.2.1.3 Scenario 3 - Frame strength

Lastly, the strength of the carrying frame was analysed to define the thickness needed for the tubes. For this analysis it is assumed that the pressure of the body's weight as well as the coffin's own weight is applied on the areas highlighted in figure 10.9. This is a rather small area of only 52815 mm2 = 0,053 m2. A mass of 25 kg for the PISOX and soap parts was used. Calculating the pressure on this part gives P = 1.25 * (91+25) * 9.8 / 0.0528152 ≈ 24 200 N/m2. The part is fixed at the hand rails as shown in figure 10.10. A course mesh was created. First, a constant thickness of 1.5 mm was used. Based on insights from the results and availability, different thicknesses were analysed.

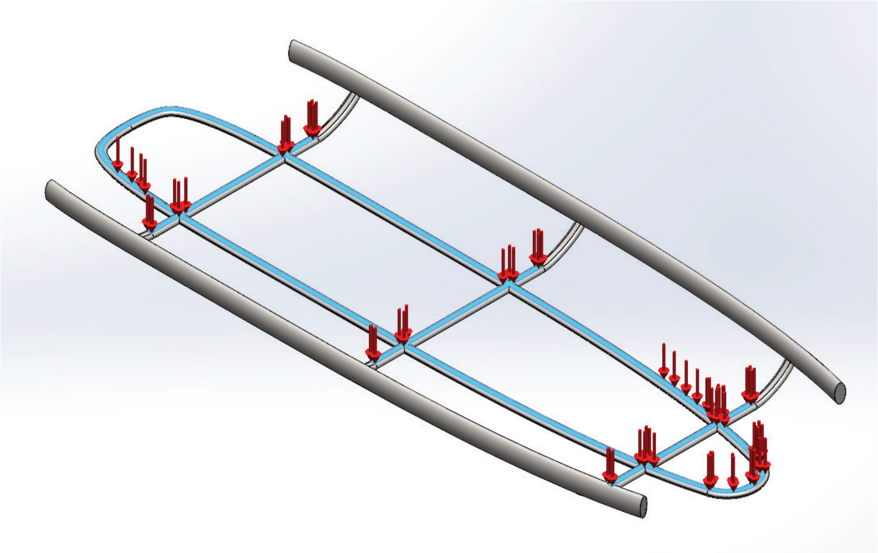


Figure 10.9: Applied load.

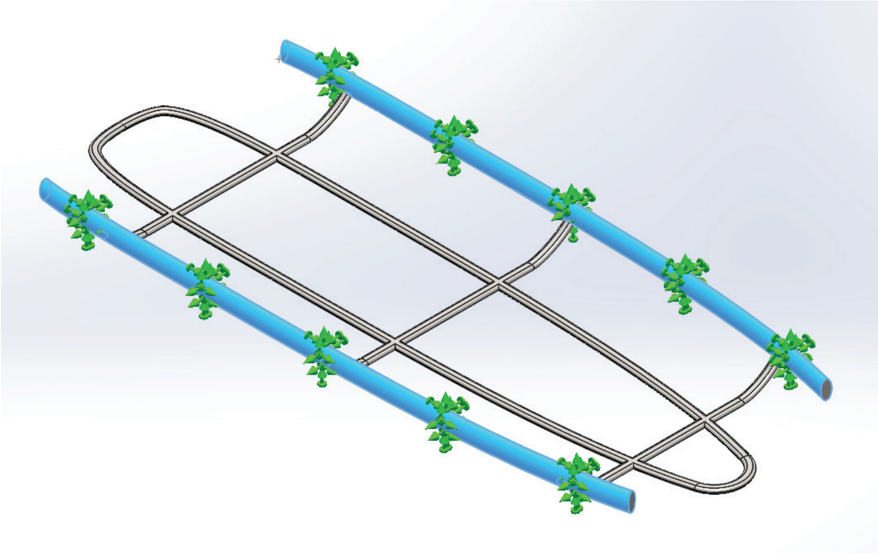


Figure 10.10: Location where the part is fixated.

10.2.2 Results

The results of the strength analysis are discussed per scenario.

10.2.2.1 Scenario 1

First a 5 mm thick design was simulated, followed by a 3 mm thick design and a 3.5 mm thick design. The results can be seen in figure 10.11.

In figure 10.11 it can be seen that the stresses and strains experienced in the material stay below the yield strength of 37.4 MPa and the elongation at break of 4% for all thickness variants. Furthermore it can be seen that the deflections stay below 5 mm for the 3.5 mm and 5 mm bottom, but fails to meet the requirement for the 3 mm thick variant.

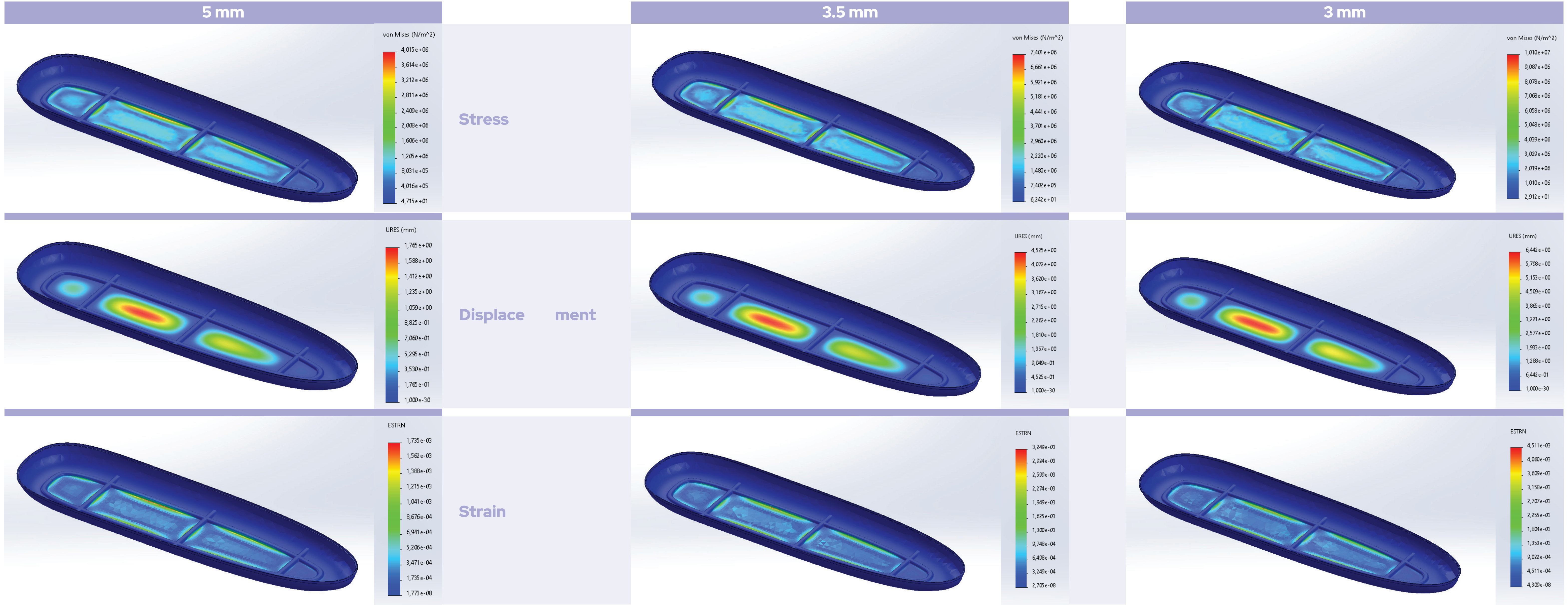


Figure 10.11: FEA results.

10.2.2.2 Scenario 2

In figure 10.12-10.14, the results of the FEA analysis are shown for a thickness of 3.5 mm.

In figure 10.12 it can be seen that the maximum stress within the material is 16.8 MPa which is below the yield strength of 37.4 MPa. Figure 10.14 shows that the maximum strain within the material is found to be 0.7% which is below the elongation at break of 4%. The maximum deflection is found to be 3.1 mm, which is less than the requirement of maximum 5 mm deflection.

Stress

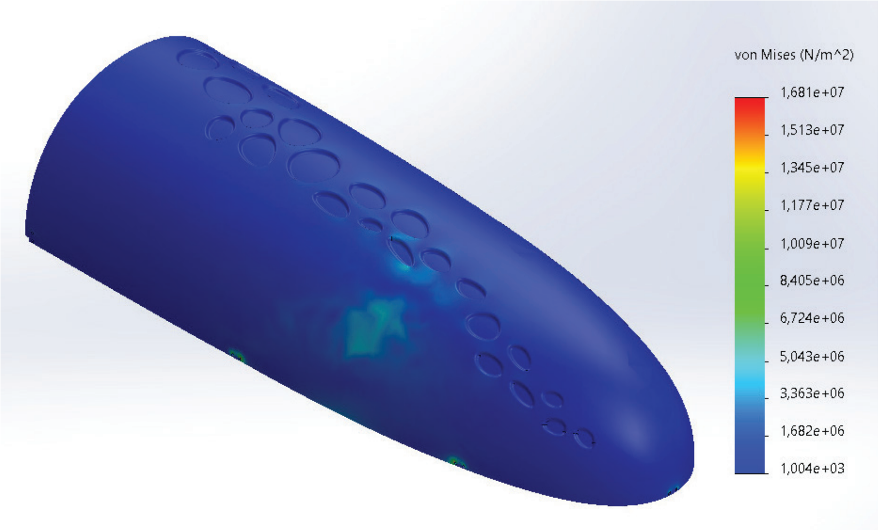


Figure 10.12: FEA result stress.

Displacement

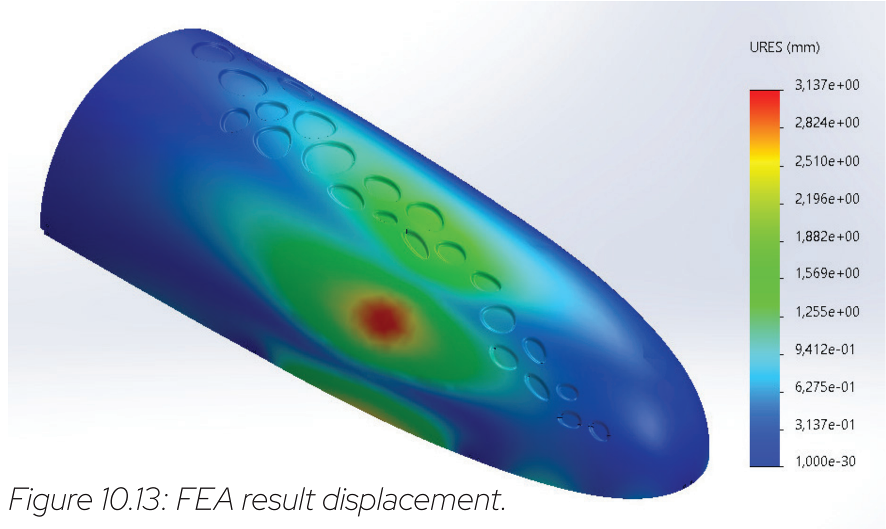


Figure 10.13: FEA result displacement.

Strain

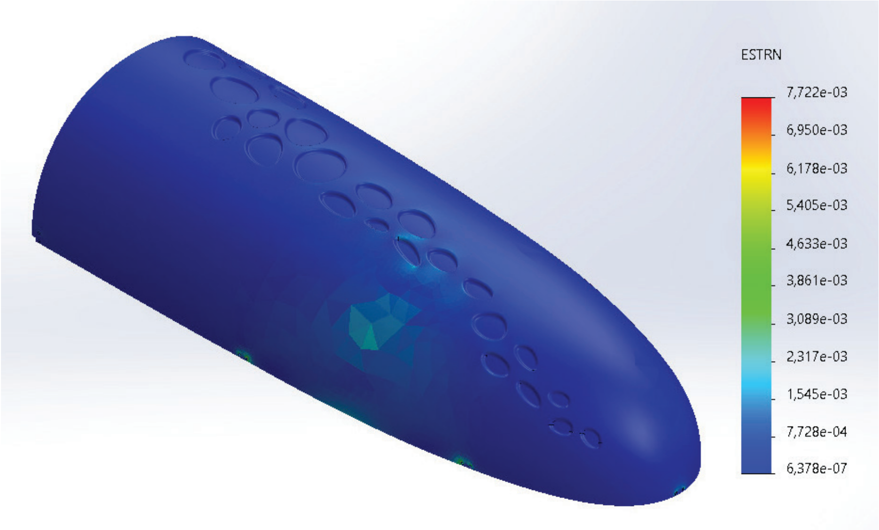


Figure 10.14: FEA result strain.

10.2.2.3 Scenario 3

First, an FEA was done with a constant 1.5 mm thickness. Based on these results, a new variant was created with a varying thickness. Since the oval tubes which are held with the hand are only available in 1.5 mm or thicker, this was kept at a thickness of 1.5 mm. The bottom, flat oval tubes could go down to 1 mm thickness, which was used in this analysis. The results of the analysis can be seen 10.15.

In figure 10.15 it can be seen that the stresses and strains experienced in the material stay below the yield strength of 400 MPa and the elongation at break of 30%. Additionally, it can be seen that the deflections stay below 5 mm for the both thickness variants.

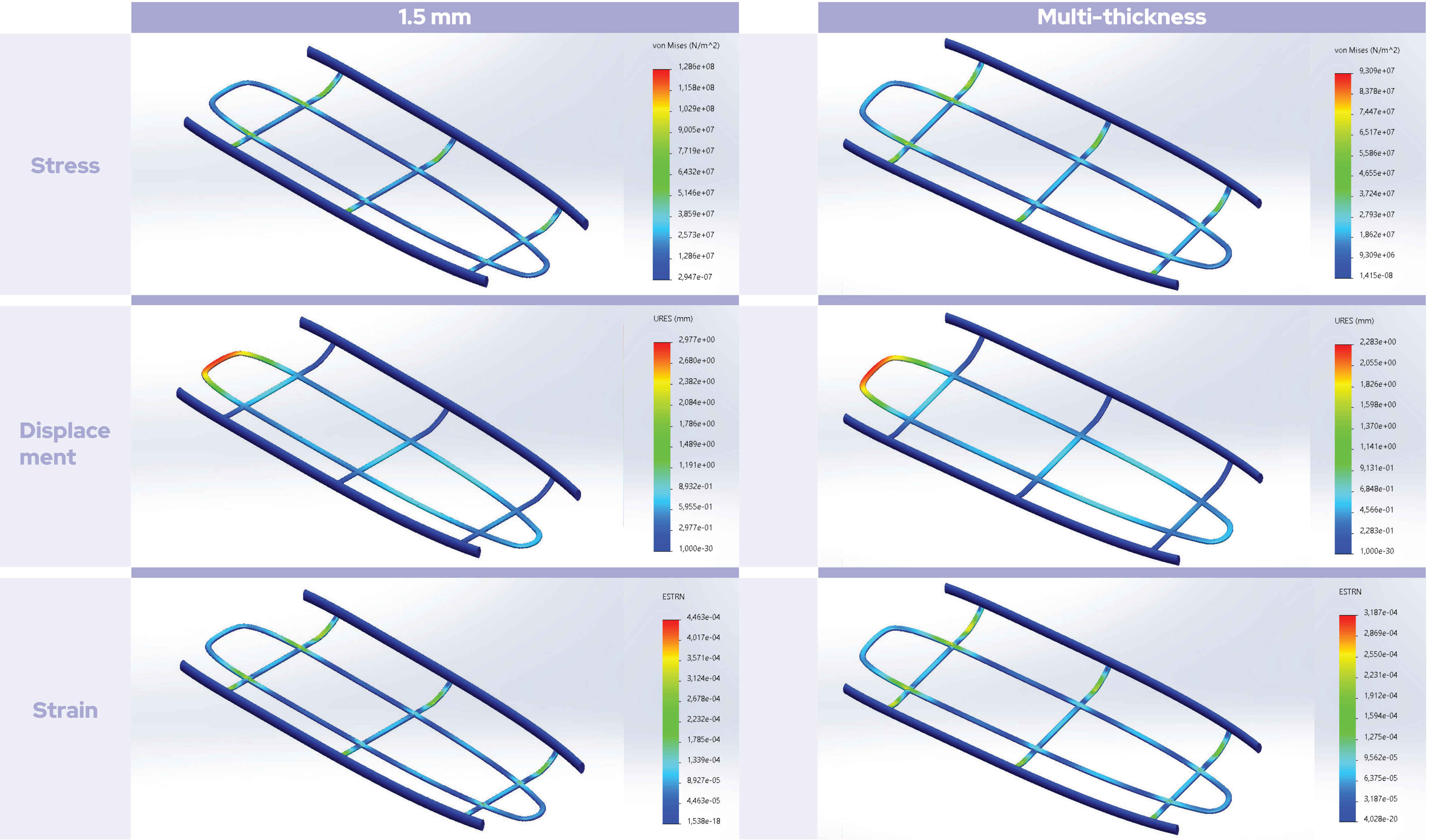


Figure 10.15: FEA results.

10.2.3 Discussion

The results show that for the PISOX parts the main challenge for the material to meet the requirement can be found in too large deflections rather than failure. This can be explained by the large size of the PISOX parts (up to two meters) and the small accepted deflection (5 mm).

When looking at the third scenario about the frame, the stresses, strains and displacements stay within the required limits for the two variants. The multi-thickness variant is therefore used in the design of De Zeepkist to reduce the material used. The analysis shows that an even lower thickness might also be suitable for De Zeepkist, but as this was not found to be available online this was not investigated further.

Though the analysis gives insight into the strength of the design and whether a small thickness (>5 mm) for the PISOX parts is realistic, more research is needed to ensure that the design will not fail in reality for a couple of reasons.

First of all, in these analyses the parts were analysed individually and fixed constraints were used, which are not a perfect representation of reality. For example during the analysis of the bottom (scenario 1), the bottom is only lying on top of the frame and it is not fixed in any way. An attempt was done to improve the simulation by creating a static analysis in an assembly with both the bottom and the frame, but this would increase the demands regarding computing power in such a way that it would be impossible to finish this analysis within the current time constraints.

Furthermore, the analysis will probably show some deviation of reality because of the selection of planes on which the pressure is applied. For the first scenario, in reality the pressure will also be applied a bit on the sides and on the ribs of the PISOX. Also, in the analysis now an even distribution of the pressure was used which will likely not be the case in reality. For the third scenario, the full handrail was fixed while in reality this will only be held at a few points along the rail. For the second scenario, most of all more scenarios of leaning using different angles and locations could be tested.

In addition, it was found that a small change such as 0.003 in the poisson's ratio used would give significantly different results, with changes of multiple millimeters in deflection given nothing else was changed. In this analysis, a literature value was used by selecting the least ideal value from a given range to guarantee that it is most likely possible. It is highly recommended to check the actual value when redoing the analysis, as a small change in the poisson's ratio can create big differences in the results.

Another aspect that is important but has not been investigated here is the effect of temperature on the performance of De Zeepkist. The effect of different temperatures on the materials and their strength should be investigated.

Lastly, these analyses assume a constant material thickness of the PISOX parts, which is not realistic when using thermoforming.

10.2.4 Conclusion

Based on the results, it can be concluded that a small thickness of >5 mm for the PISOX parts is realistic. A thickness of 3.5 mm is selected for the PISOX parts as this meets the set requirements. In addition, the analysis shows that a steel frame with a multi-thickness of 1.5 mm for the hand rails and 1 mm for the bottom tubes meets the strength criteria. These thicknesses are used in further analyses in this report.

It should be said however that the results give only a general insight into the behavior of the design and more detailed analysis is necessary to guarantee that the design will indeed not fail.

11

PROTOTYPING

A scale model prototype was made to evaluate the design and its manufacturability and to gain new insights in how the design could be improved. The prototype has been created mainly by means of thermoforming sheets of plastic and bending a frame from wire. An experiment has been done to mould soap separately. The process of creating the prototype will be discussed in detail next.

11.1

Thermoforming

Figure 11.1 : The moulds used for thermoforming.

A thermoformed model of De Zeepkist was created using the thermoforming facilities at the IDE faculty. The maximum sheets of plastic that can be thermoformed are 800x800 mm. A prototype was made on a scale of 1:4.

Before thermoforming, moulds needed to be created. This was done by CNC cutting polystyrene foam. For this, the maximum dimensions were 400x400x53 mm. The depth of the CNC cutting is limited by the length of the milling tool. Because of these limited dimensions, the moulds were made of two pieces of CNC milled hard foam glued together. These were finished by sanding and filling up undesired gaps using wall fillers. The CNC cutting models were delivered as an .STL file and include an additional centimeter at the bottom and sides of the moulds to leave space for cutting. The moulds can be seen in figure 11.1.

After creating the moulds, the models were thermoformed. First, the bottom and the functional cover were formed together from a sheet of 2mm PS. PS was chosen for its white matte appearance, removing the need to paint the model after thermoforming. The overall shape of the model turned out quite good, however the details did not form as desired. Also, it was incredibly difficult to get the moulds out of the model without damaging them. The moulds appeared to be sticking to the model as the hard foam had melted a bit due to the heat. Also, lines could easily be detected at the places where the different CNC mould parts were glued together.

Subsequently, the other parts were thermoformed using 1 mm, transparant PETG. Extra air holes were added to the indents at the top. Now the plastic formed neatly around the mould, showing all details to a good extent.

After thermoforming and removing the moulds, the models were cut out of the bottom plate using a horizontal saw. The sides of the top parts were subsequently cut out by hand. The top parts were then painted using spray paint after sanding and applying a primer to enhance adhesions of paint for plastics. The painting was done at both sides of the material to ensure it lost its transparency. Finally, the dents were coloured with a blue marker to resemble the soap. The result can be seen in figure 11.2.

11.1.1 Frame

A frame was created to resemble the frame in the final design. This was done by bending wire by hand. The wire included a combination of brass (gold) and copper wire with steel on the inside (brown). The different parts were assembled on a wood panel and kept in place using a staple gun. After an unsuccessful attempt to solder the separate parts together they were glued together using glue for metals.

Figure 11.2: Prototype.

11.1.2 Insights from the thermoforming

The thermoforming provided valuable insights and suggestions for improvement. During the process of thermoforming some adjustments were already made as explained before. It turned out challenging to produce the details with the thicker material, which could be explained by a lack of air vents and very small details in the mould compared to the material sheet's thickness. Placement of air vents need to be considered more carefully as well as the ratio between the size of the indents and the thickness of the material sheet. Furthermore, the thermoforming showed that it is difficult to create the exact shape around the mould. Using a female mould will improve the accuracy of the outside of De Zeepkist. To ensure that the top and the bottom fit neatly together, it is recommended to use a female mould for the top parts and a male mould for the bottom. Also, more attention should be given to creating a releasing mould. The sides of the moulds that will be cut off could better be rounded off to make it easier to remove the mould after thermoforming and to prevent webbing when using a male mould.

Also, it is recommended to thermoform the different parts separately. When thermoforming the bottom and the functional cover, it could be noticed that the material did not form as tight around the mould on the sides where the two moulds were facing each other, even though the moulds were positioned far from each other. Lastly, for the functional cover it turned out difficult to end in a flat part and to cut this out neatly using a horizontal cutter, as the ends of the flat part will always be a bit curved. It is recommended to use CNC milling from the top to cut out the functional cover so that the shape can be created with a good ending.

11.2

Soap moulding

For the prototype, a couple of natural pigments have been selected from YouWish.nl. These include natural indigo powder, blue spirulina powder and cambrian blue clay (YouWish, 2023a), (YouWish, 2023b), (YouWish, 2024a). In addition, a blue pigment that gives light in the darkness was ordered from online-zeepwinkel.nl (SoapQueen, n.d.-c). Furthermore, two types of natural fragrance oils were ordered from online-zeepwinkel.nl, which are water lily and mountain lavender (SoapQueen, n.d.-a), (SoapQueen, n.d.-b).

For the soap moulding experiment, four moulds were 3D-printed as shown in figure 11.3. Each mould has a variety of depths, ranging 1 mm deep, 2mm deep, 5mm deep and 10 mm deep, resulting in a mould that can hold 45 ml of soap. This enables to evaluate whether the coloured soap is opaque when only a thin layer of soap is used. Fragrances and pigments were added according to Stephenson's instructions: 1% of fragrance was added and 2% of pigments. At first, 60ml of soap was melted au bain marie and mixed with the fragrance and pigments for each sample using the setup as in figure 11.4. After two samples, the volume was increased to 100 ml since the soap was not sufficient due to losses during pouring. In addition, from the second soap sample the pigments and the fragrance were pre-mixed with a little bit of water (<5 ml) to reduce the amount of pigment lumps in the soap. The results can be seen in figure 11.5.

Figure 11.3: Soap mould.

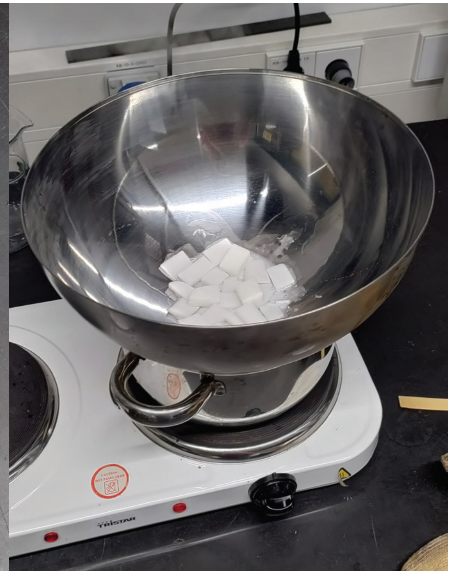


Figure 11.4: Setup

11.2.1 Insights from the experiment

The soap moulding experiment gave some valuable insights. First of all, it can be concluded that also a thin layer of 1-2 mm soap is not translucent. Hence, thin layers of soap can be applied and create a favorable effect. Secondly, creating and pouring the soap requires a little bit of skill and experience in practice. In this setup, a large bowl was used for the soap to melt, which made it difficult to pour the soap neatly. Also, since the soap is very fluid after melting, but cools down in a split second after you take the soap from the heat source, pouring the soap needs to be done very fast and neatly. If not poured fast enough, the soap will not flatten out and leave a texture on the top. Having good equipment can help to simplify this process. Proper equipment is also of importance to reach a reasonable production time. If not using proper equipment it will take a very long time to melt the soap, so it is important to have a good setup so that the soap heats up fast, but does not reach too high of temperatures so that it does not burn.

Furthermore, it turned out challenging to mix the pigments with the soap so that no lumps of pigments could be found in the soap. Premixing the pigment to create a small solution before adding the pigment to the soap can help reduce the amount of lumps, but this still needs to be done with care. Also, after pouring the soap bubbles emerged at the top of the soap as a result of the mixing. Spraying a little bit of alcohol on the soap right after pouring can help prevent bubbles on the surface (Berry, 2021).

Lastly, it could be noticed that the 3D-printed moulds distorted a bit due to the high temperature of the soap. This is explainable as the moulding temperature of soap is around the glass transition temperature of PLA. Since the glass transition temperature of PISOX is higher than the moulding temperature of soap, it is expected that this does not give any problems but it is good to keep an eye on it.

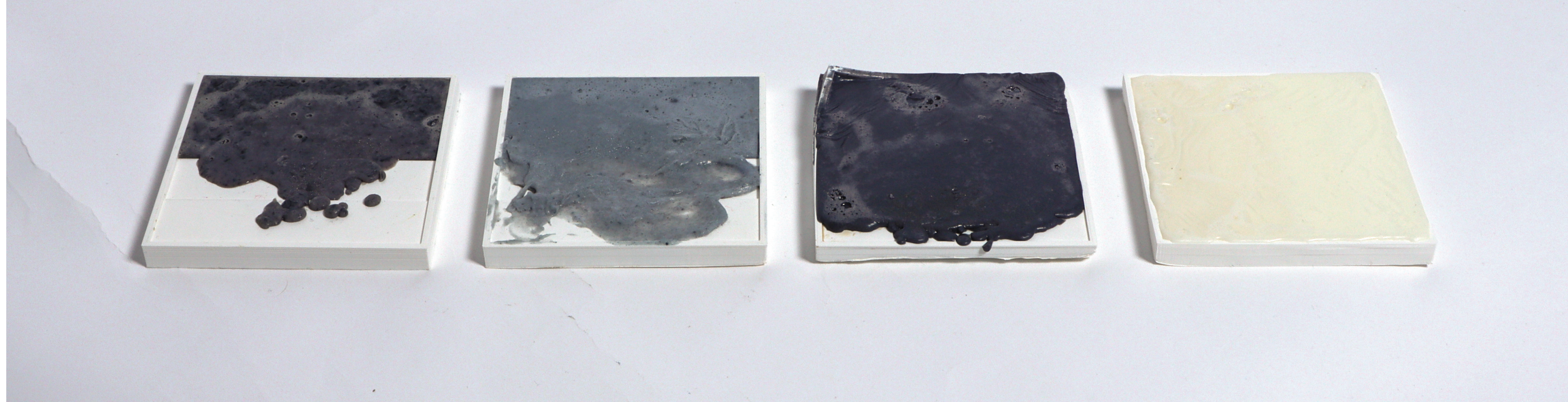


Figure 11.5: Soap results.

12

FINAL DESIGN

In this chapter, the final design of De Zeepkist is introduced.

12.1

Design

De Zeepkist finally integrates all aspects explored in previous chapters in an organically shaped design shown in figure 12.1. De Zeepkist is made mostly out of PISOX and with decorative aspects of soap and a stainless steel reusable frame. De Zeepkist is the first resomatable coffin and is designed to fit within the resomator S750. The design is multifunctional and can be used as a coffin or as a carrier as shown in figure 12.2. De Zeepkist is designed to fit 95% of the Dutch population. To maintain the sustainable benefits of resomation, the PISOX and soap are both made from renewable materials and fully biodegradable. A new 1:4 prototype was made to show the final design.

Figure 12.1: Final design of De Zeepkist.

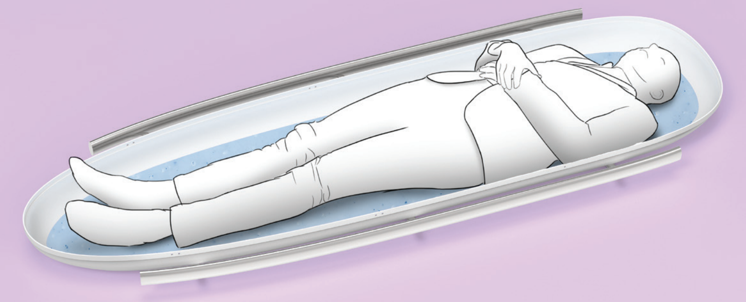
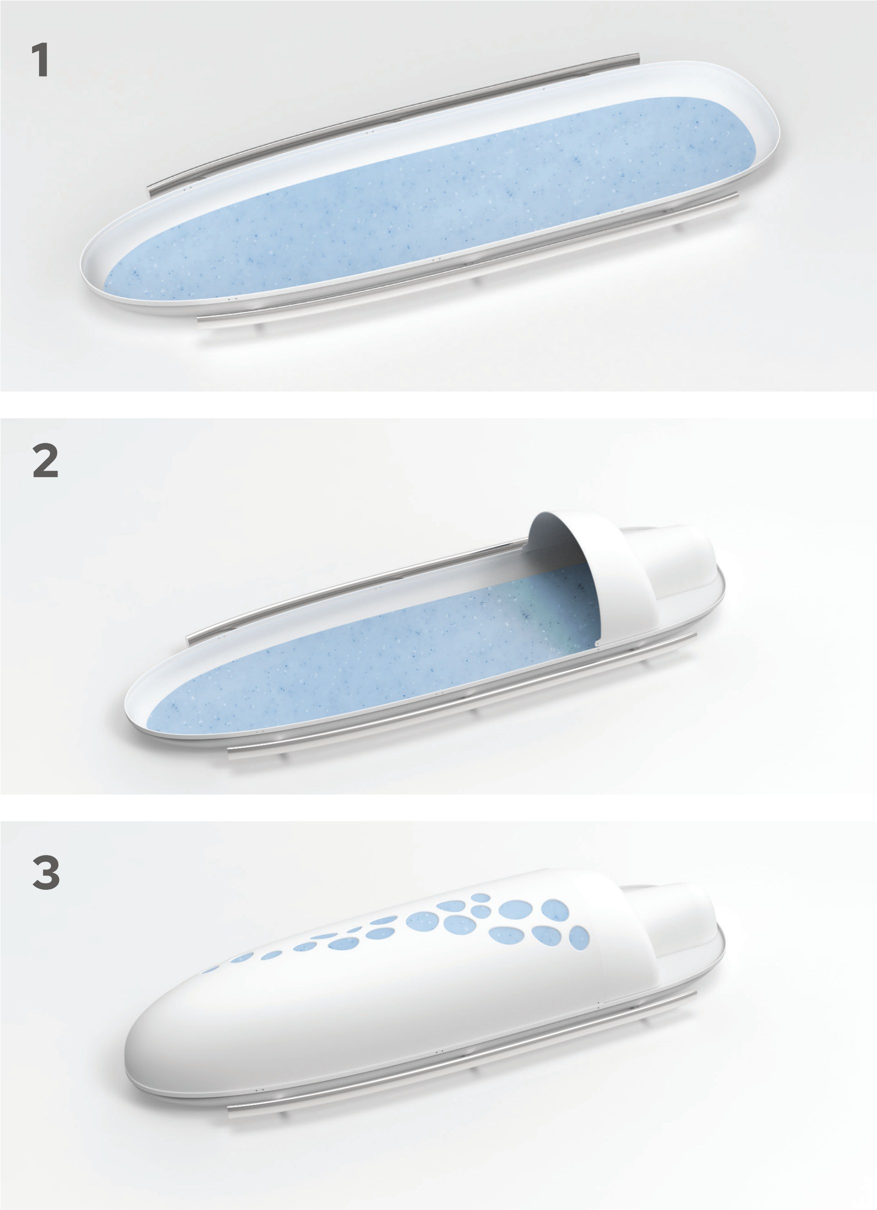


Figure 12.2: De Zeepkist used as a carrier.

Figure 12.3: De Zeepkist in a viewing room.



Closing ritual

Prior to the funeral ceremony, De Zeepkist is closed in four steps shown in figure 12.4. First, a cover is placed over the head. Then, a second cover is placed that covers the feet and hides the body. The parts are then fastened using push rivets that can easily be tightened by pushing the rivets into the holes. Finally, a cover is placed over the head cover, to complete the organic design.

Figure 12.4: The closing ritual.

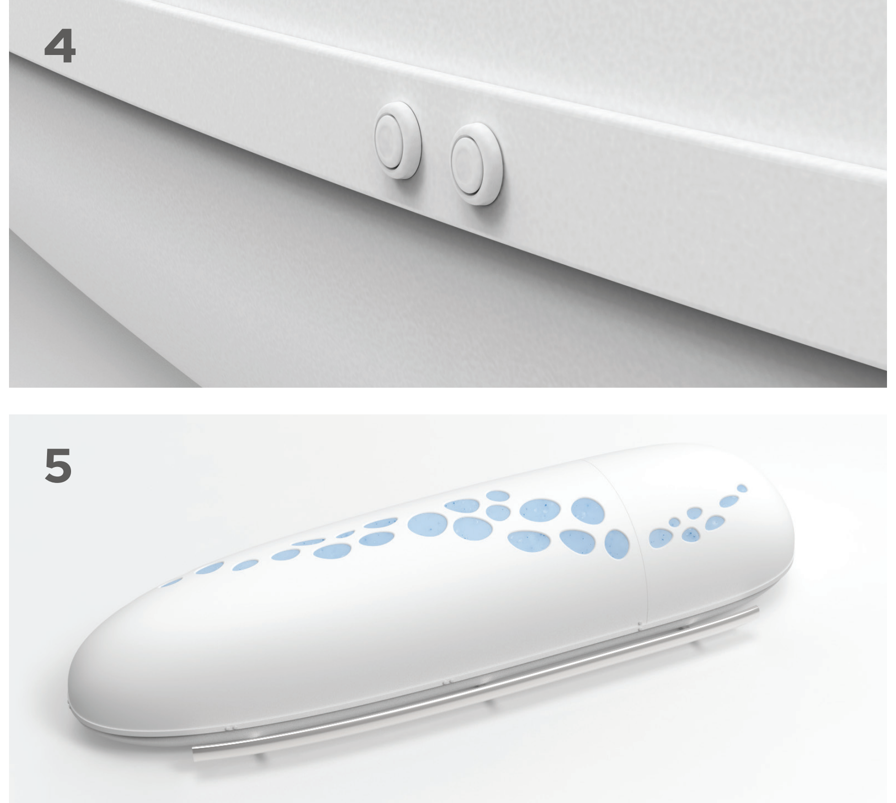


Figure 12.5: De Zeepkist in a funeral hall.

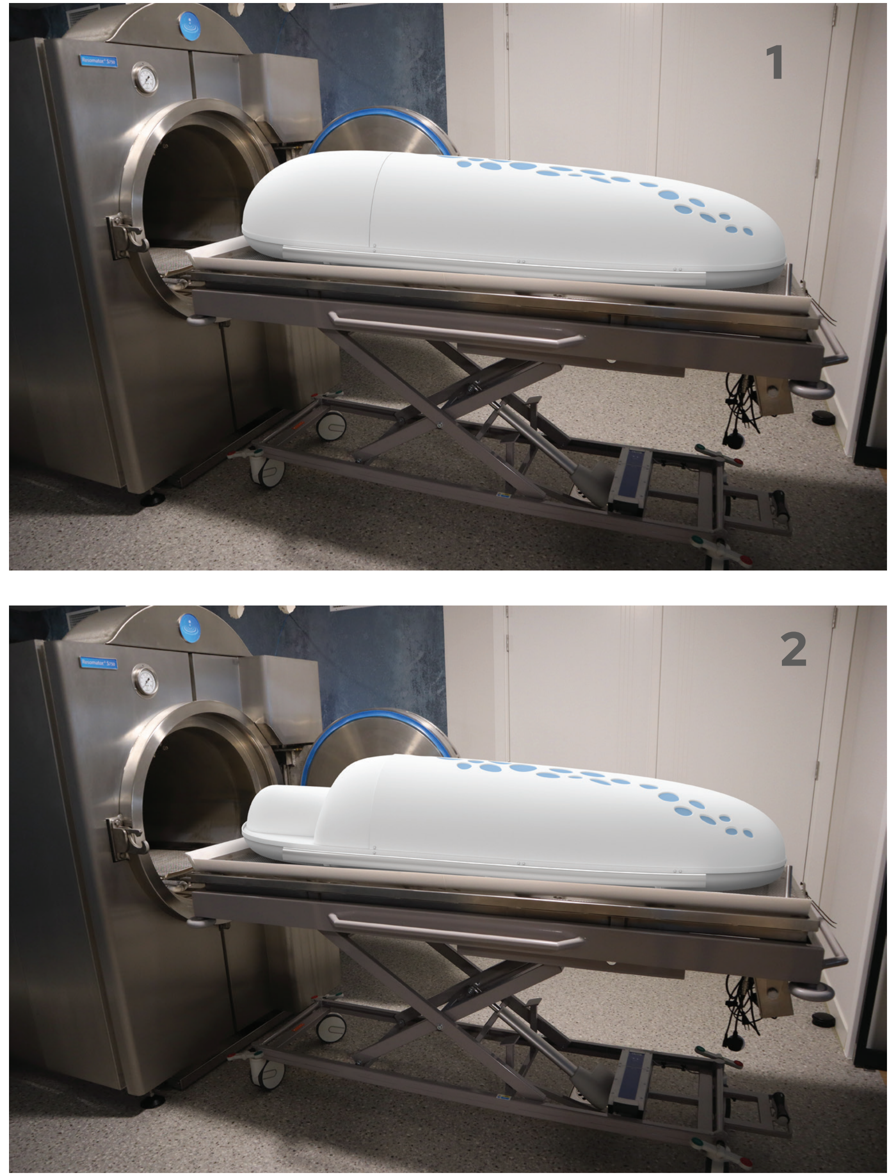


Figure 12.6: Pre-resomation ritual.

Modular design

The double cover for the head is added to offer the experience of a coffin during the ceremony and the period prior to the ceremony when the deceased is laid out, while also ensuring that the enclosure can fit the limited space available within the resomator. Just before resomation, the head cover needs to be taken away and a smaller, functional head cover will appear that fits within the resomator (figure 12.7). This process is shown in figure 12.6. De Zeepkist can then be placed in the resomator, including the frame. The bereaved needs to wear resomation-suitable clothes made of either wool, leather or silk. After the resomation, the frame is cleaned before it is used for another resomation.

Figure 12.7: Prior-to-resomation Zeepkist prototype.

Strong and comfortable

The bottom of De Zeepkist is reinforced by indents that shape around the frame as shown in figure 12.8 and 12.9. The indents in the bottom are covered up by a layer of soap, so the bereaved can lie comfortably on a flat surface. The flat surface of the bottom is also beneficial to enable the cooling plate to cool the body effectively.

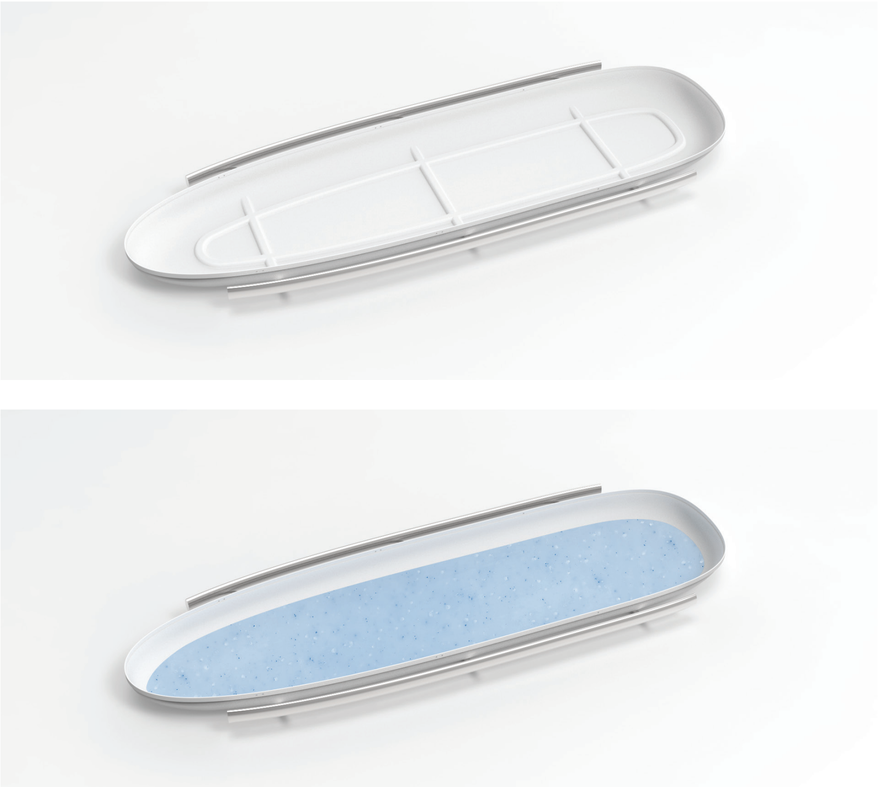


Figure 12.8: The bottom.

Figure 12.9: The bottom.prototype.

12.1.1 Logistics

Usually an enclosure's product-life ends at the burial or the cremation, however for De Zeepkist the frame is reused. This requires additional logistics compared to other coffins. The frames can be sold or leased to funeral companies by the supplier of Zeepkisten. For larger funeral homes with frequent resomations, having a couple of frames can be useful. For smaller funeral companies who have only a couple of resomations a year leasing a frame per resomation might be more convenient.

In regards to transporting or storing De Zeepkist, a benefit of De Zeepkist is that it is made of separate parts with a draft angle. Because of this, the different parts can be stacked easily, which can reduce the space needed to transport a couple of Zeepkisten.

12.1.2 Production

De Zeepkist requires few production steps and employs common manufacturing techniques. The PISOX parts are thermoformed followed by CNC cutting to cut the formed parts out of the sheets and to create holes. The soap is moulded, which can easily be done by hand for small production batches and can be automised for larger batch sizes. The frames need to be bent and welded. The rivets need to be injection moulded.

Figure 12.10: Prototype.

12.2

Technical drawings and bill of materials

In appendix 4, technical drawings show the main dimensions of the different PISOX parts and the frame. The soap parts will be moulded by adding a layer of soap into the PISOX parts. A soap layer of approximately 12.5 mm is needed to cover up the indents in the PISOX bottom to create a flat surface for the deceased to lie on. The PISOX top parts contain 10 mm deep indents which will be filled with a 5 mm layer of soap. For the rivets there are many options available, though the possibilities of having PISOX rivets produced still needs to be researched. For now a hole diameter of 5 mm is used.

A bill of materials can be seen in table 12.1. The total mass of a Zeepkist is approximately 32 kg and when loaded with a 91 kg body it can still safely be carried by six carriers within the occupational health and safety standards in The Netherlands.

One Zeepkist requires 17.4 kg of PISOX, 8.3 kg of soap and 6.6 kg of steel.

Parts	Material	Volume [L]	Mass [kg]
Bottom	PISOX	4.7	6.6
Functional cover	PISOX	1.7	2.3
Top head	PISOX	1.7	2.4
Top feet	PISOX	4.3	6
Rivets (14)	PISOX	0.004	0.01
Soap layer bottom	Soap	6.6	7.5
Soap top head	Soap	0.03	0.03
Soap top feet	Soap	0.7	0.8
Frame	Stainless steel 316	0.8	6.6
		total	32.3

Table 12.1: Bill of materials.

12.3

Costs

To gain insight into the cost of a Zeepkist, the material and production costs are calculated as well as the set-up costs to gain insight in the order of magnitude of the necessary investments. The costs are calculated per category, first the material costs, followed by the production costs and the set-up costs, and finally the total costs are calculated.

12.3.1 Material and production costs

First, the costs of producing one Zeepkist are calculated by their material and production costs. An overview of the material costs can be seen in table 12.2. The price of the PISOX per kilo was estimated to be around €10 for small-scale production (G. J. Gruter, personal communication, April 4, 2024), this can be reduced when production is scaled up but for now a small-scale production is assumed. The price of soap per kilo was used from DistrEbution (DistrEbution, 2024).

Material	Price per kilo in €	Kilo used	Material cost
PISOX	€10	17.1	€171
Soap	€9.98	8.3	€82.83
		total	€253.83

Table 12.2: Material costs of soap and PISOX.

For the frame, the material costs are calculated using the length needed and the price for a tube (table 12.3). For the selected tubes no price could be found, so similar-sized tubes were used to calculate the price for our tubes on www.metaalwinkelonline.nl (METAALWINKEL, 2024).

	Length needed per frame	Price
Flat oval	5480 mm	€92.72
Oval	3060 mm	€108
	total	€200.72

Table 12.3: Tube costs.

12.3.2 Production costs

The production of De Zeepkist contains thermoforming, CNC milling the PISOX parts after thermoforming, and moulding soap. The costs for these steps are calculated separately.

12.3.2.1 Costs thermoforming

For the thermoforming, it is assumed that it takes ca. 2 minutes to heat up the parts (la-plastic.com, 2023), after which it needs to be formed and cooled down. It is estimated that it will take 6 minutes to complete the full thermoforming process per PISOX part, meaning 10 parts can be produced in an hour. To produce one Zeepkist, four parts need to be thermoformed, requiring 24 minutes. For large-size thermoforming machines, an hourly price of €14 for using the machine in 2007 was found (Kals, 2007). To correct for inflation since 2007, a price of €20 per hour was assumed instead. This would result in a process cost of €8.

Considering the labor costs, it is assumed that the machine needs to be attended for 2 of the 6 minutes of the thermoforming machine. An hourly wage of €25 was found (Kals, 2007) and corrected to €36 for inflation. Assuming an hourly wage of €36, this would result in labor costs of €4.80.

The total costs of thermoforming are €12.80.

12.3.2.2 Costs CNC milling

After the thermoforming, these parts need to be cut out of the remaining material which is done using CNC milling. It is assumed that an average of 2 minutes is needed for each part to cut the parts out of the remaining thermoformed material, requiring 8 minutes of CNC milling per Zeepkist in total. The hourly cost of using a CNC milling machine is assumed to be €36 (Ye, 2024), which would result in €4.80 for using the CNC milling machine.

Another aspect is the labor costs for the CNC milling that is needed to place the parts, start the machine and remove them again. It is estimated that removing a part, placing a part, and starting the machine will take approximately 30 seconds per part. Again assuming an hourly wage of €36, this results in €1.20 labor costs for one Zeepkist. The total CNC milling costs are then €6.

12.3.2.3 Costs soap moulding

It is assumed that the soap moulding is done by hand at first. The manual labor will likely contribute the most to the soap moulding process. For the soap moulding it is assumed that with some practice and skill and a proper setup, around 5 enclosures can be provided with soap per hour. The only production-specific costs are energy to heat the soap, this is estimated to be €0.40 per hour (Van Veelen, 2023). Including the labor costs assuming an hourly wage of €36, this would result in a price of €7.28 to mould the soap.

12.3.2.4 Frame bending and welding

The frame needs to be bent and welded together. Six short parts need to be bent as well as one long part for the circular shape. This then needs to be welded together, which is assumed to take about an hour. The costs for these actions are found on www.bewerking4metaal.nl (METAALWINKEL, 2022). The costs of producing the frame are summarised in table 12.4.

	Price per action	Amount needed	Costs
Bending 0-1000 mm	€12.10	6	€72.60
Bending 2501 - 3000 mm	€30.25	2	€60.50
Welding	€105.27 per hour	1	€105.27
		total	€238.37

Table 12.4: Production costs of a frame.

Adding up the tube costs and the production costs, the total costs of producing a frame would be around €440. It is estimated that a frame can be reused a hundred times, which would result in a cost of €4.40 for the frame per resomation.

12.3.2.5 Total production costs

The found production costs are summed up in table 12.5. Here also the cost of the rivets is added. For the plastic rivets, it is assumed that they can be bought in for a price that is double the price of available rivets online since they will have to be made from PISOX. For this, a plastic rivet of €0.29 was found online (DigiKey, 2024).

	Price in [€]
Thermoforming costs	€12.80
CNC milling costs	€6
Soap moulding costs	€7.28
Rivets (14)	€4.06
Total	€30.14

Table 12.5: Total production costs.

12.3.3 Set-up costs

Before production can be started, some set-up costs are necessary. The set-up costs can mostly be found in the costs for the moulds needed to do thermoforming. The price of the moulds is calculated by using the mould price calculator on https://www.batelaan.nl/malkosten-calculeren/. An overview of the mould costs can be seen in table 12.6. It is expected that the moulds could be used 100.000 times, resulting in mould costs of €2.08 per Zeepkist.

Mould type	Price
Mould bottom part	€72,000
Mould top feet part	€62,000
Mould functional cover	€37,000
Mould top head part	€37,000
total	€253.83

Table 12.6: Mould costs.

12.3.4 Total costs

All the calculated costs above are summarised in table 12.7 and the cost price is calculated. A cost price of approximately €290 was found.A selling price for de Zeepkist could then be around €870. This is lower than the set goal of €1000 and this is comparable to the price of a traditional wooden coffin.

As a note, it should be added that the equipment costs for the soap moulding is not included as this is expected to be very low, as well as installation costs of the machines and their workers. The final price could thus end up a little bit higher.

Another thing to mention is that in table 12.7 it can be seen that the costs of a Zeepkist can mainly be found in the material costs for the PISOX and soap. Now, a small-scale production was assumed and therefore a relatively high price for the materials is paid. This could be reduced by buying soap in bulk and when the production of PISOX is scaled up. If PISOX is scaled up and the price of PISOX becomes competitive to those of PETG and drops to around €2 per kilo, this could reduce the cost price of a Zeepkist from €290 to around €150.

	Costs
Material costs PISOX and soap	€253.83
Production costs	€30.14
Frame costs per resomation	€4.40
Setup costs	€2.08
Total	ca. €290

Table 12.7: Cost price of a Zeepkist.

Part 3: Evaluation

In the upcoming chapters, the design of De Zeepkist is evaluated with users, and its sustainability is evaluated.

Part 3 Evaluation

13

EVALUATION OF THE PERCEPTION OF THE DESIGN

In this chapter, the design of De Zeepkist is evaluated with potential users by means of interviews.

13.1

Interviews

Interviews were conducted to evaluate how people would perceive De Zeepkist. The goal of these interviews was to gain insight in how people think about De Zeepkist, whether De Zeepkist makes it easier for participants to choose for resomation and how people perceive the design in comparison to other funeral enclosures.

13.1.1 Setup

Eight participants with a variety in knowledge about resomation, age and gender were interviewed. During the interview, the participants were shown visuals of the resomator and the design of De Zeepkist (figure 13.1), as well as a prototype of De Zeepkist as shown in figure 13.2. The interviews were conducted in Dutch to make participants feel more comfortable and confident to express themselves. The full interview setup can be read in appendix 5. For this test an ethics check has been performed and reviewed, and an informed consent form was used (see appendix 6).

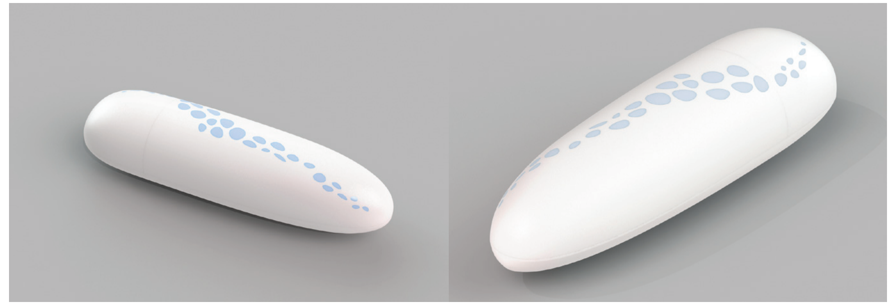


Figure 13.1: Vsuals of the design shown during the interviews.

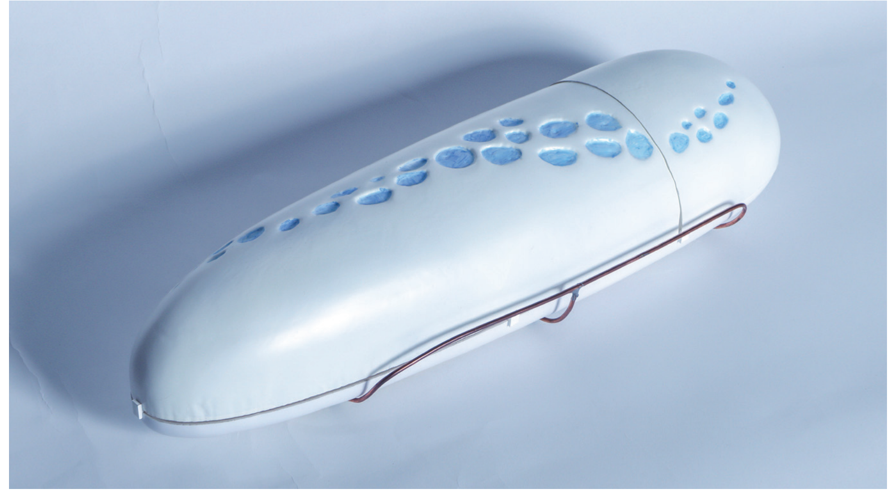


Figure 13.2: Prototype used for the interviews.

13.1.2 Results

With a variety in preferences for a certain funeral technique and varying prior knowledge of resomation, each interview has been very unique and a lot of varying associations and opinions were shared. On the other hand, there were also some beliefs that were shared amongst the participants. The results are discussed in a few topics which are: general, design and De Zeepkist in relation to other enclosures.

13.1.2.1 General

First of all, participants clearly were interested in the sustainability of a funeral. Though nothing was mentioned about sustainability in regards to resomation or De Zeepkist in the introduction or questions, seven out of eight participants asked something about the sustainability of the process and coffin, or mentioned that sustainability would be something that would influence their choices. It was clear that participants feel a need for the funeral industry to change in regards to sustainability.

Furthermore, something that was noticeable was that participants have a lot of questions themselves about funeral processes, enclosures and their possibilities and limitations. Participants are often not aware about all the options there are available or do not understand what the purpose or added benefit of some features are and why a simpler solution is not possible. This is shown by the statements "A shroud? I learn words." and "Why don't you just put me in a bag or something?". In a similar manner, some participants do not understand the function of soap and why it is added, even when they mention to appreciate the pattern of soap in regards to the design.

Sometimes, people have more practical questions such as what would happen with the cover that is taken from the coffin just before resomation.

Also, a very widely shared opinion is that participants mention the need for the enclosure to suit the bereaved and also to be considerate of other people's opinions when selecting a funeral enclosure.

13.1.2.2 Design

Regarding the design, there are a couple of opinions that are shared. There are several associations that are made when seeing De Zeepkist. As such, the overall design is associated with a cocoon, which makes them think of caterpillars and butterflies. Also, the pattern of soap on the top is associated with footsteps or life steps. Additionally, the shape of the design is associated with a medicine capsule, a car roof box. Lastly, the design is mentioned to be rather futuristic, which for some people is a bit too much, and for others it is not necessarily a problem, just something that they would need to get used to. There is a group of people that believes De Zeepkist has a beautiful shape which is liked by them, while on the other hand some people like the shape but feel that the design is quite futuristic.

Considering colour, all participants are open to having some colour on the coffin and many appreciate the added colour. Many participants would rather add even more colour instead of the white parts and many ask about the possibility of customizing the colour of both the PISOX and the soap parts.

The added scent is sometimes not noticed by participants, while others find it directly a very nice addition. Practical questions are asked about how much of a smell you will experience and one participant mentions "I don't know if you would think that it would come from the coffin or if it was just cleaned here". Some people mention that it should maybe not be a very common smell or prefer a neutral smell. Overall, people think that it is a nice addition, though one participant mentions also that it is a nice addition but it would probably not be missed if it wouldn't be there.

Overall, participants are fairly positive about the design of De Zeepkist, the design is perceived to be beautiful yet a little bit futuristic, and participants start to question the traditional wooden box.

Participants mention both that they think De Zeepkist is a beautiful design and shape, but also that they need to get used to the design, it is something very different. It seems that the participants are positive that they could get used to this new design, just that it would take a bit of time. This is shown by statements such as "This is not something you would immediately imagine at a funeral, but that is not necessarily a bad thing. I think De Zeepkist is nicer, but the cardboard coffin is more normal, more traditional" and "It takes some getting used to if you are used to a traditional coffin. [...] It is mainly a matter of switching, I was not familiar with it, it takes some getting used to the idea, but the way it is designed, it seems to me to fit the objective and the time in which we live."

Considering the head top cover that needs to be taken away, most participants find it a bit of a weird moment but they also see the need and with proper explanation they seem to be able to accept it. If it could be prevented by changing the resomator that would be preferred, but if that is not possible they can accept the process with taking away the cover. It is appreciated that people probably have already seen the functional cover during the closing ritual so that people know that they really cannot see anything of the deceased.

13.1.2.3 De Zeepkist in relation to other enclosures

Participants were asked to place a couple of funeral enclosures in order of what they think is the most beautiful and most likely that they would choose it if all funeral enclosures would fit every funeral technique. These scoring can be seen in figure 13.3. From these ratings it can be seen that on average De Zeepkist scores quite good. Five out of eight times, De Zeepkist is preferred over a shroud and also five out of eight times De Zeepkist is preferred over a traditional squared box. Two out of eight times De Zeepkist is the preferred option. It is remarkable that the traditional wooden coffin does not score as good in comparison to how often it is used in practice.

A mentionable observation is that some participants mentioned that by the entire interview they felt carried along in the thought process behind De Zeepkist which might influence positively how they would score De Zeepkist. A participant mentions: "Maybe I'm putting this here because this is what I've gotten most used to in the last hour." This showed that with some explanation and with a bit more attention for resomation and De Zeepkist, the threshold for people to choose quite a different alternative is relatively easily surmountable.

The interviews also confirm the view that many people do not feel comfortable with a shroud, and would perceive De Zeepkist as a more comfortable option. A participant mentions “I don’t feel so good about the shroud, because you can see the contours, it feels like a body bag. [...] You really have a line between distant and too close, which is what I feel here, and I think De Zeepkist is somewhere in between.”

Most beautiful/likely **Least**

Figure 13.3: Participants’ rankings of different funeral enclosures on their perceived beauty and likelihood of choosing a type of enclosure (1).

Most beautiful/likely **Least**

Figure 13.3: Participants’ rankings of different funeral enclosures on their perceived beauty and likelihood of choosing a type of enclosure (2).

13.1.3 Conclusion

The interviews point out the variety of opinions and preferences. As there are not that many options available for resomation yet regarding a funeral enclosure, adding another option will increase the likelihood that people might choose for resomation.

Overall, the design of De Zeepkist is quite well received, but some time is needed for people to switch their mind around this new design and the according funeral technique. From the interviews it can be concluded that De Zeepkist will for some people make the choice for resomation easier as they perceive it a more pleasant option than a shroud or cardboard coffin. Anyhow, the distinct design appears to be a good starting point to start questioning the traditional options. Furthermore, the high interest of participants in sustainability will probably move people in the direction of resomation and De Zeepkist. Also, the interviews point out that customisation of colour is highly desired.

Finally, one participant sums up the project nicely: "It's a bit of your approach, if you really show that it's a different technique then a different design will also fit."

14

SUSTAINABILITY EVALUATION DE ZEEPKIST

In this chapter, De Zeepkist's design is evaluated on how De Zeepkist impacts the overall sustainability of resomation.

14.1

Sustainability evaluation

As De Zeepkist is designed to improve funeral's overall sustainability, it is important that by adding a coffin the sustainable benefits of resomation are not nullified. Sustainability is an extensive topic and there are multiple ways in which products can have an impact on the environment. It is not possible to go into detail on all the different aspects that influence sustainability in a short time, due to a lack of knowledge and data. Because the materials that are used for De Zeepkist are biodegradable and used within a strictly constrained environment, the effect of De Zeepkist on the environment when considering sustainability aspects such as toxicity are assumed to be small. Rather, to evaluate the environmental impact of De Zeepkist it is focused on quantifying its impact on climate change. This was done by calculating the carbon footprint of producing the materials and considering the amount of KOH needed to dissolve one Zeepkist.

As mentioned in paragraph 2.1.3, TNO has done an extensive study to compare the environmental impact of burial, cremation and resomation. The research of TNO has calculated the kg of CO2 that is emitted for one funeral for each type (Keijzer et al., 2014). The results were as follows:

	Climate change in [kg CO2 eq.]
Burial	95
Cremation	208
Resomation	28

Table 14.1: Climate change in kg CO2 per funeral for different funeral technique.

In the analysis of TNO, for resomation it was assumed that a traditional coffin would be reused 50 times. When using a Zeepkist, this will add up to the carbon footprint of resomation as one Zeepkist is used for every resomation.

14.1.1 Carbon footprint Zeepkist

The carbon footprint of De Zeepkist was calculated using the kg. CO2 eq. per kg material produced for the different materials, see table 14.2. For the steel used in the frame, a value was taken from Granta (Granta EduPack 2022 R1, 2022d). For the soap parts, a kg CO2 eq. / kg of 1.65 was found (Francke & Castro, 2013). For PISOX there was no data available on the carbon footprint of producing 1 kg of PISOX. Therefore, the carbon footprint of PLA was used instead, as this is both a biobased and biodegradable polymer like PISOX. This value was obtained from Granta (Granta EduPack 2022 R1, 2022c). For these calculations, it is assumed that the steel frame can be reused 100 times, while it is assumed that the part that covers the head that is taken from the coffin just before resomation is not reused.

	Mass used [kg]	kg CO2. / kg	kg CO2 eq. / coffin
PISOX parts	17.4	2.28	39.6
Soap parts	8.3	1.65	13.7
Steel parts	6.6	4.09	0.3
		total	53.6

Table 14.2: Carbon footprint calculated for De Zeepkist.

14.1.2 KOH needed for dissolvement

It is calculated how much KOH is needed to dissolve a Zeepkist. To break down PISOX, every ester bond reacts with a molecule of KOH. For this calculation, the repeating unit as shown in figure 14.1 is used and an infinitely long polymer chain existing of only isosorbide and oxalate is assumed. The molecular mass of the repeating unit is 200.17 g/mol and has two esters. Complete hydrolysis is assumed.

A Zeepkist contains 14,950 g PISOX once the head cover is taken away. This would result in 76.7 mol PISOX, requiring the double amount of 149.4 mol of KOH given the two esters in the repeating unit. The molecular weight of KOH is 56.1056 g/mol, resulting in a mass of 8.38 kg needed to dissolve a Zeepkist.

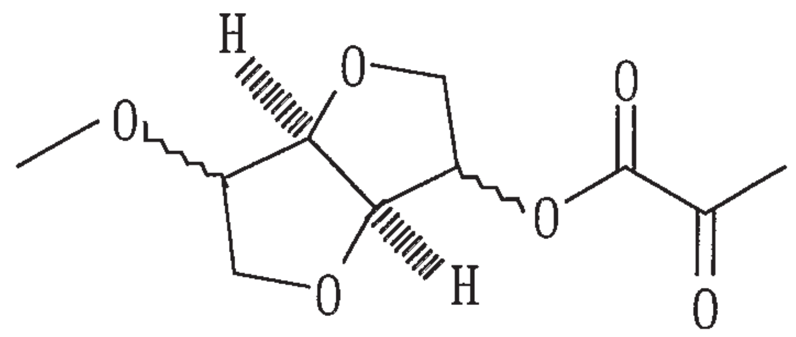


Figure 14.1: The repeating unit of PISOX.

Potassium hydroxide has a kg CO2 eq. / kg of of 0.77 (CarbonCloud, 2024). Adding 8.38 kg of KOH to the process will then add an additional 6.5 kg CO2 eq to a resomation, resulting in a total increase of 60.1 kg CO2 eq.

14.1.3 Conclusion

From the evaluation it can be concluded that using a Zeepkist will add 60.1 kg of CO_2 eq. to the process of resomation, resulting in a total carbon footprint of 88.1 kg CO_2 eq. per resomation. This is a significant increase in the CO_2 that is emitted for a resomation, however this increased CO_2 footprint is still 7% lower than the carbon footprint of burial and 58% lower than those of cremation. This means that from a sustainability point of view, choosing for resomation with a Zeepkist is still a more sustainable option as choosing for a burial or cremation when comparing the carbon footprint. An even more sustainable option would be to choose for resomation without using any funeral enclosure or using only the carrier of De Zeepkist. Assuming that resomation will mainly substitute cremation since this is process-wise a similar experience for the bereaved, the analysis suggests that De Zeepkist will offer a significant environmental benefit.

It should be noted that the evaluation creates insight into the environmental impact of adding a Zeepkist to resomation, but the quantified numbers should be considered with care as PLA was used as a reference material in the calculations due to a lack of data on the impact of PISOX. Though PLA is also biobased and biodegradable as PISOX, its origins and production process are different so there is a very high probability that the kg CO_2 eq. of PISOX is different. Something that pleads for PISOX is that the oxalic acid that is used in synthesizing PISOX can be obtained from CO_2 (Gruter, 2023). Because of this, PISOX will likely have a relatively low carbon footprint, but this needs to be investigated.

Lastly, in the original calculations of TNO, 1/50th of a coffin is used for resomation. It is unknown how much this adds to the carbon footprint of a resomation, so this is not compensated for in calculating the total CO_2 footprint of a resomation with a Zeepkist. The total CO_2 footprint of a resomation will therefore be a little bit lower, but since it is only 1/50th of the carbon footprint of a coffin this will likely not be a big difference.

15 CONCLUSION

In this chapter conclusions are drawn.

Conclusion

New types of funeral enclosures that are suitable for resomation are needed to offer people an option that they feel comfortable in. This will increase the chances of people choosing for resomation instead of burial or cremation, and make the funeral industry more sustainable. The central research question was How can a funeral enclosure be designed to be suitable for resomation in the Netherlands in 2030, using PISOX and soap as materials? This question was answered by the design concept called De Zeepkist as introduced in chapter 12. An idea for a fully resomatable coffin made of PISOX and soap is elaborated into a tangible design concept that suits the Resomator S750. It was found that the Resomator S750 is highly limiting in regards to its inner design and the available space within the machine to add a coffin. As a result, a modular design is proposed. The design can show a full coffin version which can be used during the laying out of the deceased and the ceremony, and a reduced version which can fit within the machine but prevents the bereaved from being confronted with the deceased again. De Zeepkist is designed to fit 95% of the 60+ year old Dutch population and makes maximum use of the available space within the resomator. De Zeepkist is designed to promote resomation's unique characteristics and to help resomation create its own positive image. De Zeepkist adopts a design that is radically different from traditional coffins, while the funeral process that the bereaved experience with De Zeepkist is aimed to remain as common for cremation.

The resomatability of the materials, the design's strength, cost price, carbon footprint and the experience of the design have been evaluated to prove its feasibility, desirability and viability.

During resomation, PISOX undergoes the same process as is used for chemical recycling, and can therefore be broken down at a high speed compared to other materials such as other types of plastics or wood. It was found that PISOX can be dissolved at a similar speed to wool when comparing similar weighing material samples. Regarding soap, tests have shown that soap is suitable for resomation as it simply dissolves in water. Dissolving samples of soap in a KOH solution showed that soap dissolves approximately 13 times faster than wool, which shows its high suitability for resomation. This suggests that De Zeepkist can be resomated within a similar time as a wool shroud, though more research is needed at a larger scale and within the exact conditions for resomation.

The strength analysis indicates that a small thickness (>5 mm) for the PISOX parts is realistic, resulting in a design that has a weight of approximately 32 kg, which is similar to other coffins. A cost price calculation shows that the costs to produce one Zeepkist can be expected to be around €290 at the start, but large investments of around €208,000 are needed before production can be started.

A sustainability evaluation into the carbon footprint for resomation once a Zeepkist is added shows that resomation with a Zeepkist still has a 7% lower carbon footprint than burial and a 58% lower footprint than cremation. It is expected that resomation will mostly be an alternative for cremation given its similar process experience. If the Zeepkist helps people to feel comfortable enough to choose for resomation instead of cremation, it can help decrease the negative impacts of a funeral significantly.

A 1:4 prototype was created to evaluate the design and its production and was also used in interviews to evaluate people's experience with the new design. The interviews indicated that people need time to get used to the radically different design, though they have a positive attitude towards the new design. It was found that the distinct design of De Zeepkist is a good starting point for people to start questioning the traditional options, and people are open for a new funeral enclosure to differ in design from the traditional wooden box. It was found that people are still largely unknown with resomation and their possibilities and limitations. This can be seen as the main challenge for 2030: for people to get familiar with the new process of resomation and to get used to a new design. De Zeepkist fills a demand that people do not know yet that they have, hence a market push strategy needs to be adopted and more publicity and time is needed.

Lastly, more research is needed to evaluate the material's functioning in its context. This will be discussed further in the next chapter.

16

RECOMMENDATIONS

In this chapter, recommendations for future development of De Zeepkist are discussed.

Recommendations

This report demonstrates a proof of concept for a funeral enclosure for resomation and leaves room for many more research and design activities in the future. Recommendations for future development of the concept will be discussed here per topic.

16.1 Materials' functioning additional research

The functioning of the materials in their context should be further researched, especially also with the final intended materials. This means testing with a specific type of PISOX and a soap that is customised with additives. First of all, more research is needed into the resomatability of the materials and the design, on a larger scale and within the exact conditions of resomation. I recommend connecting with Resomation to discuss the possibility of testing the materials within one of their machines. Another aspect to consider for evaluating the resomatability of the design is the effect of adding De Zeepkist on the flow of the resomation liquid within the machine. It can be expected that De Zeepkist will change the flow within the machine during the first minutes when the enclosure needs to be dissolved. It is important to look into how the flow is altered and most of all what the impact of this is for the overall resomation time. In addition, the effect of the large temperature range on the design and humidity in funeral houses needs to be researched to ensure it is not going to fail.

16.2 Detailing the design

To take the design a step further, attention should be given to the details and what can realistically be achieved in the production process. First of all, the strength of the design should be analysed more extensively. More scenarios for different types of loads need to be analysed. Also, the strength of the complete design including the interaction between the parts need to be analysed rather than the different parts separately to ensure that the design is not going to fail. Another important aspect in regards to the design's strength is that the strength analysis done in this report is based on a constant thickness of the PISOX, which cannot be achieved in thermoforming. It should be investigated how the PISOX shapes around the mould and how much the thickness varies within each part. Ideally, the thicker parts are located where the parts need to withstand the highest stresses or the thickness variations are minimised. Because the variations in thickness are difficult to predict and to model, it is recommended to evaluate the strength of the design in a full-size prototype.

Additionally, attention should be given to tolerances of the production process and the materials. It should be examined whether the small curvatures and the locations where the parts come together fit together as smoothly as designed. Optimisation is important here, given the limited space in the resomator every millimetre counts.

Lastly, it is recommended to seek contact with soap moulding and thermoforming experts to take the prototyping a step further and to finetune the design to be suitable for production.

16.3 Preparing (people) for resomation

At the end of this project, it seems that it will still take some months or years before resomation will be legalised. This means that there is still time to prepare for resomation and most of all to prepare people for resomation. As mentioned in chapter 15, De Zeepkist offers a solution for a problem that people generally don't know about, as resomation is still largely unknown. More information about resomation and exposure is needed for people to get used to this process. As De Zeepkist is a tangible design, it can help start conversations about the process of resomation and funerals in general. It is recommended to continue developing De Zeepkist in practical terms, and to meanwhile start up a thought process for people before resomation is legalised by creating more media attention.

16.4 Other

In this report, no attention is given to the clothing of the deceased during a resomation. This is something that is still very important for the bereaved and possibilities for resomation-suitable clothing need to be developed.

Furthermore, it is recommended to look into the possibilities of offering options for customisation.

Also, looking at a longer timespan it is recommended to research producing soap from scratch, using the cold processing method to create a more sustainable and cheaper soap suitable for resomation.

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Appendix 1 – Questionnaire interested groups

Resomeren

Deze enquête gaat over de uitvaarttechniek resomeren. Ik ben een masterstudent Industrieel Ontwerpen, en voor mijn afstudeerproject ben ik een doodskist aan het ontwerpen die geschikt is voor resomeren. In deze vragenlijst stel ik een aantal vragen over resomeren, wat u hiervan weet en hoe u er tegenaan kijkt.

Het kost ca. 5 minuten om de vragenlijst in te vullen. Uw antwoorden zijn anoniem en zullen vertrouwelijk verwerkt worden.

* Verplichte vraag

1. Hoe oud bent u? *

Markeer slechts één ovaal.

- >18
- 18 - 25
- 26 - 40
- 41- 55
- 56 - 70
- 70+

2. Hoe identificeert u zich? *

Markeer slechts één ovaal.

- Man
- Vrouw
- Zeg ik liever niet
- Anders: ______________________

3. Heeft u wel eens gehoord van de uitvaarttechniek resomeren? *

Markeer slechts één ovaal.

- Ja *Ga naar vraag 4*
- Nee *Ga naar vraag 8*

4. Wat weet u van resomeren? *

5. Wat is uw beeld van resomeren? *

6. Zou u resomeren overwegen voor uw eigen uitvaart of de uitvaart van iemand die dichtbij u stond? *

Markeer slechts één ovaal.

- Ja
- Nee
- Anders:

7. Kan u toelichten waarom u resomeren wel of niet zou overwegen voor uw eigen uitvaart of de uitvaart van iemand die dichtbij u stond? *

Ga naar vraag 12

Toelichting resomeren

Resomeren is een alternatieve uitvaartmethode voor de traditionele begrafenis of crematie. Het is een proces waarbij het lichaam van een overledene wordt afgebroken middels 'alkalische hydrolyse'. Dit is een proces waarbij het lichaam wordt afgebroken tot aan organische basismaterialen door onderdompeling in een oplossing van water en kaliumhydroxide. Deze oplossing wordt verwarmd tot 150 graden. Dit gebeurt in een speciaal hiervoor ontworpen machine, een resomator.

Het duurt ca. 3 uur om het lichaam af te breken. Hierbij blijven botresten over. Na het verwerken van de botresten kunnen nabestaanden desgewenst deze mee naar huis krijgen in een urn, vergelijkbaar met as na crematie.

Resomeren wordt vaak geprezen om zijn milieuvriendelijkheid in vergelijking met traditionele begrafenissen en crematies, omdat het proces minder energie en landoppervlak verbruikt en geen uitstoot van broeikasgassen zoals kooldioxide veroorzaakt. Het vloeibare bijproduct van het proces, bekend als "resomatievloeistof", kan worden afgebroken tot afvoerbaar water en kan worden geloosd zonder enige schadelijke effecten op het milieu.
Een nadeel van resomeren is dat slechts een beperkt aantal materialen kan worden afgebroken in het proces. Hout kan bijvoorbeeld niet worden afgebroken middels resomeren, waardoor een traditionele houten kist niet mogelijk is voor resomeren. Op dit moment zijn alleen wol, zijde en leer geschikt voor resomeren en er wordt onderzoek gedaan naar alternatieve materialen.

8. Zou u resomeren overwegen voor uw eigen uitvaart of de uitvaart van iemand die dichtbij u stond? *

Markeer slechts één ovaal.

- ◯ Ja
- ◯ Nee
- ◯ Anders: ____________________

9. Kan u toelichten waarom u resomeren wel of niet zou overwegen voor uw eigen uitvaart of de uitvaart van iemand die dichtbij u stond? *

____

10. Wat vindt u ervan dat u geen traditionele kist kunt gebruiken voor resomeren? *

Markeer slechts één ovaal.

- Geen probleem, het maakt me niet uit of ik een traditionele kist kan gebruiken of niet.
- Jammer, maar ik begrijp dat er niks aan te doen is dus ik kies een alternatief.
- Een deal-breaker. Als ik geen traditionele kist kan gebruiken zou ik resomeren niet overwegen.
- Anders: __________

11. Hoe belangrijk vindt u duurzaamheid in het kiezen van uw uitvaart? *

Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Tota	◯	◯	◯	◯	◯	◯	◯	Zeer belangrijk

Ga naar vraag 16

Toelichting resomeren

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Resomeren wordt vaak geprezen om zijn milieuvriendelijkheid in vergelijking met traditionele begrafenissen en crematies, omdat het proces minder energie en landoppervlak verbruikt en geen uitstoot van broeikasgassen zoals kooldioxide veroorzaakt. Het vloeibare bijproduct van het proces, bekend als "resomatievloeistof", kan worden afgebroken tot afvoerbaar water en kan worden geloosd zonder enige schadelijke effecten op het milieu.
Een nadeel van resomeren is dat slechts een beperkt aantal materialen kan worden afgebroken in het proces. Hout kan bijvoorbeeld niet worden afgebroken middels resomeren, waardoor een traditionele houten kist niet mogelijk is voor resomeren. Op dit moment zijn alleen wol, zijde en leer geschikt voor resomeren en er wordt onderzoek gedaan naar alternatieve materialen.

12. Zou u op basis van deze nieuwe informatie uw standpunt wijzigen over het wel/niet overwegen van resomeren voor uw eigen uitvaart of de uitvaart van iemand die dichtbij u stond? *

Markeer slechts één ovaal.

- Ja, ik overwoog resomeren eerst niet maar op basis van deze informatie zou ik het wel overwegen
- Ja, ik overwoog resomeren eerst wel maar op basis van deze informatie zou ik het niet overwegen
- Nee, ik ben niet van mening gewijzigd
- Nee, de informatie heeft me niks nieuws verteld

13. Kan u toelichten waarom uw mening eventueel gewijzigd is? *

____

14. Wat vindt u ervan dat u geen traditionele kist kunt gebruiken voor resomeren? *

Markeer slechts één ovaal.

- Geen probleem, het maakt me niet uit of ik een traditionele kist kan gebruiken of niet.
- Jammer, maar ik begrijp dat er niks aan te doen is dus ik kies een alternatief.
- Een deal-breaker. Als ik geen traditionele kist kan gebruiken zou ik resomeren niet overwegen.
- Anders: ______________________________

15. Hoe belangrijk vindt u duurzaamheid in het kiezen van uw uitvaart? *

Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Tota	◯	◯	◯	◯	◯	◯	◯	Zeer belangrijk

16. Bent u geïnteresseerd om deel te nemen aan verdere onderzoeken over dit onderwerp? Denk bijv. aan deelname aan een interview of een vervolg-vragenlijst. Zo helpt u mij om mijn ontwerp te verbeteren. Zo ja, laat dan hier uw emailadres achter.

17. Heeft u verder nog vragen of opmerkingen naar aanleiding van de vragenlijst?

Appendix 2 - PISOX dissolvement test Avantium

Research question:
Which PISOX material is the best candidate for fast caustic hydrolysis (resomation conditions)?

Procedure
A solution of 5 wt% sodiumhydroxide was made by dissolving 4.9 grams in 100 mL distilled water. 8 mL of the sodiumhydroxide and 0.5 g wool or polymer was transferred to a glass vial. A small stir bead was added. The glass vials were heated and stirred (200 RPM) by a hotplate (180 – 220 °C). One of the vials was monitored with a digital thermometer. A timelapse with a total duration of 300 min (1 photo per 30 seconds) was taken of the glass vials and thermometer. After the timelapse, the remaining polymer was weighed on a balance.

Results
Two timelapse videos were recorded, the video records can be found in the appendix. The first video contains the wool and PISOX samples 1-5. Note that the video starts out with label A, B, C and D, later when B and C were dissolved they are swapped for E and F. The second video contains commercial available polymers: PET, PLA, ABS and PETG as a comparison. The wool was added as fiber, PISOX as a chunk and the commercials plastic as granulates.
The timelapse videos were further processed by editing software to determine the time to hydrolyze and dissolve the materials, see the table below for an overview of the results.

Table with an overview of the caustic hydrolysis timelapse experiment results. The images used to determine the duration needed for hydrolysis and dissolution are available in the appendix.

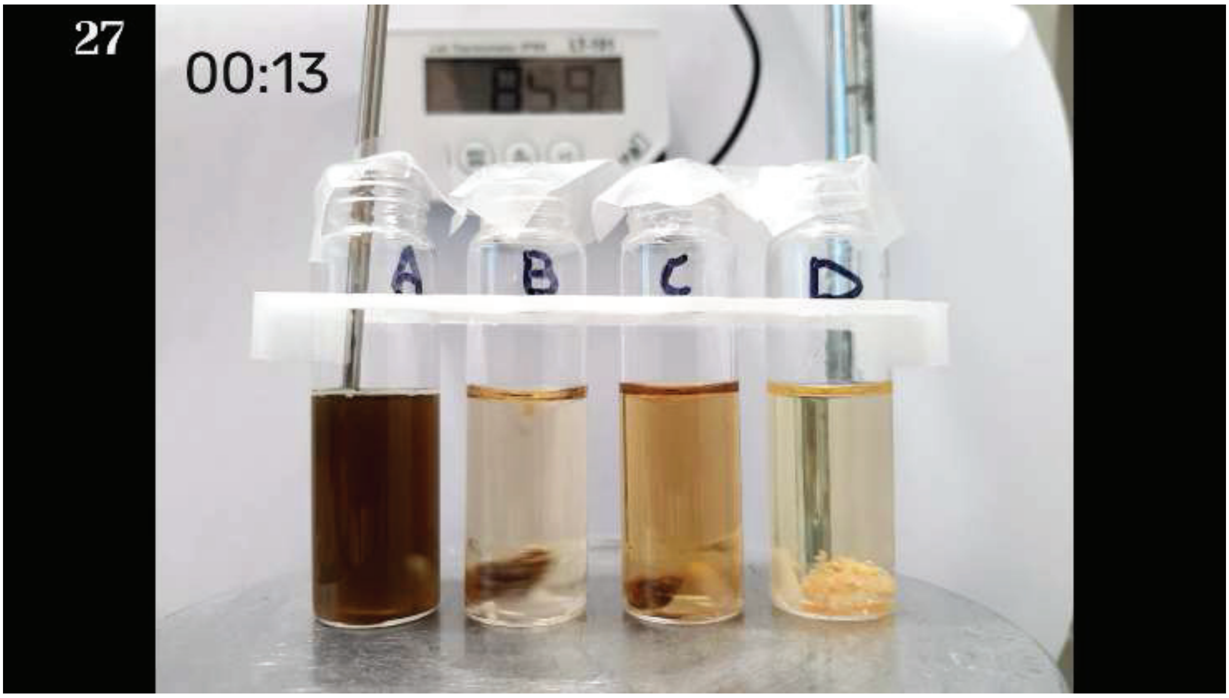
Video	Label	Type	Time to dissolve	Weight left (g)
1	A	Wool	13 minutes	dissolved
	B	PISOX 1	24 minutes	dissolved
	C	PISOX 2	16 minutes	dissolved
	D	PISOX 3	>300 minutes	Not dissolved
	E	PISOX 4	10 minutes disintegration - Not dissolved until more water added	
	F	PISOX 5	10 minutes disintegration - Not dissolved until more water added	
2	PET	PET	>300 minutes	0.5
	PLA	PLA	>300 minutes	0.15
	ABS	ABS	>300 minutes	0.5
	PETG	PETG	>300 minutes	0.5

Discussion
Despite being introduced as a chunk with limited surface area, the camera footage shows that PISOX 1 and 2 readily hydrolyze and dissolve in the caustic solution (< 30 min), very similar to what is observed for wool. The footage also showed that PISOX 4 and 5 disintegrate within 10 minutes. However, there was not enough water available to fully dissolve the residues. After adding more water all dissolved quickly. PISOX 3 did not seem to disintegrate and dissolve readily, even after 300 minutes there was still a chunk of material visible. The commercial polymers did not seem suitable for fast caustic hydrolysis. Also after 300 minutes, the materials did no fully dissolve and disintegrate in the caustic solution, only PLA partly dissolved. This demonstrates the potential of PISOX as an alternative for wool in caustic hydrolysis applications.

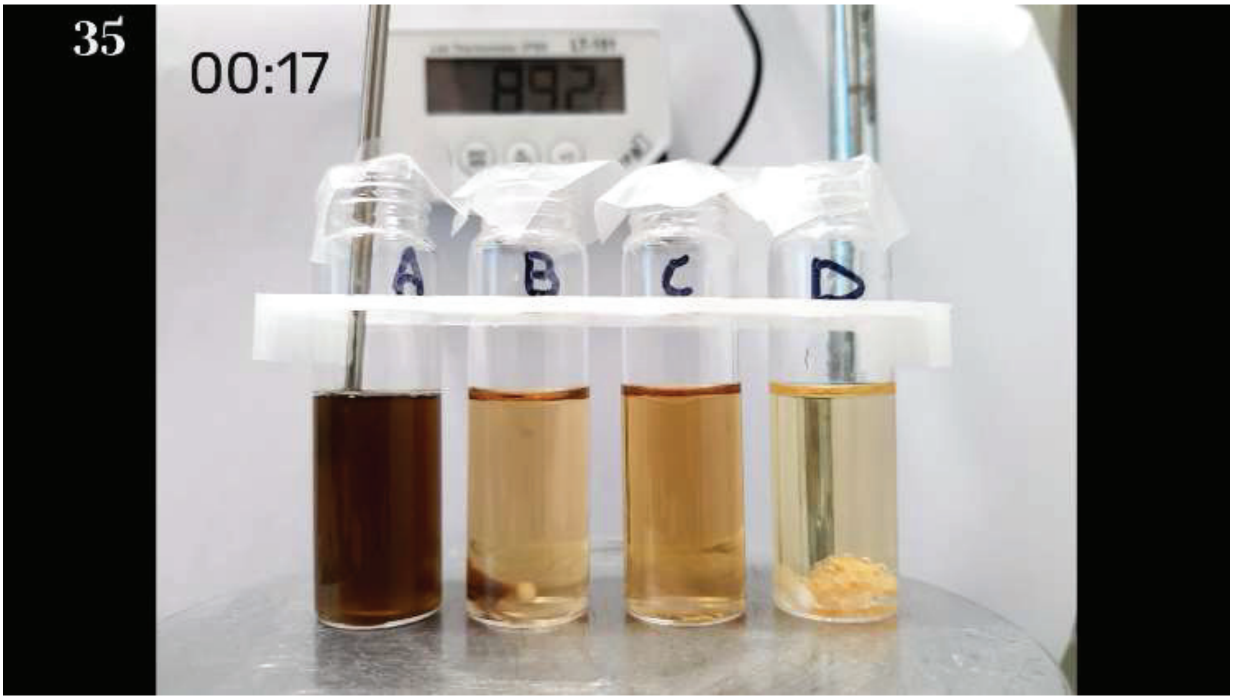
Conclusion
PISOX 1 and 2 showed the best results for fast caustic hydrolysis. PISOX 4 and 5 seem promising candidates. PISOX 3 seems not suited.

Appendix

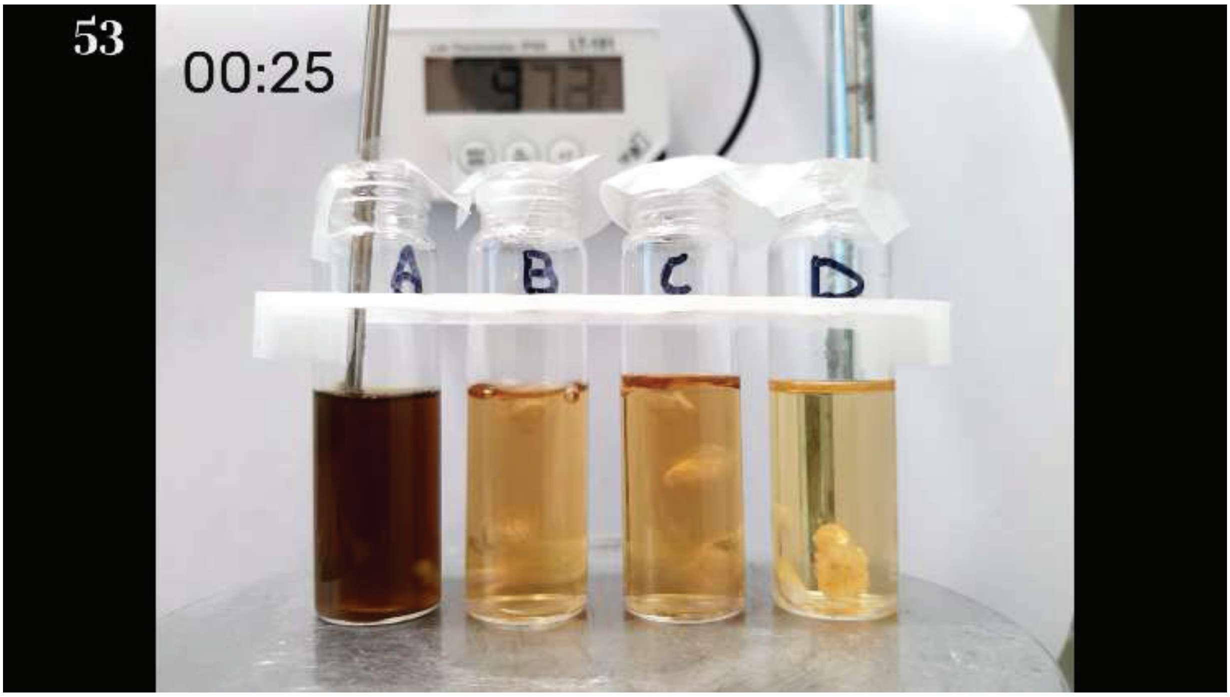
Video 1 – **00:00 start** -



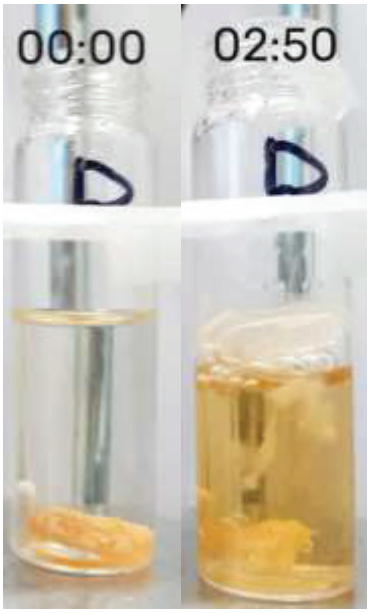
Video 1 – **00:13 -** wool seems dissolved



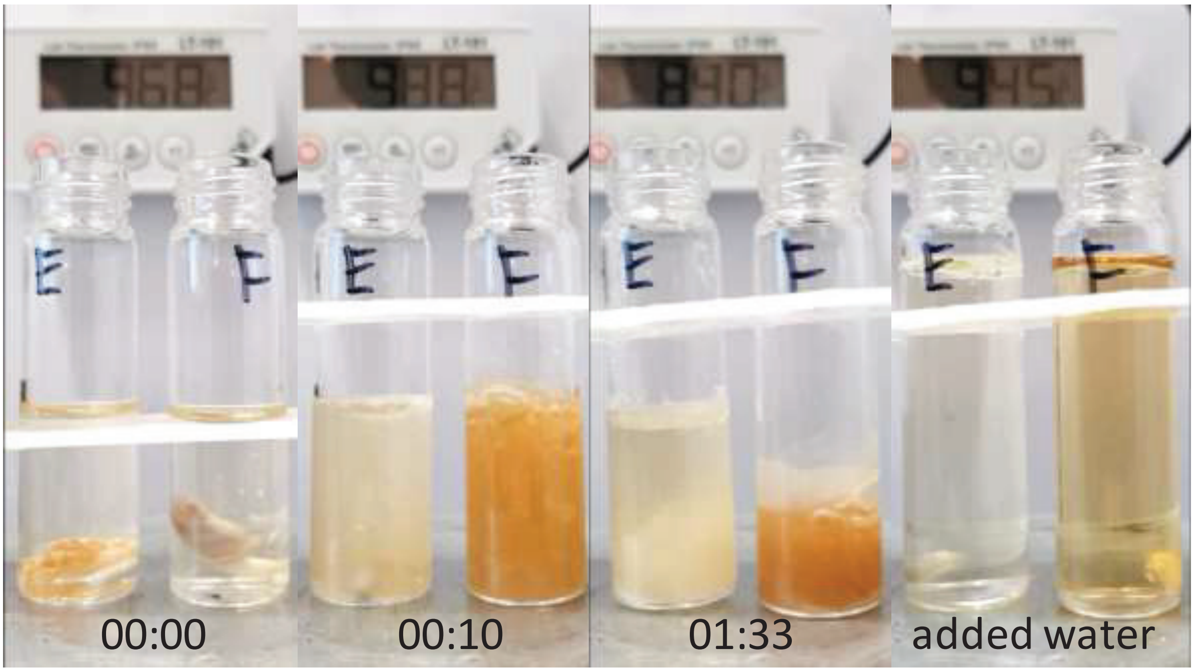
Video 1 – **00:17 -** PISOX in vial C is dissolved/hydrolyzed



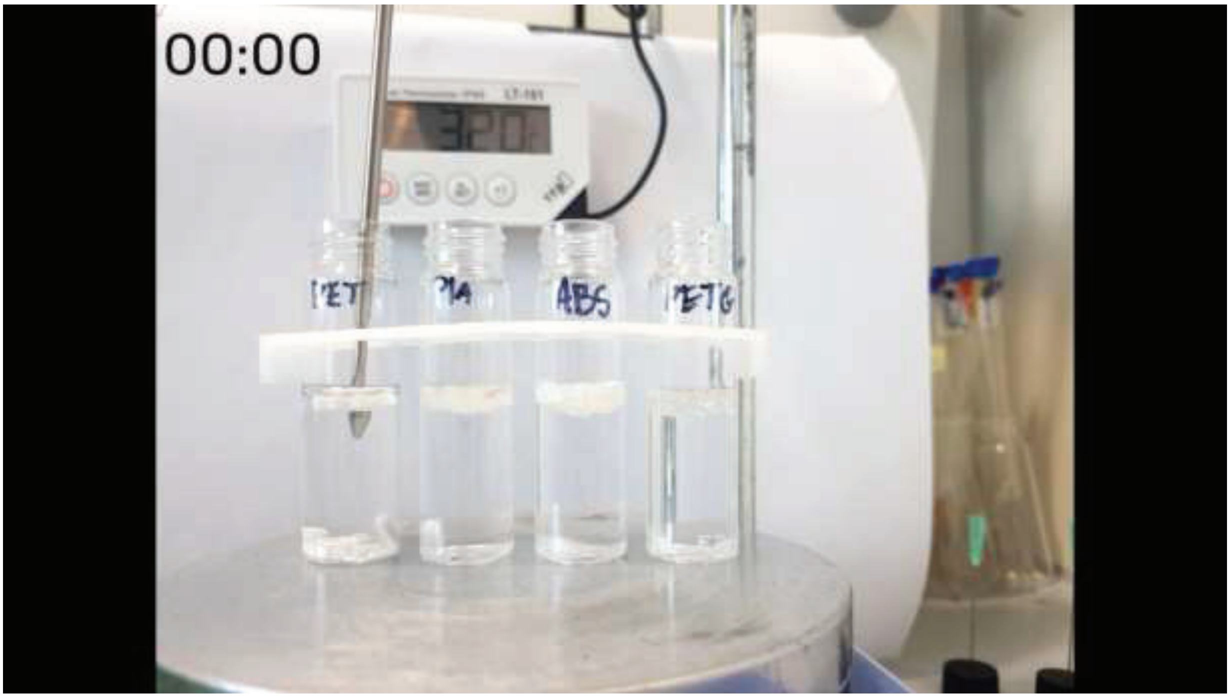
Video 1 – **00:25 -** PISOX in vial B is dissolved/hydrolyzed



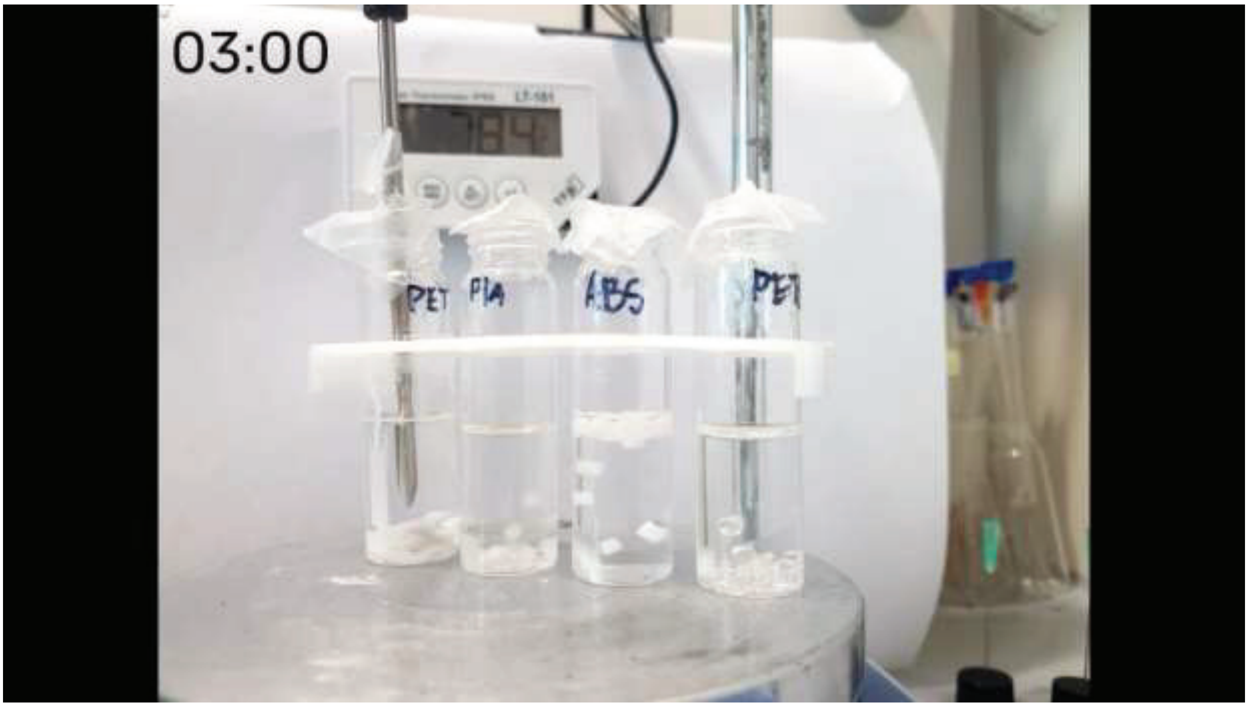
Video 1 –PISOX C at different times during the timelapse experiment. After 2:50 hours PISOX did not completely hydrolyze and dissolve.



Video 1 – The vials B and C were replaced with PISOX E and F. These pictures show PISOX E and F at different times during the timelapse experiment. After 00:10 hours both PISOX E and F seemed to hydrolyze and disintegrate, but did not dissolve. After 01:33 hours both still did not dissolve and there was a lot of bubbling and evaporation of water, especially for PISOX F. When water was added to the vials at 1:33, it became clear that the hydrolysable product were saturated in solution and needed more water to dissolve.



Video 2 – **00:00 –** Start. Not that some of the polymer particles float at the surface.



Video 2 – **03:00 end -** The materials did not completely hydrolyze and dissolve within the timeframe.

Appendix 3 - Requirements and Wishes

Functional requirements

1. The design for a funeral enclosure together with a human body can be resomated in 198 minutes.
2. The enclosure is carryable by 4 or 6 people.
3. The enclosure can store a body.
4. The deceased can be viewed before resomation.
5. Undesired smells from the body are covered.
6. The deceased does not have to be redressed or taken out of the enclosure between the ceremony and before resomation.
7. A personal number can be added to the enclosure.
8. The funeral enclosure can be used in the rain.
9. The funeral enclosure can be fixed in a funeral car.
10. The funeral enclosure has sufficient contact with the cooling plate to ensure proper cooling to preserve the deceased for 6 days.

Perception requirements

1. The enclosure is honourable.
2. The enclosure is customizable.
3. The enclosure is perceived to offer a comfortable final resting place.
4. The enclosure does not create an image that can be associated with the negative media representation.

Technical requirements

1. The product is technologically feasible in 2030.
2. The enclosure fits in the Resomator S750.
3. The product enables carrying a 91 kg weighing deceased.
4. The product can both be produced on a small scale of 100 units a year and also scaled up to a large scale of 100,000 units a year.
5. The funeral enclosure can be stored for at least 30 days.
6. The enclosure does not fail due to moisture that might be released from the deceased.
7. The product can operate in a temperature range between -25 and +45 °C.
8. The enclosure's cost price is lower than €1000.

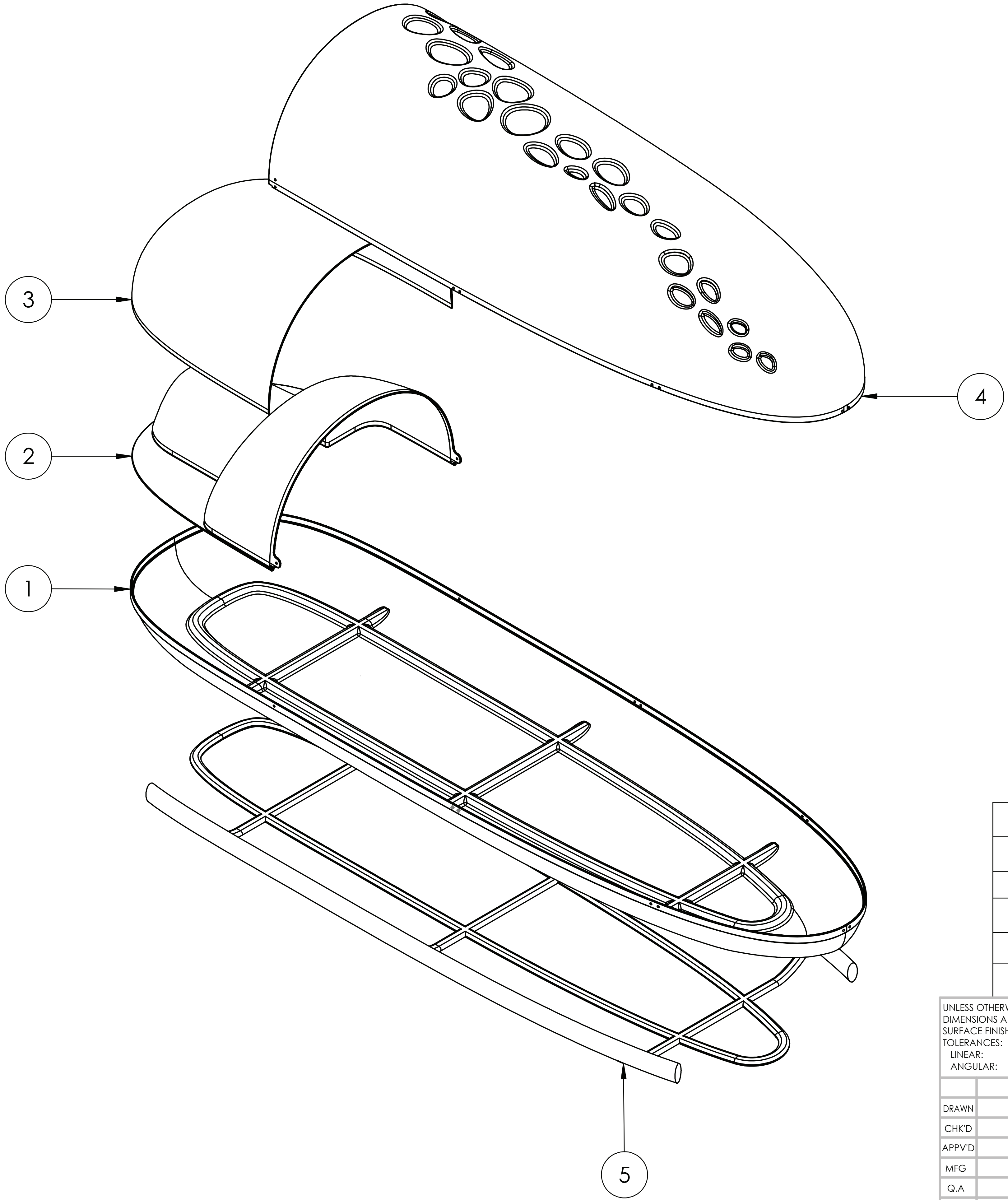
Side effect requirements

1. The pH of the affluent is between 6,5 and 10.
2. The enclosure can be carried in an ergonomical way and does not result in physical harm for people who carry a coffin.
3. The enclosure does not cancel the environmental benefits of resomation.
4. The funeral enclosure cannot fall over.

Wishes

1. The enclosure emphasises the unique characteristics of resomation.
2. The enclosure hides the contours of the deceased.
3. The enclosure does not look like anything that can be associated with a horror movie.
4. The environmental impact of the product is as low as possible.
5. The enclosure can be disassembled or stacked so it can be transported efficiently.
6. The enclosure can be produced as near as possible.

Appendix 4 – Technical drawings



ITEM NO.	PART NUMBER	Material	QTY.
1	Bottom	PISOX	1
2	Functional cover	PISOX	1
3	Head cover	PISOX	1
4	Feet cover	PISOX	1
5	Frame	Stainless steel 316	1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL:

WEIGHT:

TITLE:

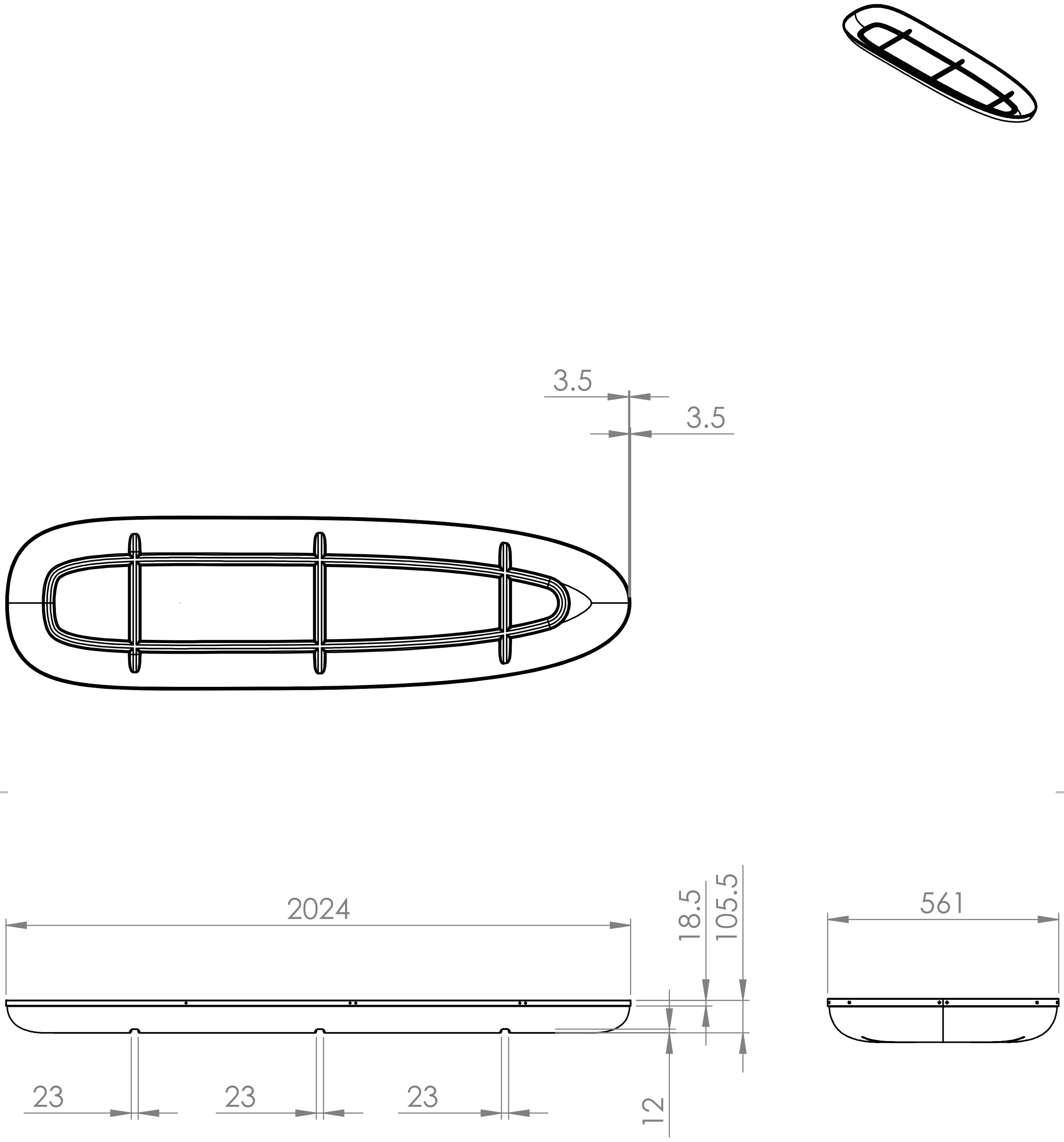
De Zeepkist

DWG NO.

A3

SCALE:1:20

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE: Bottom

MATERIAL: PISOX

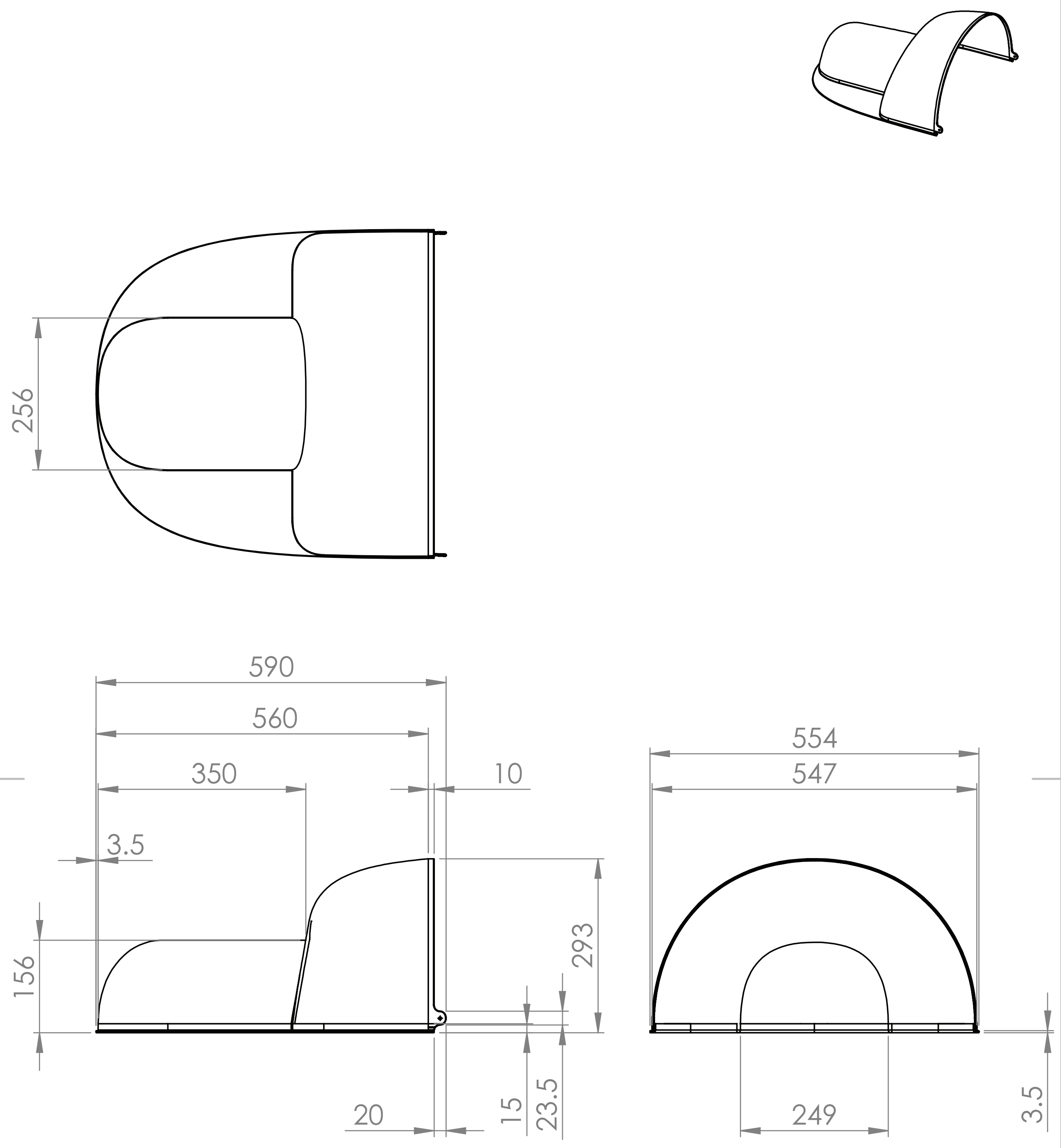
WEIGHT: 6.6 kg

DWG NO. 1

A4

SCALE:1:10

SHEET 1 OF 1



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LINEAR:
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FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

Functional cover

MATERIAL: PISOX

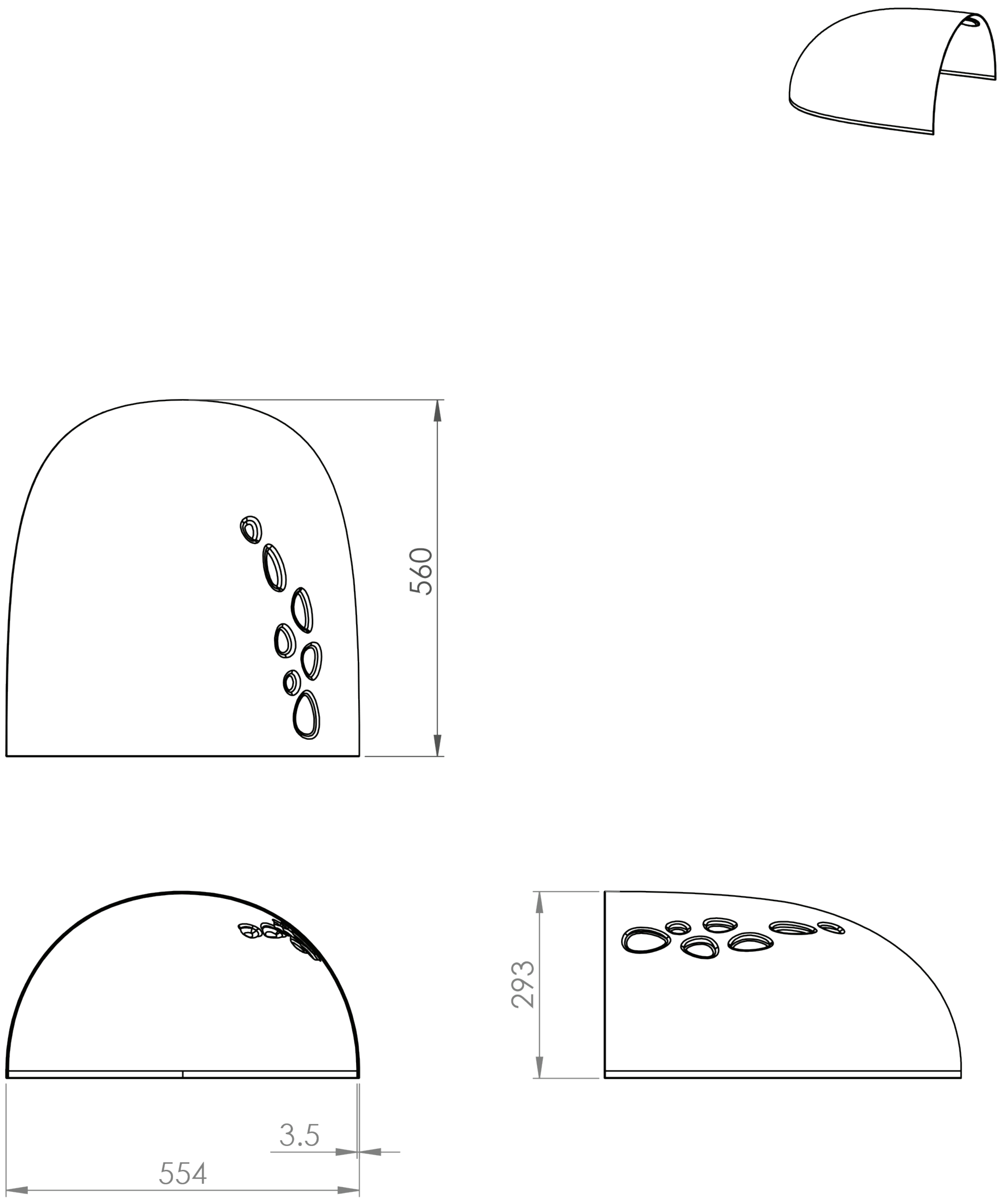
WEIGHT: 2.3 kg

DWG NO. 2

A4

SCALE:1:10

SHEET 1 OF 1



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TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

Head cover

MATERIAL: PISOX

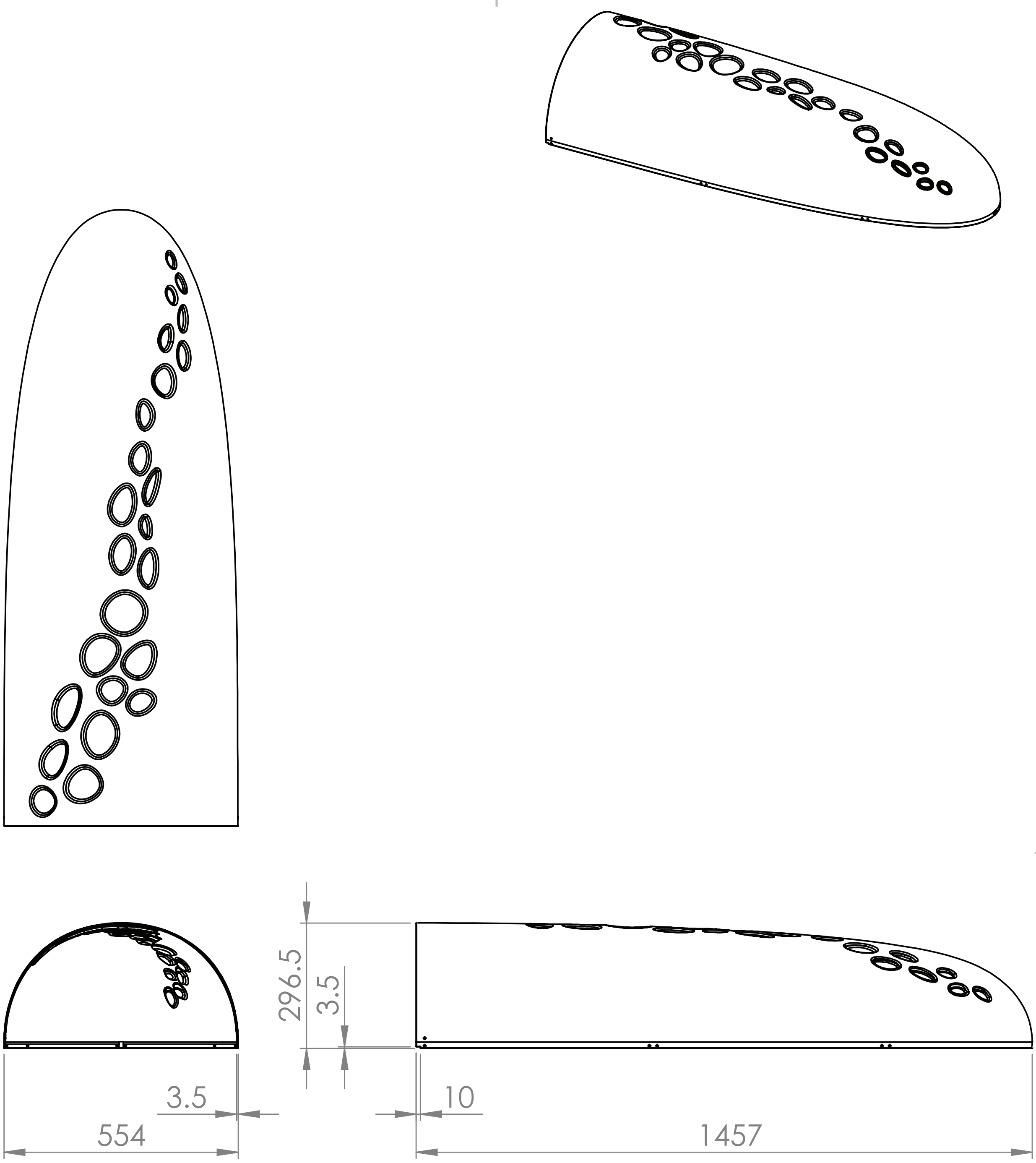
DWG NO. 3

A4

WEIGHT: 2.4 kg

SCALE:1:10

SHEET 1 OF 1



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SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

Feet cover

MATERIAL: PISOX

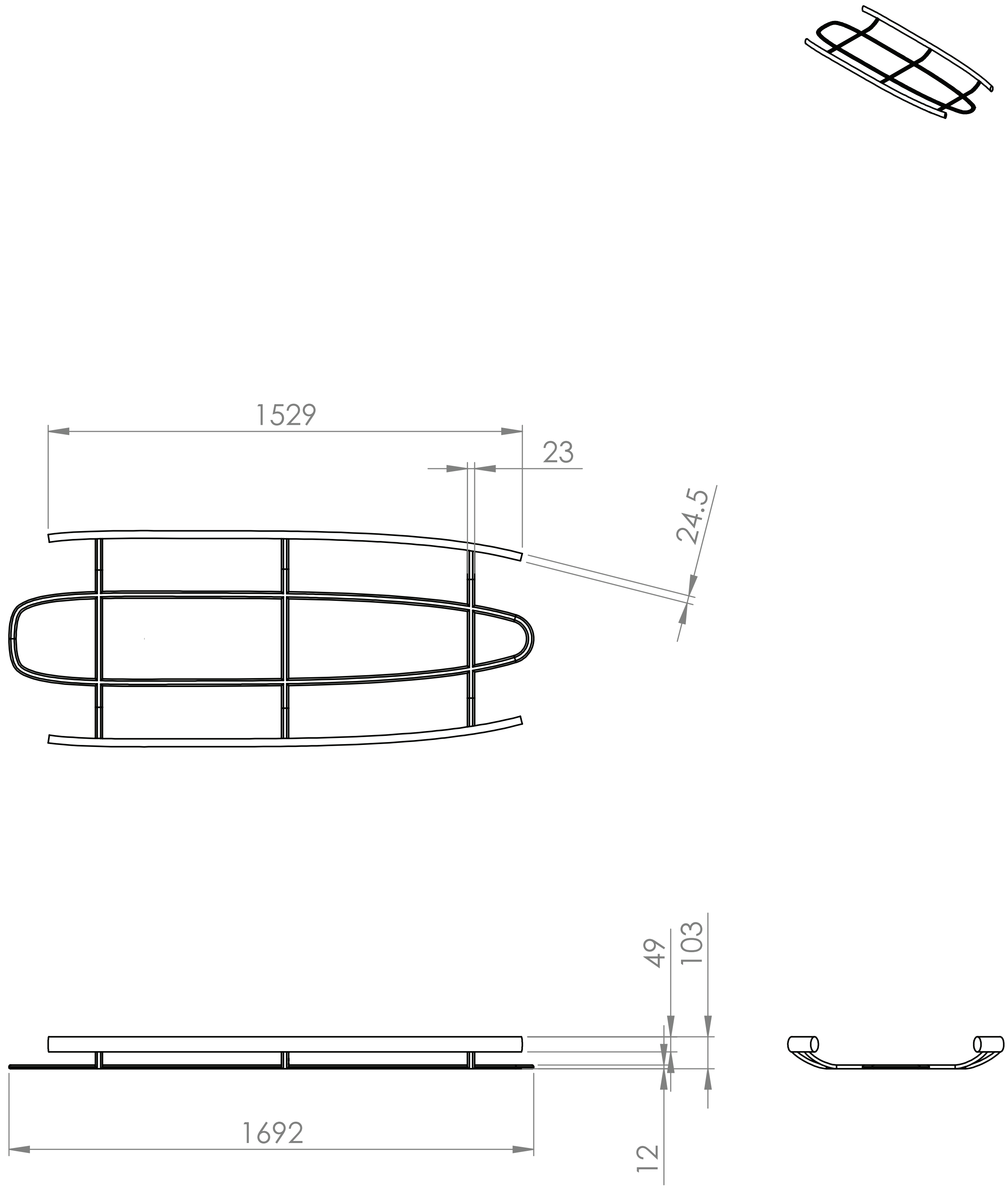
WEIGHT: 6.0 kg

DWG NO. 4

A4

SCALE:1:15

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING | REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE: Frame

MATERIAL: Stainless steel 316

DWG NO. 5

A4

WEIGHT: 6.6 kg

SCALE:1:20

SHEET 1 OF 1

Appendix 5 - Interview setup

The interviews are held in Dutch. First, an introduction is given and an informed consent form is signed by the participant. Then questions are asked with extra information halfway through the interview questions. The next paragraphs are gone through consecutively.

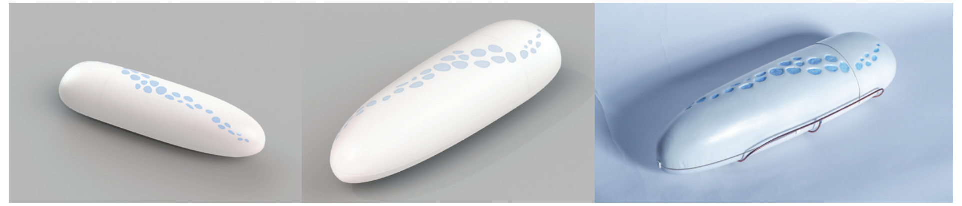
Introduction
Welkom bij dit onderzoek. De afgelopen maanden ben ik bezig geweest met het ontwerp van een grafkist voor resomeren. Dit ontwerp wil ik aan u voorleggen en aan u vragen hoe u dit ervaart. Om het ontwerp weer te geven zal ik straks een aantal afbeeldingen laten zien, zowel als een prototype. Dit mag u aanraken en hiermee spelen. Eerst zal ik u een aantal algemene vragen stellen, daarna zal ik u het ontwerp laten zien en daar vragen over stellen. Ik wil benadrukken dat het interview een onderwerp bespreekt waarbij het goed mogelijk is dat u zich er minder comfortabel bij voelt. Als u niet wilt antwoorden dan is dat niet nodig, en ook kunt u altijd halverwege het onderzoek stoppen, geeft u dat dan aan. Voordat we gaan beginnen wil ik u vragen om deze informed consent form te lezen en te ondertekenen als u mee wilt doen aan dit onderzoek.

* participant signs informed consent form *

Dank u wel voor het ondertekenen. Bent u er klaar voor?

Algemeen
1. Wat is uw leeftijd?
2. Hoe identificeert u zich? (m/v/x)
3. Heb je een persoonlijke voorkeur voor een specifieke uitvaarttechniek, voor jezelf of voor mensen om je heen?
4. Heeft u weleens gehoord van de uitvaarttechniek resomeren?
5. Wat weet u van resomeren?

Resomeren is een uitvaarttechniek die relatief nieuw is. In het buitenland is deze techniek op sommige plekken al toegestaan en in Nederland wordt er verwacht dat deze binnenkort toegestaan zal worden. Bij resomeren wordt een lichaam in een resomator gelegd, dit is een machine te zien als op deze foto. Het lichaam wordt hierin afgebroken volgens het proces van alkalische hydrolyse. Dit houdt in dat het lichaam wordt omgeven door een oplossing van warm water en een basische stof die het lichaam in ca. 2,5 uur afbreekt. Na 2,5 uur blijft van het lichaam alleen de botten over. Deze worden eerst verpoederd en kunnen vervolgens met de nabestaanden worden meegegeven in een urn. Een nadeel van resomeren is dat slechts een beperkt aantal materialen geschikt zijn voor alkalische hydrolyse. Bijvoorbeeld hout kan niet worden afgebroken in het proces, waardoor het niet mogelijk is om een houten grafkist te gebruiken. Om deze reden heb ik een nieuwe uitvaartkist ontworpen die wel kan worden afgebroken door alkalische hydrolyse.
Nu zal ik het ontwerp laten zien. Het ontwerp is een grafkist gemaakt van een combinatie van een afbreekbare kunststof en zeep, en heet daarom De Zeepkist. Hierbij zijn de gekleurde onderdelen van zeep gemaakt en de witte onderdelen van kunststof. Vlak voordat deze kist de machine ingaat, wordt een kap bij het hoofddeel weggehaald, dit gaat om dit onderdeel. De reden hiervoor is dat de kist anders niet in de machine past. In het prototype is geen zeep toegevoegd, in plaats daarvan heb ik hier een stuk zeep dat gebruikt zal worden op de gekleurde onderdelen van het ontwerp.



Ontwerp
1. Wat is uw eerste gedachte of gevoel wanneer u deze grafkist ziet?
2. Wat vindt u ervan dat er een deel wordt weggehaald voordat de kist de resomator ingaat?
3. Stel dat u naar een uitvaart gaat en u ziet deze grafkist staan, wat vindt u daarvan?
4. Hoe aannemelijk acht u de kans dat u deze grafkist zou kiezen voor de uitvaart van een familielid van u, of voor uzelf?
5. Wat vindt u van het gebruik van kleur in een grafkist?
6. Wat vindt u van het gebruik van een geur in een grafkist?
7. Stel u voor dat u een uitvaart aan het plannen bent en u kiest voor resomeren als uitvaarttechniek. Door het kiezen voor resomeren bent u beperkt in de mogelijkheden wat betreft een uitvaart-omhulsel om het lichaam in te bewaren en presenteren. In Nederland kunt u dan kiezen uit de volgende opties (afbeelding wade, zeepkist). Hoe voelt u zich over deze opties? En heeft u een voorkeur voor een van de opties?
8. Stel dat de volgende kist ook een optie is, verandert uw keuze dan? (afbeelding kartonnen kist)
9. Vergeet even de verschillende uitvaarttechnieken en welke kist waarvoor geschikt is. Hier ziet u een overzicht van allerlei verschillende uitvaart-omhulsels. Stel je voor dat elke kist voor elke uitvaarttechniek gebruikt zou kunnen worden. Kunt u de omhulsels op volgorde leggen van hoe mooi u deze vindt en hoe waarschijnlijk het is dat u deze zou kiezen?

Dank u wel voor uw deelname aan het onderzoek. Heeft u nog vragen?

Appendix 6 - Informed consent form

Participant ID: ....

De Zeepkist study

This research is conducted as part of the MSc study Industrial Design Engineering at TU Delft. The purpose of this research study is to evaluate potential user's experience of the design of De Zeepkist, a novel coffin designed for resomation.

Researcher: Sasja van Andel

Informed consent participant

I participate in this research voluntarily.

I acknowledge that I received sufficient information and explanation about the research and that all my questions have been answered satisfactorily. I was given sufficient time to consent my participation. I can ask questions for further clarification at any moment during the research.

I am aware that this research consists of the following activities:

1. An interview about the design of De Zeepkist, a design concept for a novel coffin and includes discussing about death and loss. During the interview a prototype is observed and discussed.

I am aware that data will be collected during the research, such as notes and photos, including demographic information. I give permission for collecting this data and for making photos during the research. Data will be processed and analysed anonymously (without your name or other identifiable information). I am aware that the results of this study will be shared in the master thesis of the abovementioned researcher and I approve of the use of my data for this purpose. I am aware that as a result of a small number of participants, I might be able to be reidentified by my data, though this is tried to be avoided at all cost.

The photos will be used to support analysis of the collected data. The photos can also be used to illustrate research findings in publications and presentations about the project.

I give permission for using photos of my participation:
(select what applies for you)

- ☐ in which I am <u>recognisable</u> in publications and presentations about the project.
- ☐ in which I am <u>not recognisable</u> in publications and presentations about the project.
- ☐ <u>for data analysis only</u> and not for publications and presentations about the project.

I give permission to store the data for a maximum of 5 years after completion of this research and using it for educational and research purposes.

I acknowledge that no financial compensation will be provided for my participation in this research.

With my signature I acknowledge that I have read the provided information about the research and understand the nature of my participation. I understand that I am free to withdraw and stop participation in the research at any given time without any reason, including when I start to feel uncomfortable talking about the topic of death and loss. I understand that I am not obliged to answer questions which I prefer not to answer and I can indicate this to the research team.

I will receive a copy of this consent form.

______________________	______________________
Last name	First name
___ / ___ / 2024	______________________
Date (dd/mm/yyyy)	Signature

DESIGN FOR our future

TU Delft

Appendix 7 - Project brief

Personal Project Brief – IDE Master Graduation Project

Name student Sasja van Andel **Student number** 4,660,307

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT
Complete all fields, keep information clear, specific and concise

Project title De Zeepkist, a resomation suitable funeral enclosure, exploration (examination) and design

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

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

In past centuries, only two body disposal methods were practised in The Netherlands, which are burial and cremation. These body disposal methods have a burden on the environment for different reasons. In order to provide an alternative more sustainable body disposal method, a new technique called resomation is about to be introduced in The Netherlands. In a study by TNO, it has been estimated that the eco-costs of resomation are about 8 times lower as those of burial and cremation (Keijzer et al., 2014), which shows the more sustainable nature of resomation.

Resomation is a body disposal method that involves the chemical process of alkaline hydrolysis, which decomposes a body acceleratedly (Robinson, 2021). The process of alkaline hydrolysis exempts the use of conventional funeral enclosures (Robinson, 2021), as materials such as wood cannot be decomposed through this process. Currently, only shrouds made of wool, silk or leather are suitable to be resomated (Robinson, 2021), but many people feel uncomfortable saying goodbye to their loved ones in a shroud (Bokdam et al., 2021). New types of funeral enclosures therefore need to be introduced to enable bereaved to say goodbye to their loved ones in a comfortable and respectful manner. The perception of the bereaved is important for people to accept resomation as a possible funeral technique. Important aspects that influence the perception of the bereaved is the aesthetics and the clothing of the deceased.

During the course Advanced Concept Design, the design concept De Zeepkist ('The soapbox') has been developed for Eer & Volharding, a funeral company in South-Holland. De Zeepkist is a funeral enclosure made of soap and pisox, a biobased polymer which is under development by Avantium. These materials offer an interesting potential as they can both be dissolved by resomation and can still offer the strength and honorable characteristics that are needed for a coffin. The exact material compositions of both soap and pisox still needs to be defined and their resomatability should be tested in a more advanced setup.

→ *space available for images / figures on next page*

introduction (continued): space for images

image / figure 1 De Zeepkist in a laying room

image / figure 2 A deceased person laid out

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice.
(max 200 words)

In this project I want to focus on three aspects related to the design of De Zeepkist:

1. Technical. Both soap and pisox are materials that can be tweaked by using different components for making the materials. The ideal composition of these materials need to be defined. Important characteristics of these materials are resomatability of the materials and mechanical characteristics. For soap, the fragrance is important. Additionally, it should be analysed how De Zeepkist can be produced, first on a small scale and how this can be scaled up.
2. Design. This involves aesthetics and ergonomics. Aspects such as dimensions of the enclosure, the carrying of the enclosure and the use of clothing need to be considered.
3. Acceptance. Research needs to point out how people perceive such an innovative funeral enclosure as De Zeepkist and whether they will accept it.

All these aspects need to come together in an improved design of De Zeepkist, and answer the question whether or not De Zeepkist is a viable concept.

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence) As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format:

Elaborate on the design of De Zeepkist to validate De Zeepkist's viability and chance to be accepted by 2030 for Eer & Volharding.

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

I have divided the project into four main aspects, which are technical research & ideation, Design research & ideation, acceptance research and final design. Activities for these different aspects can be done simultaneously and all aspects are an iterative process. For the design research I will include user studies regarding aesthetics and how people experience the materials. During the technical tests, wool will function as a reference material as this is the most common shroud material that could function as an alternative funeral enclosure. See the attached appendix for a planning of the project.

Project planning and key moments

*To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a **kick-off meeting, mid-term evaluation meeting, green light meeting** and **graduation ceremony**. 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 course activities).*

Make sure to attach the full plan to this project brief.
The four key moment dates must be filled in below

Kick off meeting	9 Feb 2024
Mid-term evaluation	4 Apr 2024
Green light meeting	31 May 2024
Graduation ceremony	28 Jun 2024

In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project

Part of project scheduled part-time	
For how many project weeks	
Number of project days per week	

Comments:

Motivation and personal ambitions

Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five.
(200 words max)