The First Circular Product Design with Dyneema®

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Executive summary

DSM Dyneema produces an extremely strong fibre called Dyneema® consisting of Ultra High Molecular weight Polyethylene (UHMWPE). The Dyneema® material has been trademarked by its manufacturer as The Greenest strength™. This claim is based on the non-toxic chemical nature of the material and its production, as well as on having the lowest carbon footprint on a strength to weight ratio. Due to this strength of the fibre, less material is required than alternatives to achieve the same level of performance, thus a reduction in carbon footprint can be achieved. The Carbon footprint during manufacturing and use is lower than its competitors.

However at the end of its product life Dyneema® fibre products are incinerated or landfilled. DSM Dyneema wants to have a circular alternative for the end of life of Dyneema® fibre products. In this thesis the design process is described to create a circular product from production waste material from Dyneema®.

Using the context variation by design approach, requirements for a circular product are combined with material properties and possible contexts for applications. The result is a design proposal for a summer sleeping bag, that is well suited for the different types of use that befall a summer sleeping bag. It will be made from Dyneema® production waste and recycled materials, and allows user to send it back to the manufacturer after it has lived out its useful life, free of charge. The manufacturer can then re-use the materials for new sleeping bags, or recycle them otherwise, thus preventing the material from falling out of the loop.

Glossary

Spread throughout the report several abbreviations are used. The meaning of these are as follows:

UHMWPE	Ultra high molecular weight polyethylene
CVD	Context variation by design
CPD	Circular product design
UDY	Undrawn yarn
PDY	Partially drawn yarn
FDY	Fully drawn yarn
DFC	Dyneema® Flexible Composite
CES	Cambridge engineering selector
EoL	End of life

Contents

1. Introduction

DSM Dyneema produces an extremely strong material called Dyneema® consisting of Ultra High Molecular weight Polyethylene (UHMWPE). The material is available in four forms: Fibres, Unidirectional sheets; both flexible and hard composites, Tapes and Fabrics. In these different forms the material is used in many different applications: from strong, yet lightweight ropes, to hockey sticks, from protective jeans, and cut-resistant gloves, to bulletproof vests.

The Dyneema® material has been trademarked by its manufacturer as The Greenest strength™. This claim is based on the non-toxic chemical nature of the material and its production, as well as on having the lowest carbon footprint on a strength to weight ratio. Due to this strength of the fibre less material is required than alternatives to achieve the same level of performance, thus a reduction in carbon footprint can be achieved. The Carbon footprint during manufacturing and use is lower than its competitors. However at the end of its product life Dyneema® fibre products are incinerated or landfilled. DSM Dyneema wants to have a circular alternative for the end of life of Dyneema® fibre products. This alternative should be a commercially viable circular product, or a circular application of Dyneema® in a product, which means that at the end of its life, the product, or Dyneema® yarn in the product, can be recycled, and sold again.

1.1 The assignment

The extremely strong Dyneema® fibre material, currently offers The Greenest Strength™ for high performance fibre products. The Carbon footprint during manufacturing and use is lower than its competitors. However waste, generated during production of the Dyneema® fibre (figure 1), is incinerated or landfilled. DSM Dyneema wants to have a circular alternative for this production waste. This alternative should be a commercially viable circular product, or application of Dyneema® in a product, which means that at the end of its life, the product, or Dyneema® yarn in the product, can be recycled, and sold again.

The product will be initially made from fabrication waste, generated during manufacturing of Dyneema® fibre products.

The product should be commercially viable; meaning it should fit to customer and market needs and be producable so it can be sold with a profit. It will be either produced by DSM Dyneema or in partnership with them.

The product or Dyneema® application should be circular, which means the (Dyneema® in the) product should be able to be re-used, refurbished or recycled without loss of quality.

A bussines case for the product is required to assure the implementation of circularity, whilst maintaining commercial viability.

A Context Variation by Design approach will be taken, in order to focus on getting the best possible combination of commercial viability and circular design in the final product proposal by including multiple context factors from the start without trying to simplify them early in the process. Therefore the limits set at the start of the project will be minimal and limited to those mentioned above. The full project brief is shown in appendix V.

Photo taken by F. Rutten

Figure 1: Dyneema production waste

1.2 Context Variation by Design (CVD)

Over the course of this project the Context Variation by Design approach is applied. This is a relatively young method of approaching a (design) problem at the moment of writing. The approach of CVD is to combine multiple contexts early on in the design process to create a rich and shared design space (Kersten, Crul, Diehl, & Van Engelen, 2018). In fact, "before the design task is set" systematic variation with regards to incorporating contexts is applied. Information is gathered from multiple contexts, and brought together as collective intelligence. The definition of context can differ between projects; from demographics, to use cases, to the lifecycle stages that a product goes through, etcetera. Insights gained from the context analysis are then brought together to compare and create shared insights. These shared insights contain commonalities and differences, but might also contain patterns that arose by bringing information from these contexts together. Based on this information, decisions can now be made more informed, and requirements for the product can be set. The shared insights as well as the individual context information are useful during the generation of ideas and help build the base of an adaptive product architecture. From this product architecture, one or more implementation variants can be developed. (figure 2)

1.2.1 The benefits of using CVD

By looking at multiple contexts from the beginning, CVD differs from other design processes, which focus on a single context. Having a single context can lead to early simplification guided by reductionism (Nelson, 2007). Early simplification feels like a designer or manager is creating more control over the design process, but this approach has some drawbacks (Kersten, Diehl, & Van Engelen, 2017):

Heads down design (Meyerson, 2015): A simplified analysis, focusing on one specific context results in incomplete views, which in turn results in a design space with limited relevance. This way connections to the larger system can unintendedly get lost.

Path dependency Follow up steps taken to improve the initial solution will be small variations of the first step, even if following steps require a different direction or perspective of the situation (Jones, 2015). This might not impede a solutions success in a first context, but it can slow down its success in others, since design (directions) have to be redone and adapted to the next context.

Early simplification reduces the solution space: Real life has a lot of complexity in elements and interactions. Heavily reducing or simplifying these, although a human tendency (Simon, 1969), is unlikely to lead to a design with large-scale positive societal effects.

The CVD approach evades these problems by delaying simplification to a point where a decision can be made more informed. Design decisions and simplifications can then be made with a broader understanding and thus more deliberate. Furthermore ideas created in this shared design space seem to be more rich (Kersten, Diehl, Crul, & Van Engelen, 2017), and will likely lead to solutions of a higher quality, that would not likely have been generated based on the information from a single context (Kersten, Diehl, & Van Engelen, 2018).

Kersten, Diehl, & Crul, 2017 also found that the CVD approach is experienced by designers as broadening the mind in a more purposeful way than having just random inspiration. CVD thereby seems to help designers find inspiration that is neither too far removed from, or too closely related to the subject, which according to Gonçalves (2016) stimulates creativity as well as relevance.

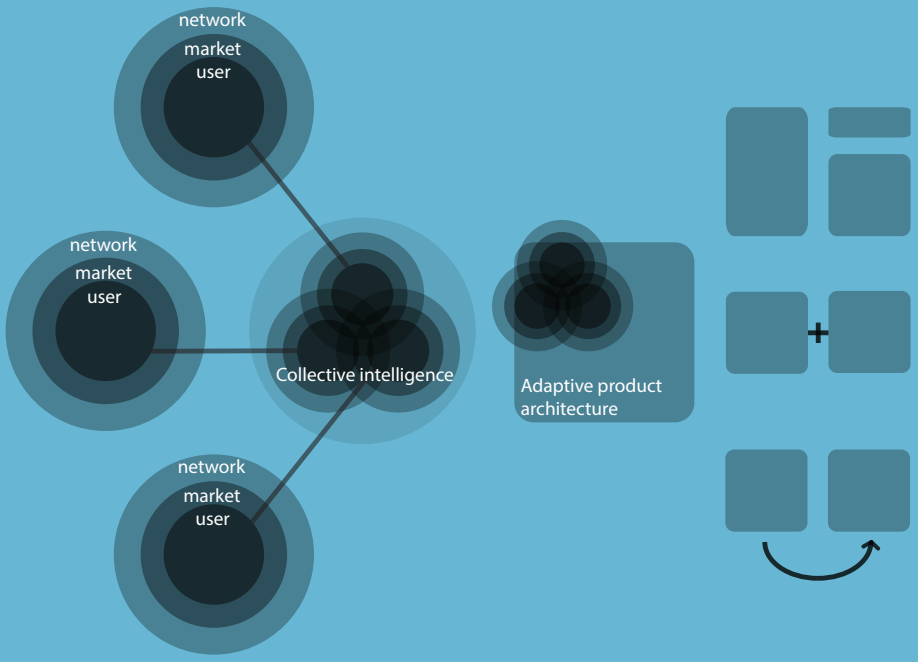


Figure 2 Context variation by design schedule based on Kersten et al. (2016)

1.2.2 CVD in this project

Within this graduation project the chosen contexts to combine are:

The production of the material and its properties. Since the material to work with is set from the beginning, insights into production and material properties are highly important for a design made with Dyneema®.

The theory on circular economy and the lifecycle stages a product goes through. Also set from the start of the project is the demand for a circular application for the material, therefore knowledge on circular design is very relevant and useful to allow to interact with insights gained elsewhere.

The market application field that is called "Commercial Marine" by DSM Dyneema. Based on volume of yarn sold this is the largest field of application for Dyneema®. The brand is well known and widespread, and has been in this market for a long time. Insights in how the material is used and what is done with it after use can be gained and offer potential for interaction within CVD.

The market application field of outdoor sports, such as camping and hiking, etcetera. This is a relatively new market for Dyneema® and can offer a lot of new methods for applications. Yet they are not totally unknown in the market either. Insights in market requirements can be combined with what the material has to offer to come to new application possibilities.

The insights from these contexts will be brought together to form a collective intelligence. This will help inspire ideas for applications for the material. If required, different types of use for this application are researched. As a second group of contexts, they help inspire and determine an adaptive product architecture out of which one or more final implemention variants will arise as conclusionary design proposals.

2. Analysis

2.1 Context one: Dyneema® Production

The Dyneema® fibre is produced through a method called gel spinning (Van der Werff, 2018). In this process Ultra High Molecular Weight Polyethylene (UHMWPE) powder is extruded together with a solvent. DSM is making its UHMWPE powder in house, to assure the molecular composition is perfected for realising a high strength fibre. The solvent is added in the gel spinning process to reduce the entanglements between the UHMWPE polymers, which in turn improves alignment in a later stage of production. During extrusion, the suspension of powder and solvent is heated to a solution, before creating strings of liquid yarn. These yarn strings are led through a cold water bath to let the polymers crystallise. The now solid yarn goes through an oven, at a temperature just under the melting stage of the polymer, to let the solvent evaporate, and to stretch the polymer. This is done to align the polymers, which gives the Dyneema® fibre its specific properties. Having less polymer entanglements allows the polymers to move more independently of each other. Therefore the polymers can align better, which makes the final strand of Dyneema® fibre stronger. After this, the yarn is rolled onto a bobbin. The material on this bobbin is called Partially Drawn Yarn (PDY), and still contains a little solvent, less than one percent. It needs to go through another oven to be stretched once more to turn it into Fully Drawn Yarn (FDY). This is the starting point for later production steps, that turn the yarn into the final Dyneema® products. this process is visualised in figure 3

2.1.1 Material Properties

Since the Dyneema® fibre is produced in such a specific way, generic UHMWPE material property information is likely to be wrong. For this reason specific material property information for Dyneema® is required. Material properties have been engineered to such an extent, that they can even vary greatly between different types of Dyneema® fibres (DSM Dyneema, 2016). As can be noted from figure 4, the Young's modulus, or tensile modulus, between different types of Dyneema® ranges from 34 GPa to 155 GPa. In comparison, the Cambridge Engineering Selector (CES, 2018) provides a Young's modulus for generic UHMWPE of 0,894 GPa to 0,963 GPa (figure 5). A similar distortion between generic and specific material property information is seen in the tensile strength. For Dyneema® this ranges between 1,6 GPa to 4,1 GPa, where CES has it for generic UHMWPE at 0,4 GPa to 0,5 GPa. Both differences show the importance of looking for the specific information for Dyneema®, rather than using generic UHMWPE material properties.

Dyneema® fibre has a large difference between tension and compression, as well as between axial and transverse properties, which are given in figure 6. Next to its remarkable mechanical properties, Dyneema® has an excellent chemical resistance, which allows for constant mechanical performance in all conditions.

It has a high axial thermal conductivity with a low transversal thermal conductivity.

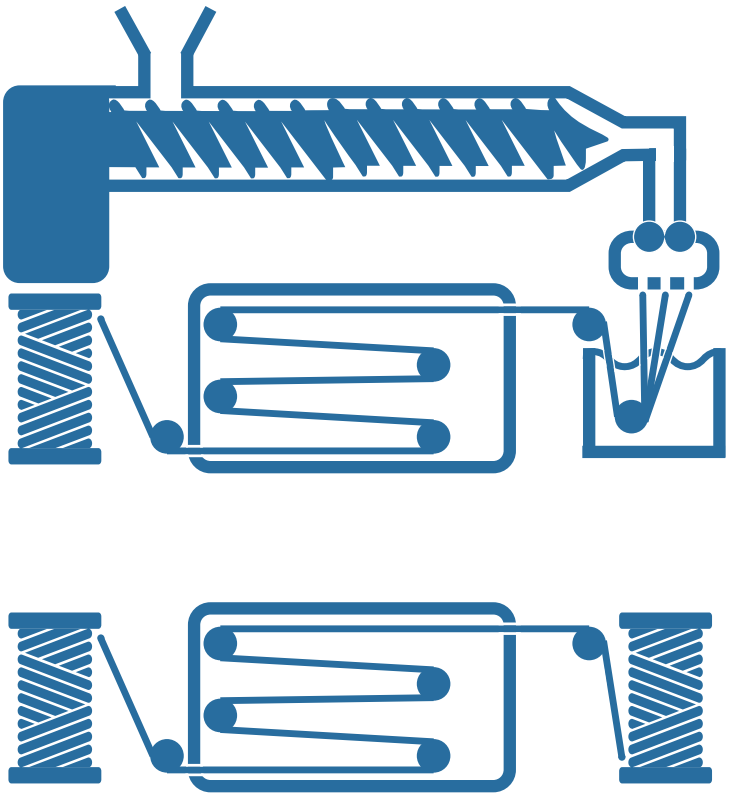


Figure 3 Visualisation of the production process of Dyneema®

UHMWPE Fiber Type	Tensile Strength			Tensile Modulus			Elongation to break %
	N/tex	g/den	GPa	N/tex	g/den	GPa	
SK99	4.3	48	4.1	159	1801	155	3 - 4
DM20*	3.2	36	3.1	96	1088	94	
SK75* SK78*	3.4 - 4.0	38 - 45	3.3 - 3.9	112 - 137	1267 - 1552	109 - 132	
SK60 SK62 SK65	2.3 - 3.4	28 - 38	2.4 - 3.3	67 - 102	759 - 1158	65 - 100	
SK38	1.7	19	1.6	35	396	34	6.5

Figure 4 Fibre strength properties for different Dyneema® fibre types (DSM Dyneema, 2016)

Mechanical properties

Young's modulus	* 0,894	-	0,963	GPa
Specific stiffness	* 0,95	-	1,03	MN.m/kg
Yield strength (elastic limit)	21,4	-	27,6	MPa
Tensile strength	38,6	-	48,3	MPa
Specific strength	* 22,8	-	29,4	kN.m/kg
Elongation	350	-	525	% strain
Compressive modulus	* 0,894	-	0,963	GPa
Compressive strength	* 25,7	-	33,1	MPa
Flexural modulus	0,894	-	0,963	GPa
Flexural strength (modulus of rupture)	* 54	-	67,6	MPa
Shear modulus	* 0,314	-	0,339	GPa
Bulk modulus	* 1,93	-	2,02	GPa
Poisson's ratio	* 0,413	-	0,43	
Shape factor	4,6			
Hardness - Vickers	* 6	-	8	HV
Hardness - Rockwell M	* 31	-	35	
Hardness - Rockwell R	48	-	53	
Elastic stored energy (springs)	* 250	-	405	kJ/m^3
Fatigue strength at 10^7 cycles	* 15,2	-	19,8	MPa

Figure 5 Mechanical properties for UHMWPE according to the Cambridge Engineering Selector (2018)

MECHANICAL		
Free breaking length	378	km
Axial tensile strength	3.6	GPa
Axial tensile modulus	116	GPa
Axial compressive strength	0.1	GPa
Axial compressive modules	116	GPa
Transverse tensile strength	0.03	GPa
Transverse modulus	3	GPa
Transverse compressive strength	0.1	GPa
Elongation at break	3 - 4	%
Work to break	45 - 70	MJ/m3
Rope Creep at 30°C, 300 MPa (SK75)	0.02**	%/day
Rope Creep at 30°C, 300 MPa (SK78)	0.006**	%/day
Rope Creep at 30°C, 300 MPa (DM20)	0.00007**	%/day

Figure 6 Dyneema® fibre mechanical properties (DSM Dyneema, 2016)

Figure 7 Dyneema® production waste in a knot, known as a bird's nest

		Twaron	Technora	UHMW PE	Carbon (PAN-based)	E-Glass	PBI	Oxidized PAN	Teijin-conex	PET	PA-6	PA-66
Density	(g/cm^3)	1.44-1.45	1.39	0.97-0.98	1.78	2.55	1.43	1.35-1.40	1.38	1.37-1.4	1.13	1.13
Tensile strength	(GPa)	2.4-3.6	3.4	2.2-3.9	3.5-7 [1]	1.5-3	0.32	0.2-0.3	0.62-0.69	1.1	0.9	0.9
Tenacity	(N/tex)	1.65-2.5	2.5	2.3-4.0	2.0-3.9 [1]	0.6-1.2	0.24	0.15-0.2	0.45-0.5	0.6-0.8	0.7-0.75	0.75
Modulus	(GPa)	60-120	74	52-132	230-540	72	5.1	7-11	-	-	-	-
Elongation at break	(%)	2.2-4.4	4.5	3-4	0.7-2.0 [1]	1.8-3.2	27	15-23	35-45	10-15	20-25	18-25
Moisture	(wt%)	3.2-5	1.9	< 0.1	0	0.1	15	10	5-5.5	0.4	3.5-4.5	4-6
Glass transition	(°C) (°F)	- -	- -	- -	- -	1140 2084	>400 >752	- -	280 536	82 180	50 122	50 122
Decomposition or Melting	(°C) (°F) (°C) (°F)	500 932 - -	500 932 - -	- - 144-152 291-306	3700 6692 - -	- - 825 1517	450 842 - -	- - - -	400 752 - -	- - 255 491	- - 223 433	- - 260 500
LOI	(%)	29 [2] - 37 [3]	25 [2]	<20	-	-	>41	55	29-32	18-21	20-21	20-21

[1] in a matrix structure
[2] fabric measurement
[3] filament yarn measurement

Figure 8 Comparison of high performance fibres according to a kevlar fibre producer (Teijin, 2016)

2.1.2 Production waste

Because the assignment set is to work with production waste Dyneema®, it is important to look into what this production waste is, and what the differences are between this material and the fully drawn yarn.

The production waste from Dyneema® usually is PDY material. It comes in two different forms: non-full bobbins, containing too little material to turn into FDY; and so called Bird's nests (figure 7), which basically are large knots of PDY Dyneema®, generated at the start of production, or when a break occurs in one of the ovens.

Since the production waste material has not passed through the entire process, the material properties are different from the ones for FDY Dyneema®. The tensile strength is not as high, and differs within the production waste itself. The thickness also differs, dependent on where in the production line the breakage occurred. Finally, there is a possibility of left-over solvent still being present in the material, though less than one percent.

Even though the thickness and tensile strength varies per bird's nest of clogged material, it can still be estimated that the tensile strength of the material is lower than for FDY. When this is compared to other fibres on the market, as can be seen in figure 8, it still is a strong competitor in this field. Next to a decrease in tensile strength, other product aspects also differ from the final yarn. The friction coefficient might be higher in PDY, than FDY, since the polymer chains in the yarn are less aligned. Cutting and abrasion resistance are also lower, since these are closely related to the tensile strength. Such differences are important to take into account when designing for an application based on these aspects.

2.1.3 Re-entry in production process

A first question might arise as to why this fabrication waste is not milled down into powder, and put back into the extruder, to be reused once more. Unfortunately this will lead to a loss of quality in the final product. This is due to the polymer molecular weight and orientation in the fibres. These polymers still have their long structure, or high molecular weight, in the fibres, but cannot stand the mechanical processes that turn the fibres back into powder. Kaupp described this in 2009 as: *"Clearly, escape of the polymer chains from impacting mechanical tools is not possible upon milling, grinding, shearing, nanoindentation, or nanoscratching. Strong bonds break mechanochemically with formation of polymer radicals and decrease of chain lengths."* (p. 395). This means that the long polymer chains break into smaller chains and radicals, which are very short polymers, split from the end of the chain. This would result in a mix of longer and shorter polymers in the new ground powder, that will not crystallise and align as well as the long polymer chains. For this reason, a loss of quality will occur when reusing fabrication waste. Maintaining the quality of the PDY Dyneema® therefore requires an alternative solution.

Next to the degradation of qualitiy in the new Dyneema®, it will also mean losing all the value that has been already created by making the material in the first place. A solution for this material would thus be beneficial, since it keeps the value created, albeit different than the fibre it was intended to become.

2.1.4 Material property insights

The most important elements for designing with Dyneema® are:

Its high tensile strength and Young's modulus in the axial direction.

Its combined high strength to weight ratio.

Its low stretch and creep percentages.

Its excellent chemical resistance.

Its high abrasion and cutting resistance.

Its low friction coefficient making it feel smooth to the skin, that it does not cut.

Its first touch cool feel, that is appreciated in clothing and apparel.

Its low density, which makes it float in water.

Its lack of water absorption.

Its availability in only two colours: White and recently also in Black.

Its transparency to radar.

Its relatively high ductility among high performance fibres.

Its melting point of 140°C.

Non-continuous creation of fabrication waste.

Fabrication waste contains <1% decalin.

Fabrication waste is on small bobbins (figure 9) or in bird's nests.

Fabrication waste can currently be a mix of different specifications in one batch (multiple bird's nests).

Mechanical production steps such as milling, cause for deterioration of polymer chains.

Too high temperatures (melting) can cause the polymer chains, within the yarn, to tangle and lose their orientation.

Photo taken by F. Rutten

Figure 9 Fabrication waste on a bobbin

Figure 10 PDY material in the oven

Figure 11 PDY curling up in the heat

2.2 Experimenting with PDY

In order to see if the ideated possibilities for PDY are indeed possible, some experiments have been performed with the material. Experiments performed are baking out the solvent and heat pressing the material into a solid plate.

2.2.1 Baking out the solvent

By baking out the solvent, the material becomes suitable again for use in contact with the human skin. The solvent could be irritating to the skin, and therefore needs to be removed. The PDY material can contain up to one percent of solvent, relative to the weight of the material. The solvent itself has a flash point of 57° Celsius, which means that the solvent, as a fluid, releases enough vapor at this temperature to be ignited by a spark, and stay lit. The melting temperature of PE, and thus the PDY material, is 140° Celsius, so it should be possible to heat the material in an oven and let the solvent evaporate, without melting the yarn (figure 10). Based on communication with Dyneema® the choice was made to bake out the solvent at 70° Celsius, to avoid shrinkage in the yarn, that would likely occur at higher temperatures. To avoid the solvent vapor from building up, and becoming a fire hazard, the experiment was done in a fume cupboard, which extracts the gases, before they can build up to hazardous concentrations.

The experiment was carried out twice: the first time the material was in the oven at 70° Celsius for 30 minutes. Every 5 minutes a little bit of the material was taken out and evaluated. After the 30 minutes the temperature was slowly increased to above the melting temperature to observe the effects of shrinkage and melting of the material. The temperature was increased from 70° to 180° Celsius over a period of 30 minutes. Pictures were taken every five minutes to document the visible effects on the yarn.

The second time PDY was placed in the oven, it was weighed before going in and then every five minutes to try and capture the decrease in weight of the material as the solvent was evaporating out. The experiment stopped, once the weight decreased no further, since this would mean that either al the solvent evaporated out, or is no longer able to evaporate out of the yarn. Based on the knowledge the material contains at maximum one percent of solvent, an educated guess can be made whether or not all the solvent has indeed evaporated out of the yarn.

Results:

Based on the feeling of the fibres, the solvent seemed to have evaporated out of them quite quickly, maybe even within the first 5 minutes. However certainty was hard to get by just feeling the fibres. Therefore the experiment was run again with the scales the second time around.

When the heat was turned up, the fibres slowly started to shrink, and curl up on themselves. This is shown in figure 11. The shrinking of the fibres before melting is a great indicator, that they cannot handle the temperature. It also means, however, that they cannot be used for applications that see temperatures higher than 70° Celsius, since shrinking might start to occur already.

For the weighed experiment the material was placed on a piece of cardboard that weighed 37,3 grams prior to the test. Together with the PDY the weight was 52,0 grams before entering the oven. After 5 minutes in the oven the combined weight had dropped to 51,3 grams. After 10, and 15 minutes as well, the weight went down to 50,8 grams. The cardboard alone weighed in at 36,6 grams at this stage, which would explain the scale of the weight lost. When deducting the weight of the cardboard, 14,8 grams in the beginning turned into 14,2 grams after 10 minutes in the oven. No further weight was lost after that. This would mean, that the material lost 2,4% weight in the oven. This is exceeding the expectation of maximum 1% by a lot. This might partly be explained by evaporating moisture, that stuck to the fibres as well, or by measurement error. Such an error might have a larger influence on smaller measurements. Therefore more material was used the following batch.

The second time a weighed test was performed, the cardboard weighed in at 36,6 grams before going into the oven, as well as, at the end of the experiment. Combined with the PDY it weighed 125,8 grams at the start, and 125,3 grams both after 5 minutes in the oven, as well as, after 10 minutes. Thus the PDY weighed 89,2 grams at the start, and 88,7 at the end. This means the material lost 0,56% of weight, which fits the expectations much better. A third test was done with a combined weight of 111,7 grams at the start and 111,3 grams after 4 minutes, when it had to be interrupted. The cardboard weighed 36,6 grams for the entire test again, which means 75,1 grams of PDY got reduced to 74,7 grams over the course of 4 minutes. This is a reduction of 0,53% in weight, which seems consistent with the previous test, but this cannot be said for certain, since the test had to be aborted.

2.2.2 Dyneema® wearing test

To test the insulating effects of wearing clothing made out of Dyneema®, an experiment has been conducted. A piece of loose Dyneema® fibres (FDY waste) was worn wrapped around one leg for an afternoon. The other leg was not wrapped to compare the differences. Several different exercises were performed, and comfort, as described by the wearer, as well as temperature were recorded.

Temperature was measured on the outside of the leg on the shin, both on the jeans outside as on the skin directly, for both the Dyneema® wrapped leg, and the control. One such measurement is shown in figure 12.

The room temperature at the start of the test was 22,4 degrees Celsius, as was the temperature of the Dyneema® before wrapping it around the leg. When wrapping the Dyneema around the leg it felt cool to the touch, though not uncomfortable.

The first measurement took place after walking down and up two floors. The second measurement after working, sitting at a desk for half an hour. The third after a walk outside for twenty minutes and the final measurement after working behind the desk for another 45 minutes.

The results are listed in figure 13.

Conclusion:

The test results show first of all that it is not uncomfortable to wear Dyneema ® directly on the skin, even if it is rough and loose. There seems to be a persistent difference in leg temperature of a single degree, over all tests, except for the first period of desk work. This might be the result of a faulty measurement. On the outside of the jeans the only observable difference is seen after walking down and up the staircases, again this could be caused by a faulty measurement, though it is also possible that heat was transferred from the Dyneema® wrap to the pant leg, through contact, that was not present on the control leg. Another explanation is, that the Dyneema® is letting excess heat pass through. Its thermal conduction might be just right to keep a person at a comfortable temperature in these conditions.

fFigure 12 Measuring the temperature of the skin underneath the Dyneema fibre wrap, after walking up and down two staircases.

Figure 13 Results from the wearin tiest with the loose fibre wrap.

Measurement	Control jeans	Control leg	Dyneema jeans	Dyneema leg	Comments
2 staircases	23,2	31,3	24,1	32,4	After walking down and up the stairs the wrapped leg feels slightly warmer than the unwrapped leg. Both feel comfortable in temperature.
Working 30 min	24,1	30,9	24,2	31,2	After working for half an hour the wrapped leg still feels warmer, though this might be caused by the wrap being in direct contact with the leg, as opposed to the control.
Walk outside	23,4	30,1	23,3	31,3	Again a slight temperature difference can be felt, but both sides feel comfortable.
Working 45 min	23,8	30,7	23,6	31,7	Both sides still feel comfortable, though the temperature difference is still present.

Figure 14 The process of heating a steel plate (left) and grid (right) and pressing it on loose Dyneema PDY fibres.

2.2.3 Heat pressing

To see whether, or not the material can be transformed into a plate or partial plate, a test was performed to heat press the material. The low melting point and fibre structure might make the material suitable for making a hybrid of solids and fabrics. Allowing products to be made of a single material whilst both having structural solid areas, and durable, flexible hinges, or fabrics. Use of such a combination might add durability to products with plastic hinges, or offer improvements on for instance body cam casings.

The test was performed by placing the material under a heated metal plate with a weight on top. The heat of the plate should melt the yarn, which is pressed on top of one another by the weight. Before pressing, the metal plate was heated with a gas torch. The plate was then placed on top of the yarn, with a 5kg weight on top. (figure 14, left)

A second heat pressing test was done with a grid instead of a plate. The grid was also heated with a gas torch and then pressed by hand onto the material. Aim of this test was to connect the tangled yarn, without losing most of its properties due to excess shrinkage and melting of the fibres. (figure 14, right)

Results:

The first heat pressing test resulted in a lot of material loss. Due to heating the pressing plate with a gas torch, control of the temperature was not present, and likely the plate was far too hot. This caused the material in the centre to decompose. Around the centre, however, the material had molten together into rough pebble like plated bits, underneath still connected to each other by fibres that had not molten. Without better control over temperature and pressure it seems not possible to turn this material into a partial plate. The heat seams to dissipate quickly through the fibres on top, not allowing the fibres below to get hot enough to melt. The fibres that do melt shrink in the process, thus causing gaps to appear, hence the grainy structure in the pressing result. From this small test it seems unlikely for a useful living hinge, or partial plate construction to be made from this material. Further testing with a proper heat pressing machine, that can regulate temperature and pressure, is required.

The second heat pressing test, with the grid, was conducted with less heat, to prevent decomposition of the material. No loss of material was observed. The fibres had molten together at the places of contact with the grid. The depth of the molten area was very shallow and in order to achieve connection of the fibres all through the bundle it needed to be pressed from the opposite side as well. If fibres did not span the length between two plates of the grid, they would shrink at the point of contact with the single plate, curl upwards and then melt, when in contact with the side of the grid plate. This turned them into a similar grainy hard element as observed during the plate pressing test. The entire molten grid-like shape in the fibre bundle was very brittle. When bending it, it broke into smaller elements, that stayed connected to the rest of the bundle. Due to the brittle nature of these molten lines, this type of connection also seems not suitable for use as hybrid between solid and fabric. Therefore these ideas need to be set aside, or more testing with heat pressing is required.

Chosen was to set these ideas aside for this project. In the graduation project of F. Rutten (2019) further more sucessful tests were performed with heat pressing this material in a heat pressing machine.

2.3 Context two: Circular product design

DSM Dyneema asked for a Circular product to be made from their fabrication waste Dyneema® fibres. In order to achieve that goal, clarity about what a circular product is, is required. A circular product is a product that ideally is not discarded at the end of its life. The product is instead brought back into the market. The model of steps taken to achieve this is circular, instead of linear, hence the name Circular product, or Circular economy, when referencing the entire system. The Ellen MacArthur Foundation has made a Butterfly Diagram (figure 15) showing all the cycles within the Circular Economy. In the middle the linear model can still be observed, while around it in the wings the circular steps are placed. Though the energy it takes to undertake steps is not directly taken into account in the model the size of the circles does correspond to the energy it takes relative to the other steps. This means that smaller circles usually take less energy than larger ones, as well as sooner reaching a new state of use. Both mean more value is kept or created, therefore it is both economically and ecologically advantageous to keep products circling through the smallest circles as long as possible (Bakker, Den Hollander, Van Hinte, & Zijlstra, 2014).

2.3.1 End of life

At the end of its (first) use life, a circular product needs to get collected to stay in the loop. Depending on the product, its state and the place of collection it can now enter one of the loops that reintroduce it, or its resources, back into the market. As stated earlier a smaller loop is likely to be preferable over a larger one, though it has to be noted that the smallest loop, maintenance, takes place during use. The next best option is reuse or redistribution of the product, which does not alter its properties, but might require maintenance before being sold or leased out once more. The next best option is refurbishment, which, according to Bakker et al. (2014), brings the function of the product back to the state it was first sold in, or better.

Although remanufacturing is mentioned in the diagram to be in the same circle as refurbishment, there is a clear distinction between the aforementioned options and those to come, including remanufacturing. The first circles of reuse, redistribution and refurbishment, all focus on the product as a whole, and keeping it as such. Meaning anyone with enough knowledge of the product could potentially take the product through one of these circles, or even base his business around it. These circles require relatively low effort, when compared to the larger ones.

The larger circles of remanufacture and recycling no longer necessarily focus on the entire product, but more on the resources it can offer to other products. Remanufacturing of a product, is using the product to make something else out of it, but keeping some value, by showing of, or using elements of the original product.

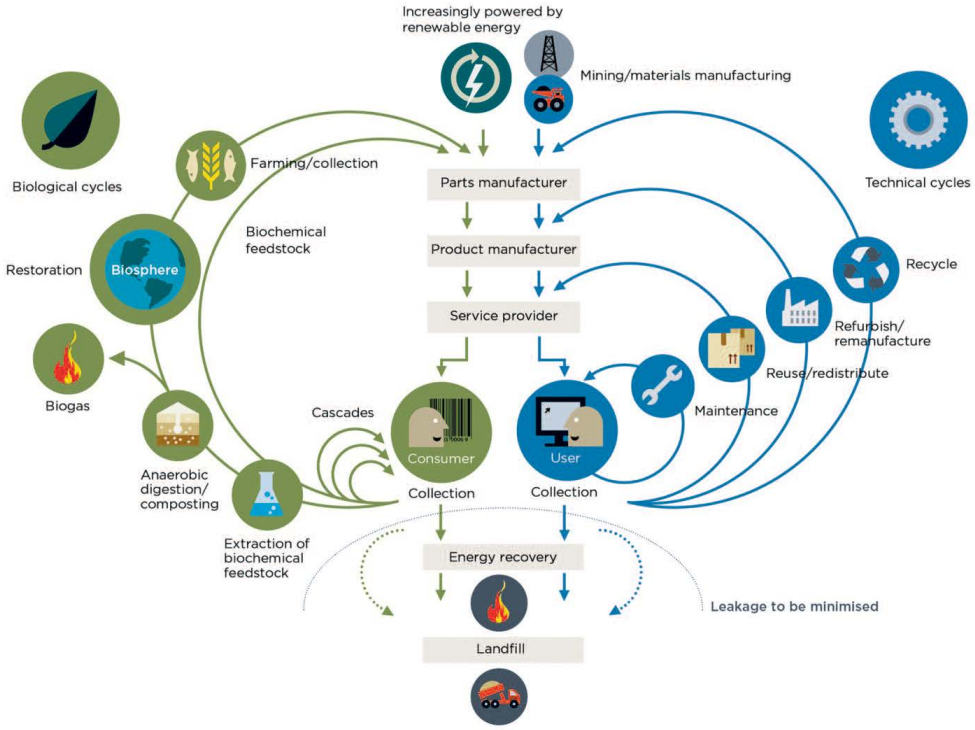


Figure 15 Butterfly model of the circular economy by the Ellen MacArthur Foundation as shown by Making it Magazine (2016).

2.3.2 Collection

An important step for any product to be circular is collection after use. Basically, after users are done using their products, they have to take active action to have the product, either enter a next loop, or be disposed of. They might give the product to family for them to use, or might send it back to the lease provider, if it was leased, or might just throw it in the garbage, to end up in incineration facilities. Preferably the product enters another circle, so the decision to throw the product away should be discouraged as much as possible, or even taken out of the user's hands completely.

By changing the business model to make money of a product, in such a way that the ownership does not lie with the user, the decision what to do with the product after use, no longer falls upon the user, but with the product owner. This way the control is kept over what cycle the product can enter next. There are several ways of achieving this. Bakker et al. (2014) describe two models that keep full control of products: the access model and the performance model. The access model provides access to the product, but ownership is retained by the access provider. Offering lease or rent on a product is an example of this model. Important to note is that the customer usually is concerned with the product, and uses it often. The second model retaining full control of the product is the performance model. Earnings are based on performance provided, and the responsibility of what machines and products are required to achieve that performance lies with the provider. Users are only interested in the service and its quality, and not in the product that provides it. Examples can be seen in data cloud usage, and in (public) transportation. This business model usually operates with the so-called inseparability principle: the services are used at the same time they are generated (Snelders, 2017).

Not all products are (yet) eligible for functioning in these models, therefore other ways of collection are still required. Different solutions are preferable in different situations. Products that are used often and can be considered disposable, such as packaging and paper, are collectively collected through (separate) bins in the streets. Other products can sometimes be categorised together, and collected as such, at special collection points, for instance in supermarkets, or at the shops where they are sold. Even more specific products can be interchanged when a replacement is bought, either by bringing your old product back to the store, for instance Puma Incycle (ListedFit, 2013), or by handing in the old product, upon delivery of the new product, for instance washing machines and other white goods. All methods of general collection can be seen in figure 16.

However as soon as a deliberate action is required of the users, they need to be motivated to do so. Possibilities for motivating this user are: creating a downside when not doing it, such as having to walk further for the non-separated trash; or by making them aware about the environmental consequences when not separating, as is done with batteries; or by offering them a benefit to hand in their old product, such as a discount when buying a replacement. Benefits for handing used products in can have a downside themselves, when looking from an environmental perspective. Usually product collected in such a way end up in a recycling stream, which is the largest circle, and therefore the least desired one. People might choose to hand in their products back at the store for the benefit, instead of giving it to family or the thrift shop, what they might have done otherwise. The product will then end up recycled instead of reused. The latter of which would have been more environmentally beneficial. Therefore it would be better to assess the products handed in during collection based on which products can be repaired and resold once more, and what products really serve no other purpose than recycling. A specified brand hand in usually combines their product marketing with the hand in opportunities, but it stands to reason people might have forgotten that they can hand their products back in after several years of usage. A marketing campaign should reach the desired audience and usually requires a long time to achieve the desired societal change.

Based on the chosen application for the product, different options of collection are possible. Market wishes do not allow all options to be successful. For instance, renting a sleeping bag for a holiday might feel like lying in someone else's filth, and is therefore undesirable and unrealistic. The performance model only works for inseparable applications. General collection with street bins requires a lot of volume, and easy distinction from products that are collected together. All methods of collection thus have their up- and downsides and the best method can only be chosen, once the application has been clearly defined. However, if an access or performance model seems desirable, it is important to choose this model quickly, since it requires an entire system with servicing of the products as well. This is not the case for a product that is merely sold and persuaded to be handed back in, once the user is done with it.

Method of collection	**Examples**
Bins in the street	PMD, Compost, Glass, Paper, Rest waste
Bins in common places like supermarkets	Batteries and Light(bulb)s, Clothing and shoes, Small electric appliances
Hand in when buying replacements	Small electric appliances, Whitegoods, Large electric appliances
Specified brand hand-ins	Puma Incycle (ListedFit, 2013), Patagonia Worn Wear (Patagonia, n.d.-a)
Discount offered when/by handing in old products	Patagonia Worn Wear (Patagonia, n.d.-a)
Marketing environmental awareness/impact	Batteries and Paints
Thrift shops (also redistribution)	

Figure 16 Current methods of collecting products after use.

2.3.3 CPD insights

Smaller circles are:

- More energy efficient,
- A quicker path to (re-)use,
- Both economically and ecologically preferable.

Products need to be collected to be circular (stay in the loop).

Repair, re-use, redistribution and refurbishment options, keep the product the same or very similar to what it is. As a result these steps are relatively easily applicable, or low effort options.

Design for maintenance not only improves use life, it also improves possibilities for reuse and refurbishment.

Remanufacture or recycling, changes the function of the product, or its parts / materials.

Remanufacture requires a new design or product idea, based on the collected old products resources, which inherently requires extra effort to be taken.

- It is usually based on a certain aspect of the original product such as appearance.
- It usually decreases the size of resources (e.g. cutting up a bike tire to make a belt.)

Recycling focuses on keeping the material value, and therefore has no direct need for a new design, all other non-material value is lost.

- High value items are removed by hand, which should take as little time/effort as possible,
- Must be worth the effort/time.

Liberation through shredding;

- Materials need to separate in a shredder,
- Particle size decreases,
- Improper liberation leads to mixed materials;
  - Thiss lead to quality degradation,
  - Mixed materials might lead to faulty concentrations,
  - Mixed materials lead to loss of resources.

Concentration is based on material properties;

- Metals are separated based on magnetic attraction and electrical resistance (eddy current),
- Plastics on density (sink float) and infrared refraction (FTIR), FTIR does not work on black plastics.

2.4 Context three: Use of Dyneema® lines in maritime contexts

A large field of application for Dyneema® is the maritime sector. Dyneema® fibres are found in all kinds of ropes and lines, nets and lifting slings, etcetera. To get a glimpse of how people in this sector use their lines, whether or not they are made with Dyneema®, interviews have been conducted with people working in this sector.

2.4.1 Ocean-wide shipping

The first interview was with a third mate of a company specialised in worldwide dry cargo transportation. The company owns a fleet of multi-purpose dry cargo vessels on which the interviewee sails. On board the vessels, they usually have a lot of different purposes for ropes and lines, as well as a lot of different sizes of them to fit all purposes. An example of a dry cargo vessel can be seen in figure 17.

Their largest and thickest lines, for mooring, require certification to be suitable for the size and weight of the ship they are used on. At this company these lines are ordered centrally, and usually price is the mayor deciding factor for which lines are acquired. The result is, that these lines usually consist out of natural fibres. These mooring lines are each 120 metres long. For regular mooring ten of them are connected to the shore. In case of bad weather, or strong winds, more lines are set to shore. The maximum the interviewee has experienced is 24 lines in total. These lines usually break on strain and therefore an estimated average lifespan could not be provided, since this would depend too much on differences between mooring locations, such as: the height of the tide, and whether or not the ship lies protected from incoming waves.

When these large lines break, they are reused depending on the location that a break occured. If the line is still long enough, a new eye will be spliced to the end and the rope will serve as mooring line once more. In case too little of the rope is left, the rope will be spliced into a fender, that protects the side of the ship from banging into the harbour wall when moored. In case the line has abrasion spots in well used areas, old cargo belts will be spliced through the line to lengthen its lifetime a little more. In case there are enough fenders on board, broken lines are discarded, once ashore. They are trashed and not exchanged as part of acquiring a new line.

Next to the large mooring lines, several hundred meters of line, called Manilla rope is on board, in varying thicknesses, at all times. These lines are thinner than the big mooring lines, and are much easier to handle. They are used for all kinds of purposes, which require a line such as: extra fixation of cargo, next to the cargo belts, lifting of small things in and out of the hatches by hand, fixating loose elements, etcetera. This line is bought cheap and also discarded after use.

The only Dyneema® lines can be found in the flag line, and for use indoors; in the crews cabins, since it looks better than the manila line. The use of these lines is thus limited on board of their vessels. Since the strength of Dyneema® lines only requires a thin rope, handling load bearing lines cuts the hands quicker, so the thicker Manilla ropes are preferably used. Dyneema® is also used in the safety netting around the sides of the ship, preventing people from falling overboard in heavy weather. Finally synthetic cargo belts are used, certified up to 10 tons, to secure large loads. At the end of their lives these might be used to extend the lifetime of a mooring line as described before, and are otherwise discarded.

Figure 17 A dry cargo vessel, that takes a variety of cargo, which has to be securely tethered with straps and lines.

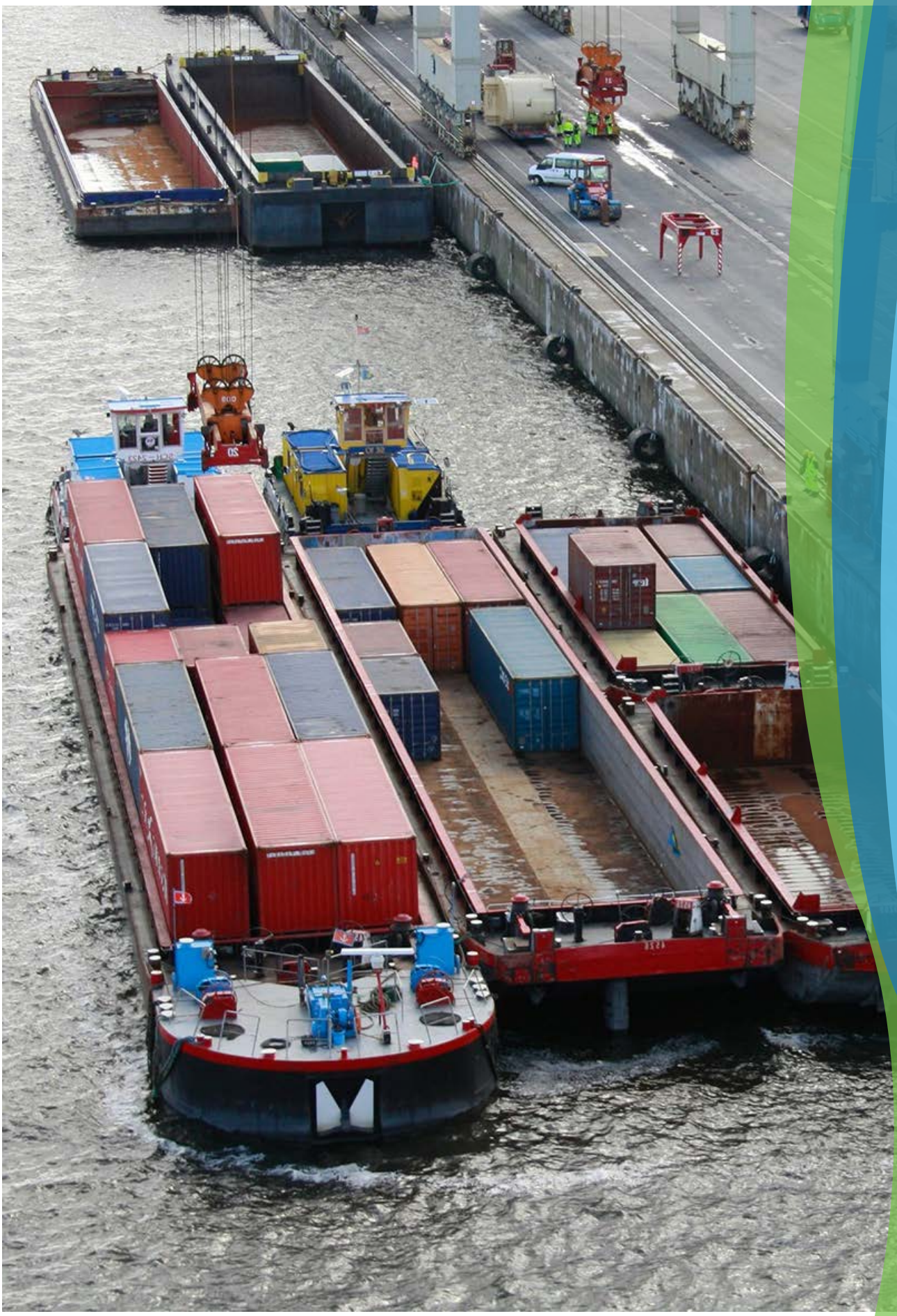


Figure 18 Container carrying inland ships, the containers lock onto each other. Therefore the need for ropes is far less than on multi-purpose dry cargo vessels.

2.4.2 Inland shipping

The second interview was with a skipper on an inland vessel, that solely transports containers, within The Netherlands. Therefore the applications of lines are fewer on board this vessel. An example can be seen in figure 18.

Their largest and thickest lines are also used for mooring, but they make use of synthetic lines. The main mooring lines require a certificate as well, and they need to be at least half the length of ship. On board the ship are five of these lines ready for mooring, of which two are on a winch. Of the remaining three lines, two are placed at the front of the ship, and one at the rear. Added to the rear is a small Dyneema® line of 20 metres, that can be set as an extra line. Usually however, the ship is moored by two lines from the front and one from the rear. The small Dyneema® line is the first extra line to be attached if more lines are required. Once the thick main mooring lines lose their certification, or minimal required length, they can no longer be used as main lines. They are still used as extra lines, or are spliced to be of use as fenders, similar to the ocean-going vessel. Again these lines are thrown away, without returning to the manufacturer at their end of life on board.

The skipper prefers to have a combination of the thin Dyneema® lines and the thicker ropes, for their respective differences in properties. When there is a need to have a lot of load on a line in a sudden instant, for instance when turning the vessel using the ropes, the stretch of the thicker line eases the load. Where in his experience the Dyneema® line takes all the strain at once, and either produces a shock going through the ship, or breaks because of the impulse. Whereas on the plus side, the lack of stretch secures the vessel to its place very thoroughly. Another point of importance is the possible loss of quality through UV radiation, that he feels is happening more in the Dyneema® line than the thicker mooring line. Again he faults this to the thickness of the line, where a thinner line has a larger respective surface area in relation to its volume.

Other use for a Dyneema® line on board is in spud poles, that this ship is equipped with. They are large poles, that fix the ship in place by being lowered into the riverbed. The Dyneema® lines are used to raise and lower these poles. They have to be replaced every two years, and are then used on deck to act as secondary mooring lines. The skipper has also used Dyneema® lines on a different ship, to secure a barge in front of his pushing ship, because they are safer to use than steel lines. The only steel line he has on board is in the crane that lifts his car aboard ship.

2.4.3 Maritime interview insights

Mooring lines are:

- Used as long as possible,
- Repaired if possible,
- Otherwise downcycled into fenders.
- At the end of their use on board discarded as waste.

Preference in lines to acquire has to do with:

- Certification,
- Price,
- Properties of the line,
- Safety.

Preference in lines to use on board is based on:

- Ease of use (thickness),
- Comfort (cutting the hand, thickness),
- Location of use, personal space or outside,
- Safety.

2.5 Context four: Outdoor equipment

An interesting field Dyneema® is starting to enter is the outdoor market. By acquiring Cuben tech in 2015, they gained entry into the outdoor equipment world, with Cuben fibre textiles. They are renamed to Dyneema® Flexible Composites (DFC). The material is used for tents, tarps, dry sacks, backpacks and was used in the coats of USA winter Olympians for the 2018 winter Olympics. The material is the lightest on the market for these applications. However this benefit comes at a price, the material is still very expensive. The outdoor light packing community has differing opinions concerning DFC. Based on the feedback on websites offering the material there are different points of view: Excellent material and worth the extra money, but also hard to work with, since al the edges need to be taped, which is difficult in bends or curves.

Packing light is a growing trend in the outdoor market (Becker, 2018), and the fabric of Dyneema® is being used by amateurs and professional brands alike. The awareness of the material is growing among potential customers. They are already enlarging the application field for this material themselves, for instance by using the fabric to make kayaks (Evans, n.d.). Because people pack lighter, the differences grow between the stuff they bring along on their trips. People make sure they bring the bare minimum for the duration and location they are going to, which differs from trip to trip. By having the minimum in gear, perfectly matched for your trip, it is therefore very important you can rely on that gear. This means the gear should be durable, and kept safe and dry when not using it, since no replacements are available on the trip.

The outdoor market is larger than just camping, and more applications might be possible for Dyneema®, for instance with their yarns as well. In climbing Dyneema® yarn is being used in tackles for its lack of stretch and high strength to weight ratio. In diving, cut resistant gloves with Dyneema® are used for wreck diving and spear fishing, as well as safety lines connecting a diver to the boat, when diving in strong currents. The near weightlessness underwater and the hydrophobic nature of the material are important to divers, since it keeps the weight of their already heavy equipment down under water, and the Dyneema® products do not need to dry as long, when storing them between dives.

2.5.1 Questionnaire among users

A questionnaire has been performed to get more insight into how people handle their outdoor gear. They were asked about what outdoor hobbies they have, whether or not they have their own gear, and how they handle their gear, once they are done with it. Additionally they were asked about what waste they separate at home, to see how they regularly handle their waste.

The questionnaire has been filled out by 52 people, with a 50-50 male/female distribution. Age of participants ranges from 16 to 66, but there are only 2 respondents aging between 30 and 50 years old, the rest of the respondent are older, and, mostly, younger (figure 19)

35 of the 52 participants hike, 25 cycle, and 6 perform no outdoor sports. 19 People do snowsports, like skiing and snowboarding. Further responses were less than ten respondents per hobby and can be seen compared to those mentioned, in figure 20. 65% Of participants has their own gear, and another 20% have some of their own gear. When getting rid of their old gear, half of the participants pass it on to others, either by selling it, or giving it away to others to use, within the family or through thrift shops. 14 Participants just throw it in the trash; residual waste, and 14 others would like to hand it back in at the store. Overlap as well as other answers end up together in the other bar, therefore this seems unreasonably large in comparison. The only other answer given was handing it in with the textile waste. (figure 21)

There was a lot of interest in bringing old equipment back to a collection point. Convenience seems to be key in collection, since most of the other responses are combinations of "*Yes*", and "*Only if it is convenient*" (figure 22). Among respondents "*No*" has not been answered though this could well be because this seems like the undesirable answer to give. Therefore it may well be that those responses saying "*Maybe*", might turn out to mean "*No*".

Respondents separate their waste quite well, with batteries separated by most, followed by glass. Regular waste is separated by more respondents, than respondents seem to be willing to hand their old gear in for recycling.

The raw data, and all graphs can be seen in appendix I.

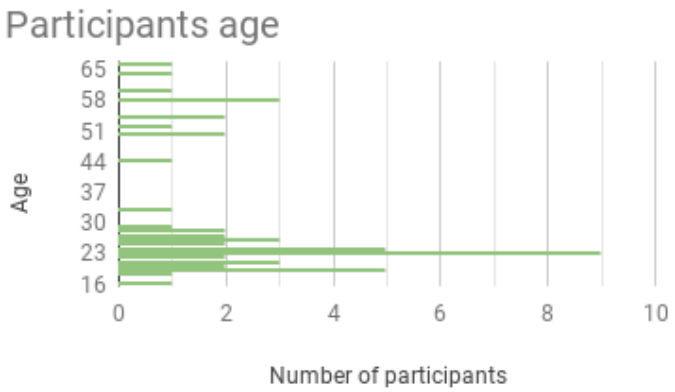


Figure 19 Age of participants, there is a clear gap in responses between 30 and 50 years of age.

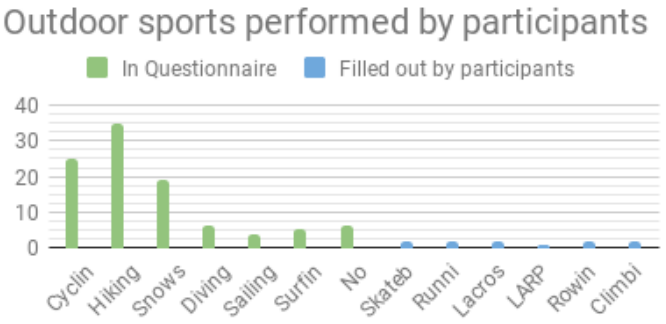


Figure 20 The sports that respondents perform.

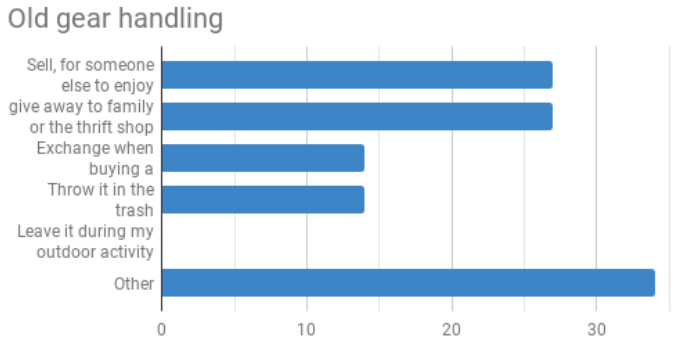


Figure 21 The way respondents handle their gear. The other bar is unreasonably large, since combined answers are also counted as other.

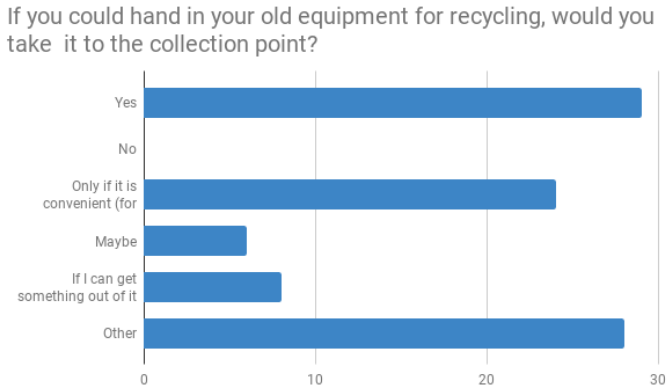


Figure 22 The willingness amongst respondents to handle their old gear in for recycling. Again the other bar also contains combined answers.

2.5.2 Outdoor equipment insights

Dyneema® flexible composite fabric is the lightest fabric material available.

It is also very expensive, second grade material could make this cheaper.

Opinions differ, from very good, to hard to work with, to not very durable.

Focus is more and more on light packing .

Competition can be observed in nylons and polyesters.

No real circular alternatives in this tech driven sector.

It is still a niche market, lower prices could enlarge this market.

Gear is packed to match the trip.

Keeping gear dry outdoors is important.

Preserving nature, while in it, is considered important.

Durability is a concern when gear is bought.

2.6 Dyneema® product branding

Dyneema® is currently used in a lot of different products, mainly for its strength. Marketing of the fibre logically also aims to portray this strength, with trademarks as “The world’s strongest Fiber™” and “Greenest strength™” (Dyneema, n.d.). Use of Dyneema® in applications such as heavy lifting slings, lifting chains, (permanent) mooring lines, and seismic ropes showcase these claims. Other applications for the fibre can be found in netting, for fishing, and aquaculture, but also in air cargo and ship railings, paracord, composites, in carbon fibre for toughness and as a fabric for tents, motorcycle jeans, cut resistant gloves; and life protection: bullet and stab resistant vests and helmets. While most of these applications also require the strength of the fibre a different angle on branding the product can also be given: that of protection and safety. Dyneema® even has a slogan that is already perfect to present this: “With you when it matters”. Currently this slogan is mainly used to refer to the performance and the quality of the fibre, though the application in safety equipment most likely already plays a part in why this slogan has been chosen. The presentation angle of protection and safety also applies to the applications that at first seem to be only about strength, like the mooring lines, steel cable replacement wires and lift slings and chains. Since the Dyneema® products are lighter than their competitors, they carry less inertia upon breakage. Therefore they do less harm when hitting something. Also the brunt of the force when breaking is in the length of the line, making it less likely to hit a person standing next to the line when it breaks. Steel cables tend to fray and jump to the side when breaking, thus being a larger risk to things near the line (ATLANTICBRAIDS, 2010).

One might ask, “Why change the branding when the current one works?” Which is of course a very good point. However, for circular Dyneema® products, like the one designed in this project, the strength is degraded compared to the original Dyneema® material characteristics. A different branding strategy than the current one of strength is more suitable. When aiming at cut resistance, or even weather protection, or insulation, branding towards protection; from the weather, sharp objects, or even the cold, still holds true.

3. Ideation

3.1 Combining context insights

After gathering insights for all the different contexts, interaction between them is created through a clustering session.

For all insights found, when analysing the different contexts, an insight card was provided. Next to the actual insight, the card also contained the context that it belongs to. A few of these insight cards are shown in figure 23.

The participants of the clustering session were given an introduction to the problem and the different contexts, and were then instructed to combine the insights into clusters. First in a spontaneous manner, without a directive given. Next with a directive, for instance to create a cluster for all material property insights, or to find a connection, and cluster, for two seemingly very different insights.

The created clusters have been photographed and can be found in appendix II.

Since a lot of the insights still contained jargon related to the different contexts, extra explanation during the clustering was required. This allowed the possibility to arise, that some insights were left aside for their unclarity.

To counter the chance of lost connections, a second, individual, session was held. The result from this session became more of a relations chart, rather than a set of clusters. The chart is visualised in figure 24.

From the clusters of the first session and the chart from the second, a list of shared insights can be created. This list encompasses similarities, and differences as well as other relations such as causes and effects.

Gained insights:

The low density and water resistance, or lack of water absorption from the material suit the wishes from the outdoor market for lightweight and water resistant gear really well.

The reuse and remanufacturing of lines on ships is a great example of the economical and ecological preference to keeping the circular loops small.

The material is really resistant to shredding, which deteriorates the material as well. Shredding thus causes damage to both the shredder in the shape of excessive wear, and to the material by decreasing its material value.

The material has recently become available in black, but this is hard to separate in the recycling process, since it is not picked up on the FTIR infrared plastic separating machine, due to the absorbation of (infrared) light by the black material interfering with the machines process of determining the molecular structure of the material.

When recycling all value of the material is lost. Recycling is focusing on separating materials for their value, all other value is thus lost. Part of recycling is shredding the materials coming in before separation. As mentioned before, shredding decreases the material value of the Dyneema® fibres. This shows that recycling the material should be avoided, and can be seen as the last possible way of bringing the material back into use. In this case however it is most definitely downcycling. Smaller circles should be encouraged for this material.

The results from this session are useful to guide the ideation process. The insights provide areas of interest. In this case an application for the outdoor market, since properties of the material seem to align with requirements for outdoor equipment. They also provide areas to avoid, or to think about improving. Keeping this material in a smaller loop than recycling is more important than for other materials, since most of the value is in properties that get lost when recycling.

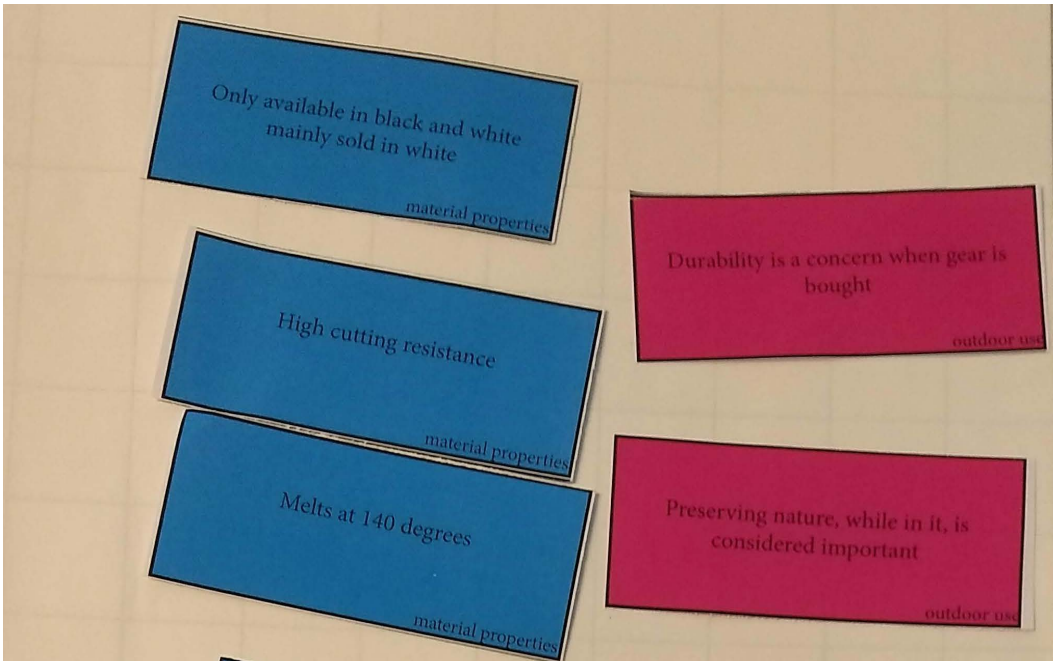


Figure 23 Insight cards that were used for the shared insights session

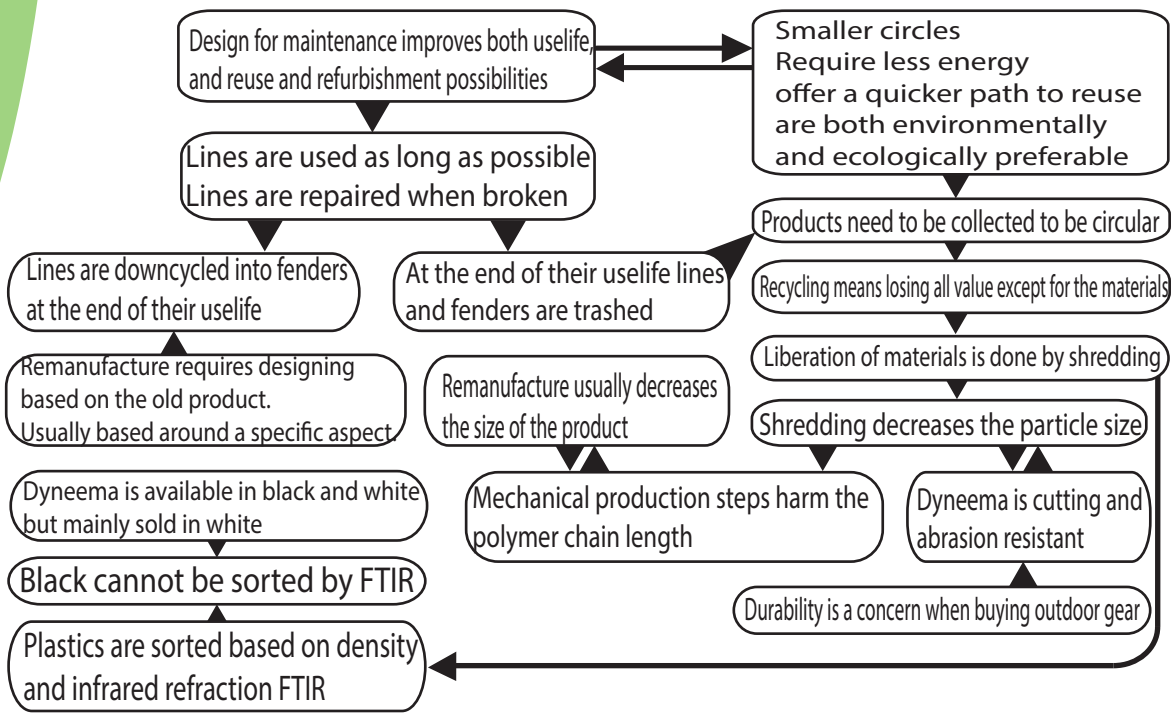


Figure 24 Relations chart with insights following from the individual cluster session.

Figure 25 A synthetic sleeping bag, which could be made with Dyneema.

3.2 Ideas

An individual ideation session was done to look for possible applications. Based on the different properties of the Dyneema® PDY material several fields of application have been discovered. Its light weight makes it ideal for applications in fields where weight can quickly become an issue. An example of such a field is outdoor vacations. People tend to bring everything they need on their own backs or bikes, and have to carry it all around. Saving a couple of grams might go a long way in these fields.

Other possible fields of implementation lie in its excellent resistance of elements, not taking on any water, and by being near weightless when submerged, or lightly floating. These aspects make it ideal for use outside, and in, or under water.

Dyneema's abrasion resistance, and low friction coefficient, make it ideal for tough sliding applications like in skiing or snowboarding. For instance: ski and snowboard bases are already made out of UHMWPE, changing them to Dyneema® might add strength to get the desired bending resistance, reducing the amount of fibreglass used in skis and snowboards elsewhere, and decreasing the weight. Applications in bristles for so called dry or wet (snowless) slopes might very well also be an option.

Dyneema's cool first touch feel and thermal conductivity, make the material ideal for "perfect temperature" applications, which is about keeping a comfortable temperature at all times. For instance a pillow that is neither too cold nor too warm, by having a Dyneema® filling or layer between the filling and pillowcase. The same goes for applications in matrasses, sleeping bags, and use in coats.

Dyneema's cutting resistance and flexibility allow the material to offer new ways of protection against cuts. For instance as foldable and machine washable cutting boards, once the solvent has been removed. Potentially even, when combining multiple aspects, in diving gear specialised to protect against shark bites.

3.2.1 Insulation applications

As shown by the wearing test, Dyneema® has a comfortable cool first touch feel to it. This coolness however does not linger, and the material quickly comes up to the temperature of the skin. When wearing it wrapped around a limb, the wrapped area consistently stays warmer than a non-wrapped area would. Interestingly enough the difference remains about 1°C, even after heavy exercise, or when little to no exercise is performed. These features seem to make it ideal for personal insulation applications, such as use in jackets or sleeping bags (figure 25). Important for the filling, which could be the PDY bird's nests, is that it retains it thickness over time, and decompresses relatively quickly after being compressed (Creech, 2013). This way the layer of air trapped around the body stays equally thick all around and cold spots are avoided. Compared to the commonly used duck or goose down, the PDY bird's nests decompress quite slowly, but they do so themselves. The thermal conductivity of the Dyneema® is also larger than that of the down, which means it probably is not very well suited for winter sleeping bags, but more likely to be applicable for summer sleeping bags, or for use in warmer climates. If the material behaves like it did during the wearing test, and therefore does not allow the temperature to get too high. This might mean that it is hard to get too hot in the sleeping bag, making it great for these summer, or warm climate sleeping bag applications.

Traditionally filling materials used in jackets, quilts and sleeping bags are natural, such as duck and goose down, but also wool and animal furs. Only wool also insulates well when wet (Creech, 2013), duck and goose down can be kept dry to a certain extent by the protection of the outer fabric, to keep both benefits of its insulation and its weight. Synthetic alternatives might, however, offer better performance when visiting a wet climate. Synthetic fillings are designed for their ability to trap air and decompress quickly. Features such as hollow curling fibres are exemplary of these designs. These fibres are produced, among others, by Nomad (n.d.) from a combination of polyesters, that shrink differently during production to induce this strong curl. Other fibre designs siliconize the fibre for a soft touch. These specific fibre property designs for sleeping bag applications are not possible for the PDY Dyneema®, since it is a by-product from the production of Dyneema® fibres. This means a sleeping bag designed with these fibres needs to play on the strengths of this fibre, whilst compensating for properties it might lack, compared to other filling materials, in other areas.

3.2.2 Outdoor equipment

3.2.2.1 Diving and surfing gear

Another implementation option, that combines the material properties of Dyneema® with market needs, is in diving gear. More specifically, Dyneema® PDY material could be of use in shark protection suits. Diving with sharks is currently done in one of three different ways: Cage diving, where divers are submerged in metal cages, to protect them from sharks; Without any added protection against sharks; and with a chainmail suit made out of stainless steel. These suits are very specifically made just for the purpose of offering shark protection, by a company called Neptunic (n.d.). It is shown in figure 26.

Other ways to improve safety from sharks in the water is done by shark sprays and electric pulse devices, although their effectiveness is not yet proven (Ocean Guardian, 2016). The same can be said for new wetsuits with prints designed either to disguise a diver in the water, shown in figure 27, or to look dangerous with a high contrast Murene eel pattern on the arms for surfers (Grozdanic, 2014).

Dyneema's cut and abrasion resistance, combined with its near weightlessness under water could offer an alternative solution. Allowing divers to be safer than without protection, whilst not increasing their weight too much. However, before any claims can be made such a product needs to be tested thoroughly, to assure it can withstand a shark bite.

Dyneema® is already being used in the diving world for (spear) fishing lines; cut resistant gloves, for wreck diving, as well as spear fishing; and for guiding, and personal safety lines, to keep track of where you are underwater, and prevent you from straying too far from the boat. This means that some divers are already familiar with the Dyneema® name, which is beneficial for adoption.

Next to divers other wearers of wetsuits stand to gain from more shark protection. Snorkelers and surfers often find themselves in water favoured by sharks as well. Surfers are sometimes being mistaken for seals by sharks, and find themselves preyed upon. In a lot of cases great white shark bites on surfers can also be sparked by curiosity, since they tend to investigate objects floating on the surface by biting them, according to marine scientist Clinton Duffy.

Often people survive shark bites, because the incident is a so called bite and release incident (McMurray, 2018). This means that the shark releases instead of biting fully through, and does not continue the attack. This also means that the main injuries people sustain, come from the sharp teeth and not necessarily from the biting force. Protection from the sharp teeth can thus already prevent most of the injuries sustained.

Figure 26 A chain mail shark protection suit by Neptunic.

Figure 27 A wet suit that should disguise divers in the water to avoid shark attacks.

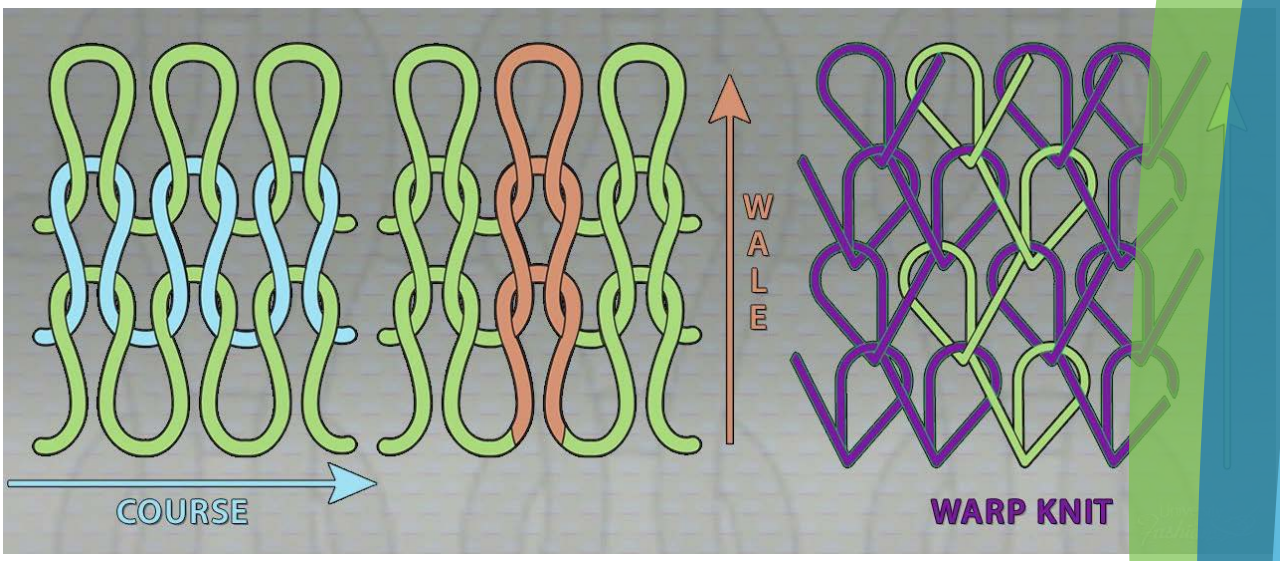
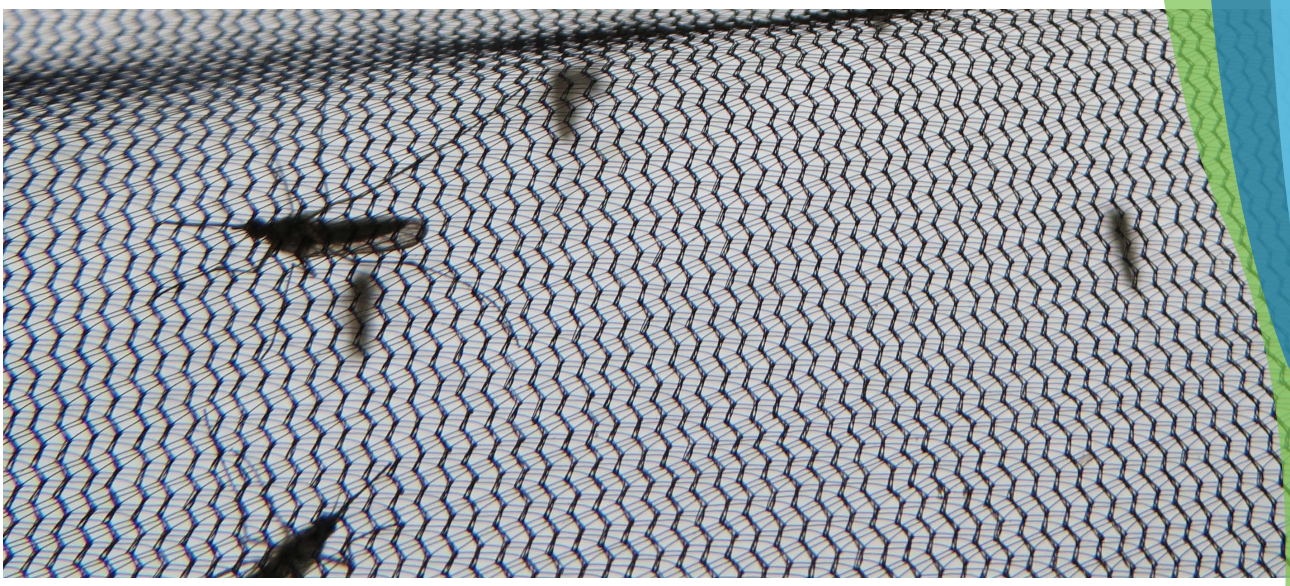


Figure 28 The patterns of weft knitting on the left, middle, and warp knitting on the right. The warp knit locks the yarn in place, thus preventing the knit from unraveling.

Figure 29 Noseeum netting, A type of warp knit with holes, that do not allow a mosquito to get through.



3.2.2.2 Insect protection

Combining the light weight of the fibres, their strength and the thickness of the monofilaments, Dyneema® or the PDY Dyneema® on bobbins should make a great material for insect protection netting. Furthermore the chemical and weather resistance of the material allows such nets to be made without a coating, thus easing the process for re-use of the fibres.

Insect protection netting is currently made out of different materials depending on the application. In more permanent applications, such as year round window screens and pool and patio enclosures, PVC-coated fibreglass, or painted and heat treated aluminium is used (Vandervort, n.d.). These meshes are woven and need the coating to lock the joints in place. For window nets and door screens that are used less extensively, nylon, or PVC-coated polyester, to keep pets from tearing the screens, is used. For personal mosquito nets, around a bed, or when camping in the wild, the most common materials are also nylon and polyester. Sometimes even cotton is used, but mainly in more permanent set ups, since it is heavier and susceptible to moisture. It can however offer a better sleeping climate, and, by purposefully sprinkling it with water, help keep you cool in hot climates (Mosquito-netting.com, n.d.).

Mosquito nets are either woven, and coated, or knitted. Knitted mosquito netting fabric is knitted in such a way that the yarn is self-locking. Multiple yarns are knitted together on multiple needles, with one yarn per needle (Islam, 2016). A basic warp knit is shown in figure 28 on the right. Regular knitting as done by hand or when spool knitting "*punniken*" is called weft knitting. The basic weft knit is also shown in figure 28, on the left. The yarn does not lock and multiple needles can be used for a single yarn. When a hole arises in a weft knitted fabric the chances of it falling apart completely are much higher than when this happens in a warp knitted fabric. In a knitted fabric holes are created based on the stitch, the thickness of the yarn and the thickness of the needles. This way a knitted sweater can have no holes, whilst a mosquito net, made from thin yarn, is more hole than fabric. Because the holes are created in the knit, they cannot shift as much as in a woven net, and therefore do not require a coating to lock the weave, or in this case the knit, in place. Knitted mosquito netting is most commonly seen in tents. The fabric goes by the name of noseeum netting (figure 29), based on the slang term for midges and other little biting flies, which is No-See-Ums, because they are hard to spot.

The size of the holes in insect repellent netting is depending on the size of the bugs it needs to keep out. According to Mosquito-netting.com (n.d.) a mesh size of 1,2 mm by 1,2 mm is common, but to keep out the sand flies, midges and other No-See-Ums a mesh size of 0,6 mm by 0,6 mm is required. Furthermore to ensure protection mosquito nets are impregnated with insecticide. Functionally the net should also not be allowed to touch the skin of the person in the net, since this might still allow the mosquitoes to bite the person inside the net, through it.

The benefit of PDY Dyneema® in mosquito netting is a lighter mesh, with thinner yarns, allowing for better visibility through the net, less weight of the netting, whilst maintaining ,or even improving the strength of the net. Its abrasion resistance makes it suitable to withstand wear and tear, whilst its UV resistance can stand up to use in the sun. Its all-round chemical resistance will assure no harm is done to the fibre from impregnation with insect repellent. Current nylon noseeum netting will get no lighter than 17 grams per squar metre (Ripstop by the roll, n.d.-a), whilst Dyneema® flexible composite fabric gets as light as 11 grams per square metre (Ripstop by the roll, n.d.-b). When Dyneema® is used for noseeum netting, the weight will likely drop even further, since less material is required for netting than for fabric.The only hurdle to overcome is to split the yarn coming from the bobbin into thinner yarns, that will be knitted into the final fabric.

Collection of the mosquito netting can be achieved through collaboration with home rental organisations. This way renters can be provided with top notch protection from insects with window screens and screen doors, whilst the broken nets can be collected while replacing them, assuring the possibility of re-entering the loop. When the Dyneema® mosquito netting is used in the tents already making use of the Dyneema Flexible Composite Fabrics, the tents get lighter, since the mesh will become lighter, and the tent will be completely made out of Dyneema® material. This will save time and effort having to separate the mesh from the rest of the tent, when recycling the product.

Using the nettingDyneema for a mosquito net will not only lighten the net, but also improve the amount of air being able to pass through, which is important to note, since it might get smothery in warm climates inside a mosquito net. This is a reason for people not to use them, according to HoboTraveler (2007), thus putting themselves in danger of contracting malaria, and other mosquito transferred diseases.

3.2.3 Friction based applications

3.2.3.1 Snowless skiing

Options for implementation of Dyneema®, both PDY but also for regular Dyneema®, are in the field of skiing. Skis are made with complicated laminated constructions, to keep the weight of the ski as low as possible, while tuning other properties to the skiers desire (Made how, 2018). For friction purposes UHMWPE is already used in ski bases, which are made by compressing powder into base shaped sheets (Brooker, 2009). If these bases could be made out of Dyneema®, the bases could add even more to the ski than just its friction coefficient. The tensile strength of the fibre will help the upward bending resistance of the ski, reducing the amount of fibreglass in the rest of the ski, necessary to get the desired bending resistance. When the skis bend under load, they bend upwards. This means the top of the ski will be compressed and the bottom is put under tension. Adding the tension resistant Dyneema® fibre to the base, will thus help resist bending of the entire ski. Due to the location of the fibre on the bottom, away from the bending centre from the ski, it will almost solely be put under tension. Therefore its lack of handling compression is not an issue. A similar trick has been used for ages in the biocomposite bows of Asia and the middle east. They used to back their bows with sinew, made from animal tendons, whilst on the belly of the bow they used horn, which is compression resistant.

Furthermore Elert (2007) provides the friction coefficients for different types of skis on snow, combined from different researches. He says the friction coefficient for a waxed ski on snow lies between 0,1 (static) and 0,05 (dynamic). DSM Dyneema (2016) provides a friction coefficient yarn on yarn of 0,05 as well, which likely concerns dynamic friction. Of course yarn on yarn, and yarn on ski values are likely different, but these numbers might still allow Dyneema® to be used as snowless skiing surface as well, even with a possible differentiation of 10% for PDY yarn in the friction coefficient, as presented in chapter 2.1.2. The materials abrasion resistance should allow it to stand up to the use of skiers passing over it.

Different types of so called dry slopes are already available on the market, all with different ways of trying to mimic a snow surface. There are bristle mats, containing just bristles between a metal base (Skitech Systems Ltd, 2018). The layout is in a diamond shape to reduce the contact area and offer places for slalom poles. (figure 30)

There are multi-layered systems that offer less contact when going straight yet more contact, when turning. This is due to the ski biting deeper into the fibres, when turning on its edge, thus catching the second layer of fibres (Proslope, 2018). (figure 31)

There even are single material mats, with more rod-like bristles, that are cast rather than drawn like fibres (Neveplast, 2018). (figure 32)

All types of dry slopes currently on the market seem to make use of bristles standing upright, as shown in the examples. Dyneema® yarn, however, is not stiff enough for these types of bristles. Therefore an alternative should be developed if this application is going to be made with Dyneema®.

Figure 30 Bristle dry slope by ski tech. The diamond pattern reduces contact area and offers room to place slalom poles.

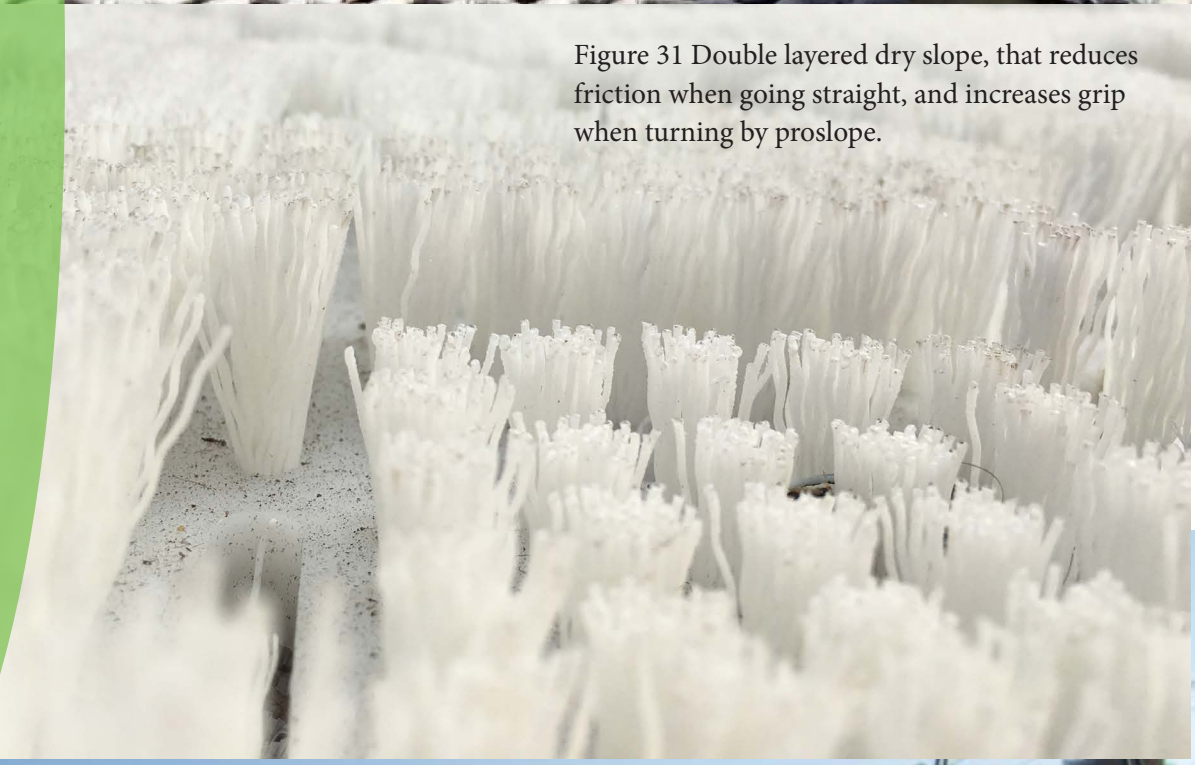


Figure 31 Double layered dry slope, that reduces friction when going straight, and increases grip when turning by proslope.

Figure 32 Cast dry slope, that is made from a single material by Neveplast.

Figure 33 Semi-flexible cutting board, that can be bent to help put cut vegetables in the pan.

3.2.3.2 Flexible slides

When thinking about sliding applications the first idea that springs to mind is the regular slide. They are made out of stainless steel in most playgrounds. Most home slides are usually vacuum formed HDPE (TP Toys, n.d.). Next to the playground slides, there are waterslides, large slides you go down on mats on, and even the steel zipline has a lot in common with regular slides. Due to its low friction coefficient, Dyneema® might prove to be a great material for a slide or sliding mat. When creating a fabric from the fibres a flexible slide might be created from this fabric. Such a slide needs to be either placed on a frame, which makes it similar to a regular slide in use, or to inflatable waterslides for use in the backyard (Bartswatersports, n.d.); or it needs to be hung to offer a more zipline like experience, without the need for the more thorough control that a zipline usually requires.

When hung a strong fabric is required to keep the slide and its occupants safely in the air. The PDY Dyneema® fibre is strong but can vary greatly between bobbins. The FDY fibre is stronger and might therefor be even better suited for this application. Furthermore the idea is very novel and might not be accepted in the market. First a thorough market research is required to see if this might be a sellable product, or if the demand will not be there. Positively, such slides will morel likely be created for public playgrounds, or even attraction parks, making collection after use easier compared to offering the product to consumers. This means the resources are more likely to re-enter the loop.

3.2.4 Specialised kitchen applications

The softness of the fibre as well as the cutting resistance might make the material suitable for use in various kitchen applications. A simple fabric sheet could prove an excellent flexible cutting board. Preventing the knife from cutting more than what needs to be cut, whilst doubling as an easy way to lift the vegetables, or meat that has been cut to the pan or pot they need to be put into, without them rolling of the sides. Current cutting boards that offer the extra feature of helping to put your cut vegetables in the pot are made out of silicone, or PP, as a rigid board (figure 33), sometimes with living hinges.

The benefit of a Dyneema® board over these alternatives, is that a larger size sheet can be folded to present a smaller cutting sheet. When a larger cutting board is desired, for instance when cooking for more people, the same sheet can be used. This prevents having to keep switching between cutting, and putting the cut produce in the pan, because the board is full. Another benefit is that the thickness of the cutting sheet can be made thinner. When something rolls away during cutting, it hardly falls of the cutting board, and will not bounce away. Unfortunately, the Dyneema® material is not very heat resistant, with an advised using temperature up to 70° Celsius, so cutting items straight from the pan is not an option.

Next to a cutting sheet soft brushes can be made from the fibres, that are ideal for cleaning delicate vegetables such as mushrooms, that can be harmed by coarser vegetable brushes.

3.3 Idea selection

To determine which idea direction is best to pursue further, all ideas need to be compared. They will be judged on a general list of requirements, of which some might mean different things for different applications. The requirements have been formulated in such a way that an unbiased comparison can be made. Based on how well they fit an idea direction can be chosen to pursue further.

3.3.1 List of Requirements

The product should not compete with current Dyneema® products made with FDY

The product should be (partially) made with PDY Dyneema®.

The Dyneema® in the product should be reusable or recyclable.

Over time it should be possible to have the Dyneema® fibre in the product become (part of) feedstock for new Dyneema® fibre at the end of product life.

It should be possible to collect the products after their use life, either for reuse in a different application, or for use as feedstock for new Dyneema®.

The product should have market potential.

The product should be usable within its market of application.

The Dyneema® material in the product should offer an improvement to the product, compared to other products in its market of application.

The product should fit the branding of Dyneema® in the direction of protection or safety; Fitting the slogan "With you when it matters".

The comparison in figure 34 weighs ideas on three elements. Plusses, minuses, and other possibly important factors that do not carry a positive or negative load. Each of the strikes stands for an argument for, or against an idea.

None of the applications compete directly with FDY, yet some are better suited for FDY material. When this is the case the strike will be placed on the negative side.

In the case of the PDY to be used; one strike means PDY on bobbins can be used. Two means Bird's nests as well. Three means another type of waste, in this case B-grade DFC. A strike in the middle means the solvent needs to be removed from the PDY for use in this application, and a second one means splitting of the yarn is required.

Collection is either difficult, or easy to achieve at this stage, which determines the location of the strike. The second negative strike for the wetsuit is placed since it will likely be very hard to separate the Dyneema® from the neoprene of the wetsuit.

For the market application every strike is an argument for, or against this aplication from its market perspective. A strike in the middle is an extra consideration, not necessary beneficial, or negative. For the sleeping bag the positive strikes are that it prevents the user from getting too hot, and it has a comfortably cool first touch feel. However, it can only be

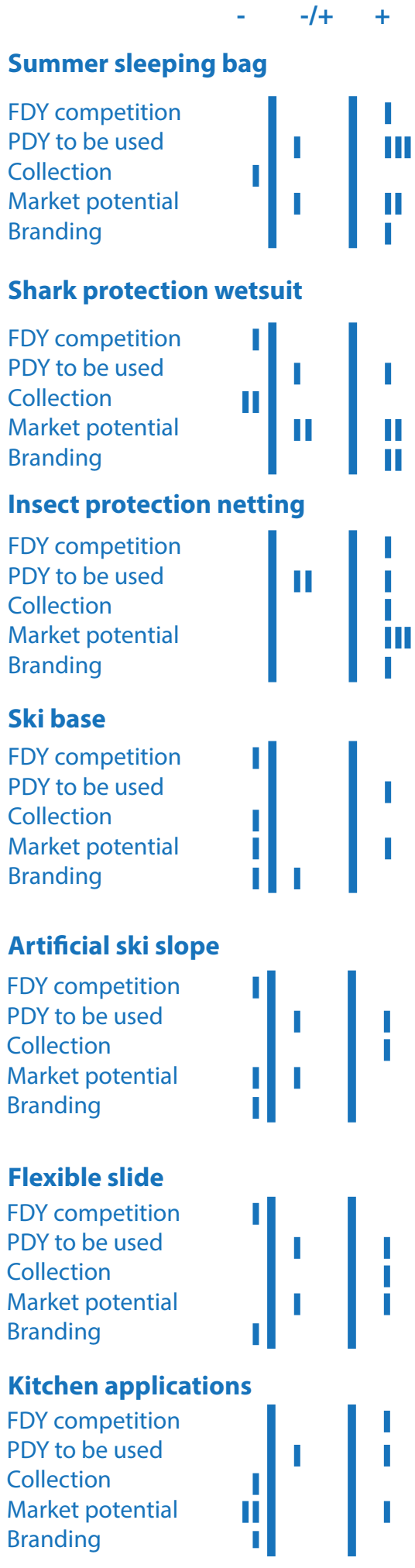


Figure 34 Comparison between the ideas, based on plusses (right), minusses (left) and insecurities(middle).

applied for a summer application. The shark protection is very lighweight, and fills a gap in the market. However, it will require a lot of testing and it only protects against the cutting of the teeth. The insect protection netting is lighter than competitors, allows more air to pass through, and does not require a coating. The ski bases increases the bending resistance of the ski, but will also make the ski more expensive. The artificial slope needs stiffer fibres than the PDY, or FDY are, and its friction coefficient is similar to current applications. The flexible slide is a novel idea, but market acceptation is insecure. The kitchen application cannot handle the heat of food straight out of the pan. It will be expensive in an already overcrowded market, but for the positive stroke, the cutting board will be very flexible.

Finally if the branding of the application can fit in the protection, or safety strategy of Dyneema® the strike is positive. Shark protection has a second strike, since Dyneema® is already being used for safety lines attaching divers to the boat, which offers the possibility of brand recognition.

3.3.2 The top three

Based on the comparison Mosquito netting seems the most promising idea, closely followed by a summer insulation application and a shark protective wetsuit. The other application fields have little or insecure market potential as well as a bad fit with the branding strategy of Dyneema®.

The only downside for the mosquito netting application is that only material on bobbins can be used. Furthermore the yarn needs to be split, which seems possible at this stage, but needs to be examined further.

Runner up is the summer sleeping bag, which can use all types of material and even include waste DFC material as outer shell in the sleeping bag. Collection of these sleeping bags is going to prove difficult.

The third possible option of a shark protective wetsuit, has both the downside of insecure collection, and only being able to use material from bobbins. On top of that, the more abrasion and tear resistant FDY Dyneema® is better suited for this application. Therefore it might still prove a great opportunity to pursue as a new application for regular Dyneema®, but not for this project. For this reason it was decided not to pursue this direction further.

Figure 35 Mosquito nets that are currently available, from luxury constructions, to full fabric models.

4 Conceptualisation

4.1 Mosquito net

Based on the selected idea of insect protection netting, a mosquito net will be designed, that will incorporate Dyneema® Noseeum netting. The net will be made for both use in Africa as well as in Europe.

4.1.1 Current market

In order to design a better net than what is currently available on the market, it is important to know what the market is, and what products are considered good and what the main problems are with the currently available products. Currently available nets are shown in figure 35.

The most widely used mosquito net is a simple square net that fits the dimensions of the bed. It is attached to poles at the corner of the bed, or hung from the ceiling. A lot of issues with this net occur due to improper use. According to HoboTraveler (2007) it can be wrongly attached in a lot of different ways: it can be hung too high, so it cannot be properly tucked under the mattress, or come loose at night; it can be hung on the outside of the poles or frame, thus making it no longer possible to be tucked under the mattress; or it can be torn from being hung improperly, on the fabric and not the hanging straps, and from tearing at the tucked edges, due to excessive strain. Since it also does not have an entrance, difficulty might arise when having to tuck it under the mattress, when on the mattress yourself.

Another quite common design for both indoor and outdoor use, is making use of a small single hanging point, either attached to the net directly or with a small spreader, such as a bar or circle. The main problem with these nets is that the spreader is so small that the net is falling in over the bed on all sides. This increases the risk of touching the net, which in turn allows mosquitoes to continue to bite the person inside (MousetrapGenius, 2018). Some of these designs come with doors, which are overlapping flaps of fabric, and need to be closed properly and tucked under the mattress as well, thus facing the same problem as those without these overlapping doors.

Then there are pop-up designs that cover the entire bed, with zipped doors at the edge of the mattress, so you can sit in them without the risk of tearing the fabric. They also allow the net to remain tucked under the mattress when entering or leaving. However, if they need to be stored, folding them back up is quite a hassle and once packed they are quite a lot larger than the aforementioned models. Smaller pop-up models, only extending a space over the head, lie on top of the bed at the legs and feet, thus again facing the risk of skin touching the net and mosquitoes reaching the person inside. These models again have no door so need to be tucked under the mattress from the inside.

Other mosquito nets, are more tent like constructions you put on, or around the bed. They vary from ones you fold over your bed, that cannot be tucked in, to those you put under the legs of the bed, with similar overlapping flap doors. that need to be tucked from the inside. Others look like domes, standing on top of the bed, which you have to crawl under to get into, leaving you again with the problem of tucking. Set up instructions and packaging sizes, differ as much as the designs do, though overall they are quite heavy, and can take quite a while to set up.

In order to improve on the current mosquito nets, the new design should be easy to set up and dismantle, be able to be tucked from the outside, and not slip out from underneath the mattress during the night, have a door that does not require tucking it from the inside, and it should not touch the people lying inside. The design should not be too heavy and should be easy to take with you on a trip.

4.1.2 Inspiration for the new design

Based on the current mosquito net designs and their connection with the camping world, additional inspiration for a new design is sought in tenting. Tents and mosquito nets share a similar goal, of setting up a protective layer around the user. Tents against the weather and to help keep warmth in. Mosquito nets against mosquitoes, without interfering too much with the climate (HoboTraveler, 2007). Therefore, when designing a new Mosquito net, tents may offer great inspiration, as they clearly have done for some of the current designs. When keeping in mind the requirements following from the issues with current designs, tents with standing poles to keep them up, will likely not be suited for mosquito nets that should cover people in a bed. Tents with flexible frames however should suit this purpose much better. Due to personal experience with the tents from MSR, these are used as inspiration. A look is taken at the Hubba Hubba NX (figure 36) and the Elixer 2 (figure 37). Both tents are designed for two people but also have variants for one person and for three people.

Both tents are double walled designs, but only the inner tents with the frame are considered, since a double walled design is not required for a mosquito net. The designs use a flexible frame with collapsible aluminium poles. The tent clips onto the frame from the inside, with colour coded plastic clips. This system allows for the tent to be set up very quickly, and easily, and would be great to use for setting up a mosquito net as well. The differences between the tents is based on overhead space and weight. The Hubba Hubba NX has less headroom than the Elixer 2, but is therefore also lighter. The Elixer 2 makes use of a frame of two poles that form double intersecting arcs. They are connected on the overlapping areas by a hinge. If this hinge can be made so that it can slide over the poles to offer different intersection points, multiple different ground areas might be covered with the same pole structure, allowing for a modular design of mosquito net, that can cover multiple different bed sizes.

Based on the MSR Elixer 2 tent, a mosquito net design will be made with a frame consisting of two intersecting arcs, in between which the netting will be connected to the frame with clips. Modularity of the frame, to suit multiple bed sizes will be researched.

4.1.3 List of requirements for a mosquito net

Easy to setup and break down.

Can be impregnated with insecticide

Can be tucked under the mattress from outside the net.

- Cannot come untucked during the night.
- A person should be able to enter the net without having to untuck it.

Protect easy to tear places.

Cannot (accidentally) sleep with the skin against the net.

Small packing volume.

Lightweight for its structure.

Bed sizes:

- The net should be adaptable to cover multiple bed sizes.
- The top of the net should be no lower than one metre of the top of the bed.

The fabric:

- The fabric should allow more air to pass through than nylon noseeum netting with a similar hole size.
- The fabric should no longer contain harmful chemicals, such as the decalin solvent still present in the PDY material.

4.1.4 The frame

Depending on the needs and location of the user, beds have different sizes. Ranging from narrow beds, to king size beds that are as broad as it is long. Length of beds also differs from country to country with a standard bed length in Africa of 1,88 metres, up to an extra length bed in the Netherlands of 2,20 metres. When placing a mosquito net on a bed, it has to fit that bed. With different global standards, this might require a lot of differently sized mosquito nets, or a modular solution. Therefore, a setup for a modular frame was made to test the ranges of bed sizes that one size of poles can cover.

4.1.4.1 Frame sizes

Since mosquito nets are used more in Africa than in the Netherlands, the setup will first be made for the African standardised bed sizes, which can be seen in figure 38, and are based on the information given by Genie Beds (2018). After enquiry, they were able to tell, that the most popular bed size in Africa is the double bed. Next to the size of the bed, the sitting height under the mosquito net is also important. Therefore the sitting height that covers 95% of Dutch students was taken, because they are the tallest group of people to likely make use of the mosquito net. According to Dined (n.d.) this distance rounded up is one metre (figure 39). This distance might seem on the larger side, since most people to make use of the mosquito net will likely be smaller. It has been purposefully set a little on the larger side however, since most people to make use of the mosquito net do not want to be restricted by it too much. Most people are not very mosquito-net-minded, which means their focus is likely not on the fact they are in the mosquito net, and therefore they will not be having the restrictions the mosquito net poses on them in mind. By offering a little more space in the mosquito net, they are less likely to accidentally come into contact with it, and cause unwanted damage. For the same reason the door in the net should be placed so, that the user can sit on the bed in the opening, without putting tension on the mosquito net.

Figure 36 The MSR Hubba Hubba NX, a lightweight construction with a fully connected supporting pole network.

Figure 37 The MSR Elixer 2, slightly heavier in construction but its pole design shows possibilities for a modular design.

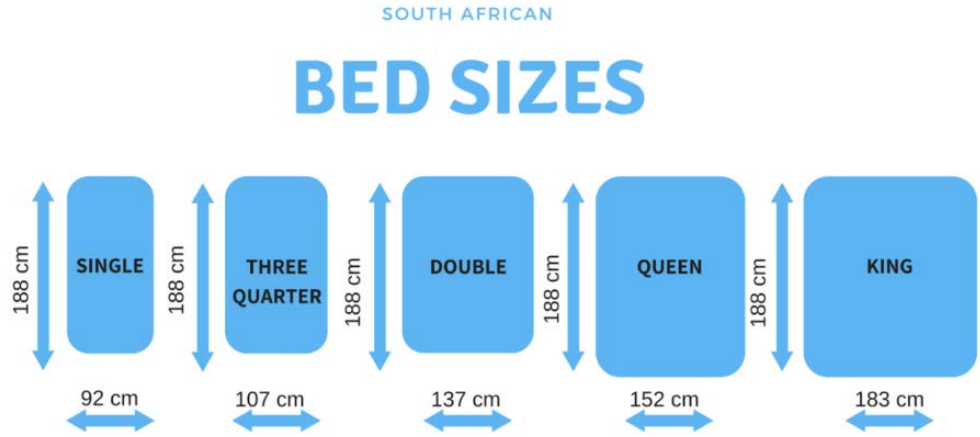


Figure 38 Standard bed sizes in south africa, all of these models are also available as extra long model of two metres.

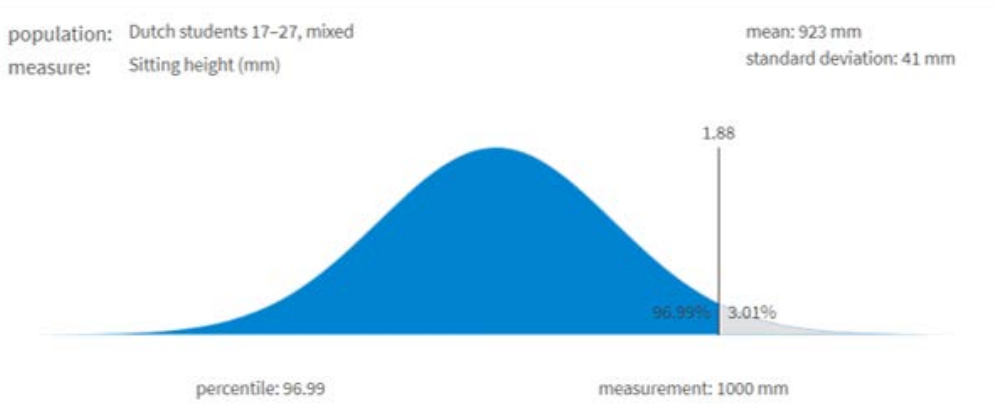


Figure 39 Sitting height for the population of Dutch students.

Figure 40 Test setup for the modular frame of the mosquito net, made from PVC-pipes of four metres long.

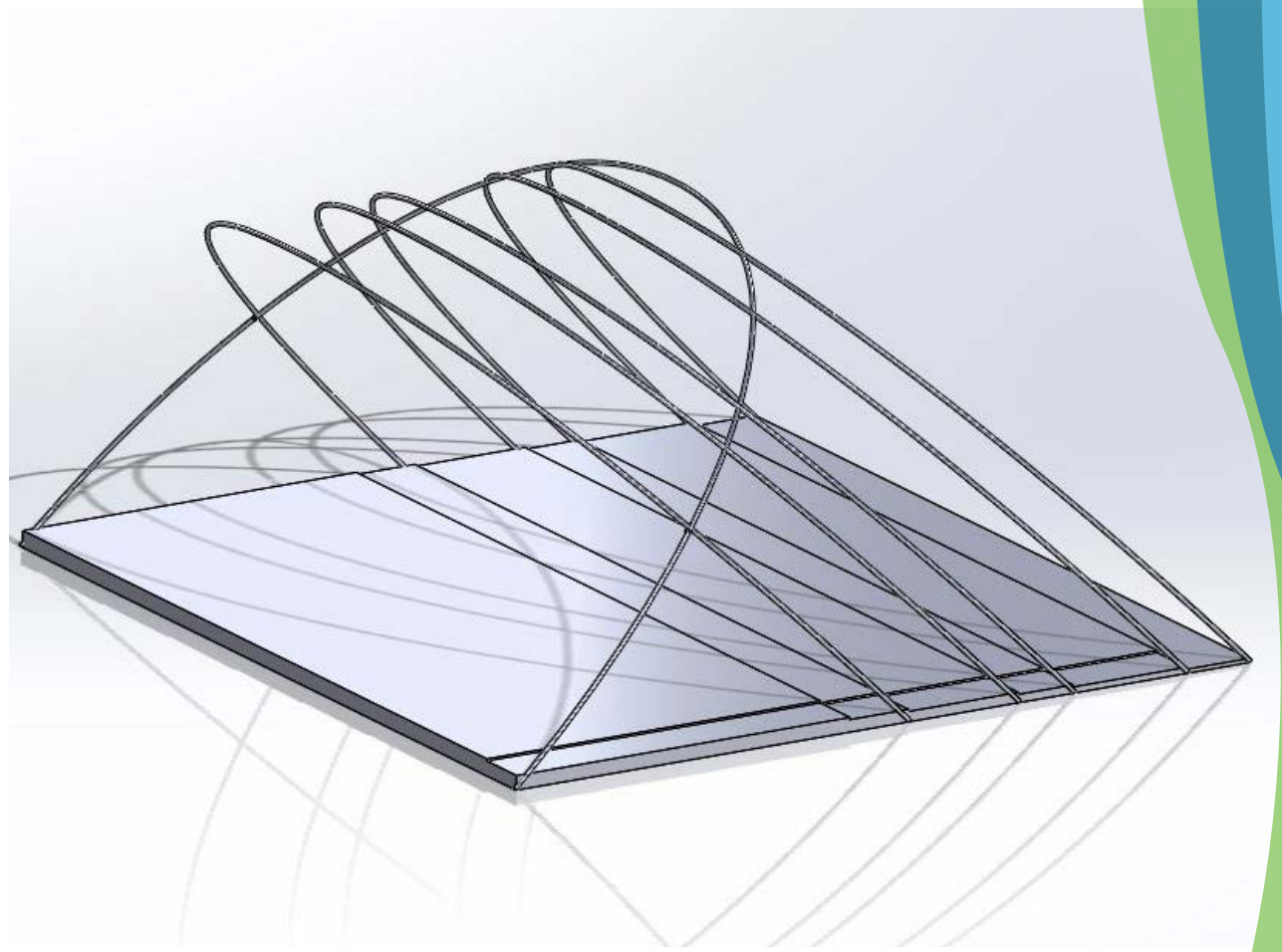


Figure 41 Model of the frame poles for different sizes of bed, whilst maintaining the sitting height of one metre.

4.1.4.2 Testing the frame

To test the range of beds that could be covered with a single-sized set of poles, a test setup was made. This setup is shown in figure 40. Mounting points for the poles were made on the floor, to the measurements of the African standard and extra length beds. These mounting points were created by duct-taping screws to the floor. Over the centre of the bed sizes a horizontal bar was hung at one metre height. PVC Pipes, of four metres each, were then placed over the screws to form arcs, and laid over the horizontal bar to form the shape, that the final frame should have when on top of a bed. Measurements were taken on the intersection points of the two poles, and on the distance from the side of the bed at the highest point. These were then used to create a 3D model of the frame in Solidworks, a CAD moddeling tool. This model is shown in figure 41.

Based on the test, poles of four metres could be used to frame beds between the sizes of super king to the three quarter bed with extra length. Smaller beds need smaller poles, or the frame gets wider than the bed, or higher than the height of one metre. Based on this information two sizes of modular mosquito nets seems likely to be the best way to cover the entire range of bed sizes. Both sizes will be able to cover the double bed, since this is not only the middle in size, but also the most popular bed.

4.1.5 The net

The mosquito net itself will be made from the PDY Dyneema® fibre. The net will be knitted into a noseeum mesh, which is made by a self-locking stitch called warp knitting. A more detailed explanation can be found in chapter 3.2.2.2. This mesh is machine made on warp knitting machines (WarpKnitting4U.com, 2011).

These types of machines use multiple threads in parallel. The yarns are wound next to each other on large bobbins or separate on multiple small bobbins. Before the PDY material can be knitted it therefore has to be aligned in such a way that the knitting machine can use it. The PDY material also needs to be split before realigning, because it has too many filaments together on the bobbin after its first production step. Using the material to knit as it is on the bobbin, will lead to a very thick mesh, which loses all its weight benefits.

4.1.5.1 Splitting the filament

Based on the production method of Dyneema®, the filament is locked at both ends (1). The extruder at the beginning, and the bobbin at the end. This means that twists in the yarn can only occur in between those locked points (2). Since the yarn is locked at both ends, twists that occur have to be symmetrical, meaning that the yarn would untwist itself, if it was spanned long enough.

Therefore, if the yarn were to be split into all its different single filaments, little to no twist would arise, if enough space is granted for the yarn to unravel itself properly (3). The twists that are in the yarn can still be present in the bobbin, therefore, when splitting, enough space in line with the fibres is required to allow the yarn to unravel itself.

If the yarn were to be split into several multifilaments, the possibility of entanglement might still be present, because single filaments going into different groups might block the entire yarn from untangling properly (4). Therefore splitting needs to be done into all the loose monofilaments, before combining them into multifilaments again.

After they have been properly split, multiple single filaments can be combined again into multifilaments (5). This can be done with a single machine as long as separation into monofilaments is first ensured. A way of splitting the yarn into several multifilaments will then follow the lines as iconised in step (6) of figure 42.

Several multifilament splitting machines on the market use this theory to split these types of straight wound filaments into single filaments. To see if it is possible to split the PDY yarn on these machines contact was made with Progressive Technologies (figure 43)(n.d.). Their response was, that it was not possible on their machines. A second company that produces multifilament splitting machines is Aiki Riotech in Japan (AIKI RIOTECH CORPORATION, n.d.) (figure 44), unfortunately they did not respond to enquiries made about the possibility of splitting the PDY yarn on their machines.

After enquiry within DSM Dyneema® to their expert, that has looked into splitting of the multifilament yarn before, it seems not possible to split the PDY. The main reason is that the filaments sometimes have the tendency to stick together, which makes splitting more problematic. In order to solve this a change in spin plate is required. Because such a change results in altering all the following production steps for DSM Dyneema, and all other stakeholders with the material, as well, this solution becomes no longer viable to pursue. It can be compared to entering the high performance fibre market as a new company. Such a change is therefore not possible. This means that the PDY bobbin cannot be split into thinner yarns, thus the netting cannot be made. Therefore the concept of a Mosquito net out of PDY Dyneema® is also not possible, and a different solution has to be sought.

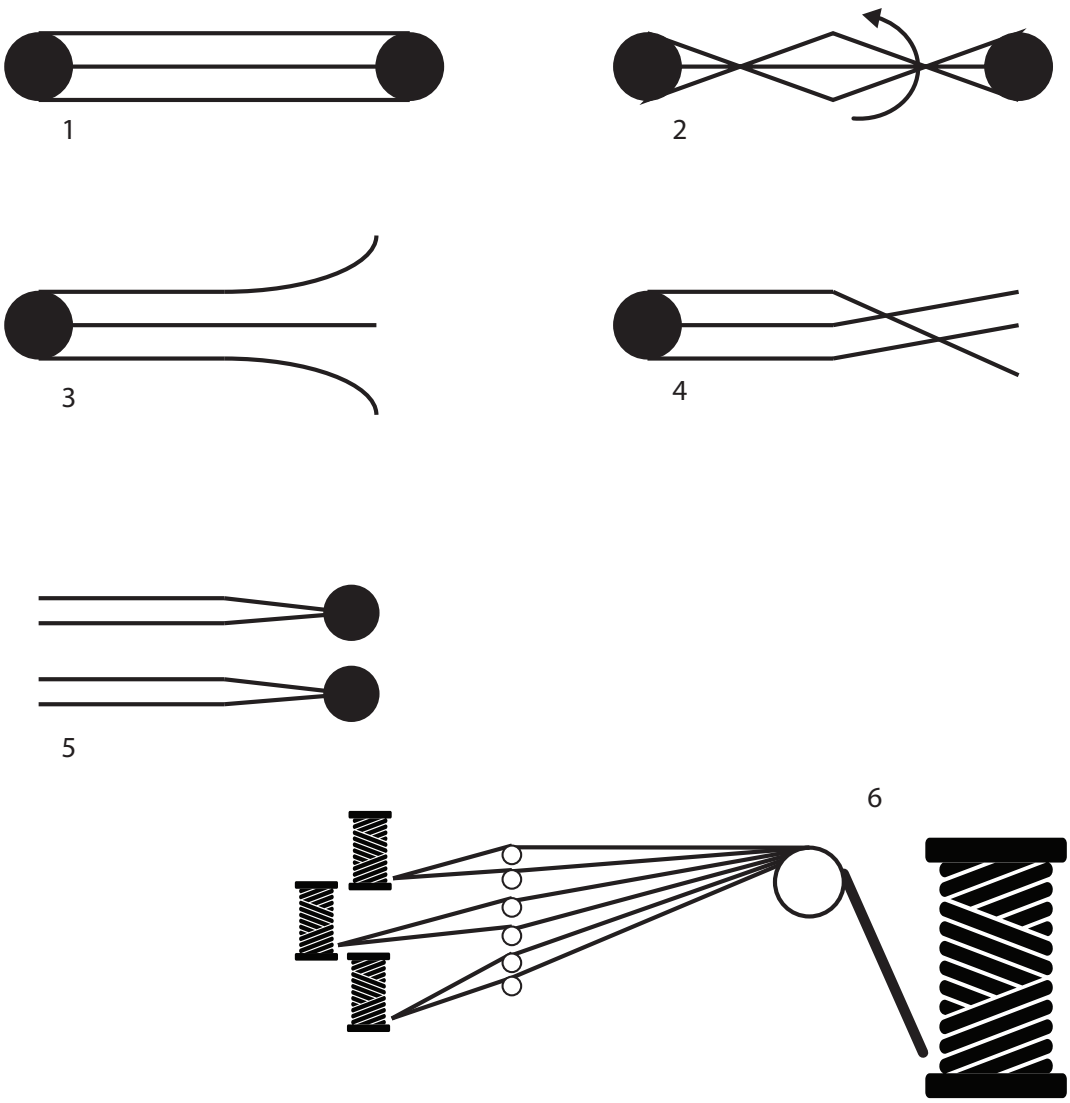


Figure 42 The theory of splitting straight wound multi-filament into several smaller multi-filaments.

Figure 43 Multifilament splitting machine of Progressive Technologies

Figure 44 Multifilament splitting machine of Aiki Riotech corporation

Figure 45 From top to bottom, the different shapes, opening methods, additional features and baffling patterns of sleeping bags.

4.2 Sleeping bag

Since using the PDY Dyneema® to make a mosquito net is not possible, a different solution for the Dyneema® fabrication residue is required. Following the idea selection outcome, an insulation application seems the next best option. Most interesting within this field would be a sleeping bag for summer use. This application can help Dyneema® to increase their share in the outdoor market, and it also offers a way to use Dyneema Flexible Composite fabric material or DFC waste material as outer shell for the sleeping bag.

4.2.1 Current market

According to Creech (2013), sleeping bags use a couple of techniques to keep the person inside them comfortable through the night. They stop convection by blocking the wind. The outer layer of a sleeping bag does not allow wind to pass through keeping the air inside stationary and preventing the person inside from getting cooled through convection with the wind. The insulation inside is distributed evenly so that large air pockets are avoided, this prevents air from moving and causing cold spots. By trapping stationary air in the insulation, conduction is reduced keeping the person inside warmer for a longer period of time. The final trick used in sleeping bag design is not always applied. Some sleeping bags make use of the radiation a person emits, either by reflecting it back to the body, or by absorbing it in the insulation, to help heat the sleeping bag and keep the user warm all through the night.

Sleeping bags come in all kinds of shapes and sizes, a comparison has been made based on the assortment of outdoor chain Bever (n.d.) (figure 45). The general shape of the sleeping bag differs considerably between models:

The blanket model is basically a folded rectangle.

The egg shaped mummy is a more form fitting model, that in some places resembles the shape of an egg.

The mummy fits to the shape of the body, yet still allows some movement.

The almost inverted egg shaped, tight fitting mummy, leaves no air pocket between the person in it and the sleeping bag. Even though these sleeping bags are labelled unisex, they might be less suitable, or even uncomfortable for certain body types, especially for females.

Adaptations in the shape can be seen in the inclusion or exclusion of differently shaped hoods, and some models offer a slightly larger footbox. Some even seem to be a hybrid between the blanket model, the mummy and a jacket.

Many different design elements can be found for ways of opening and closing the sleeping bags. The zipper down the side is often replaced for one of half its length, which can also be placed in the middle, or on both sides, to present a blanket when both opened. Zippers can come down the front in an S like shape, presumably to allow some cover over the torso, but leave the rest of the body free on a hot night. Similar designs stay on the side, only to swoop over the front of the sleeping bag just above the feet, to allow those to lay on top of the sleeping bag when opened. Others have no zippers at all, only overlapping flaps to get in and out of the bag. In some cases these flaps themselves might even have overlap on the corners to act as mittens for the user.

As the zipper, or lack thereof, gets used to offer more features in the sleeping bag, so do other features pop up as well. Extra holes appear to allow arms and feet to be stuck out of the bag on hot nights. Elastic is added around the knees to offer more freedom of movement when sleeping, without allowing air pockets to be formed when the added space is not used. Fleece liner in foot boxes is added and so are extra quilts, either separable or attached to the sleeping bag. Pockets to store important items can be found inside the sleeping bags, and pockets outside will hold the sleeping bag firmly attached to the sleeping pad.

Finally, the type of padding, or baffling differs between sleeping bags. Some have baffles running horizontally, others vertically, or diagonally, but diamonds or circular shapes can also be observed. These baffles hold the down, or the synthetic fibre in place, and the way they are constructed is important. When stitched trough completely, less insulation is located underneath, or near the stitches, causing cold spots in the sleeping bag. By having baffles in the shape of boxes, or triangles; in a cut-through view; these cold spots are avoided, they do however, require an extra layer of fabric in the sleeping bag, which will add weight (Nelson, n.d.). Some synthetic sleeping bags have insulation material on a roll. This is stitched to the outer fabric directly to resemble baffles, to then be processed together, during patterning and assembly of the sleeping bag.

4.2.1.1 A closer look at one of the competitors

To properly see how a summer sleeping bag is constructed, a competitive model was bought and taken apart. The model chosen is a Nordisk Abel +10. An egg-shaped, fully synthetic summer sleeping bag, rated for a temperature of 10° Celsius and up.

The sleeping bag consist out of three layers of polyester. On the outside is the outer shell, to which the insulation layer is stitched from the roll. This might cause cold spots though not as badly as regular down, or loose-fibre baffles, since the insulation material is still present at the location of the stitches. They have been cut to the desired patterns and sewn together. This way of construction assures extra insulation in the areas, where multiple pieces of outer fabric are stitched together, for instance in the foot box (figure 46), and down the sides. Interestingly, no extra insulation seems present at the bottom of the sleeping bag (figure 47), which is compressed during use, due to the user laying on it. This weight pushes the air out, thus losing insulator capabilities. By adding more insulation some of these effects might be countered (Creech, 2013). However the designers likely thought, the user would use a sleeping pad, which will isolate and insulate him from the cold floor.

The lining on the inside is made out of brushed polyester, and is attached to the insulated outer layer on both sides. The foot box of the lining is attached to the footbox of the insulated outer shell through strips of scrap polyester, allowing the liner-footbox to move a little within the footbox of the outer shell. A similar strap is attached to the end of the pocket inside the sleeping bag, to allow larger items to fit in the pocket, without affecting the shape inside the sleeping bag as much. Finally the hood is a very simple flap, that is a continuation of the bottom of the sleeping bag. A standard drawstring allows the user to pull it up and around his head and thereby shape the hood.

This sleeping bag has a weight of 900 grams, of which 250 grams is the insulation, and 65 grams the stuff sack.

Figure 46 The connection between the lining and the outer fabric with insulation of the sleeping bag. This construction allows more freedom of movement for the user during the night.

Figure 47, The seam between top and bottom of the sleeping bag. The insulation layer is of equal thickness on both sides.

Figure 48 The multiple contexts of use of a summer sleeping bag: Summer camping, Festival camping, Sleeping bag hacking, and Family camping, either by tent or caravan.

4.2.2 The multiple contexts of summer sleeping bag use

Summer sleeping bags are used in a couple of different ways by different users. Different types of use bring different types of requirements for a sleeping bag, that tend to not always be in line with each other. Therefore, not all summer rated sleeping bags are necessarily a good choice for all types of summer rated camping. There are four contexts of use for summer sleeping bags: summer campers, festival campers, sleeping bag hackers and family campers. An impression of these types of camping is giving in figure 48.

First of all camping in the summer, as the name suggest, is one of the types of uses. What is meant by camping needs to be clarified here, since it means different things to different people. In this case lightweight camping is meant as a means to enjoy another hobby for which no other means of spending the night is an option, for instance backpacking, hiking, cycling, or climbing. The main concerns for a sleeping bag in this scenario are: *weight,* it needs to be as light as possible, *packing volume,* as small as possible, and t*emperature rating,* it needs to offer sufficient insulation to sleep in the chosen environment at the chosen time of year. Other factors, such as humidity of the environment, help make a choice between more moisture resistant, and heavier synthetic bags or lighter, yet less moisture resistant down sleeping bags.

The second type of use for a summer sleeping bag is for visiting festivals. Since the tent and gear in the same place for an entire festival, weight becomes less of an issue for this type of use. Especially since transportation to the festival often is by public transportation, or even by car, the gear spends little time on the backs of the user. Comfort and ease of entry in and out of the sleeping bag becomes more of an issue for this type of use. Price is also more important for people visiting a festival, since they are mostly young people, that are still in college and do not have a lot of money to spend on a sleeping bag. They prefer to spend their money on entry to the festivals and consumptions once they are there.

The third category of use is for the hackers, that are trying to get the best and lightest gear for every situation without breaking the bank too much. They have opted to follow a modular system to suit all their sleeping needs in different circumstances. They have three different sleeping bags, that they combine to get the lightest, optimal combination for every environment. A lightweight down summer sleeping bag is used, for dry and warm environments. For wetter and warm environments a synthetic summer sleeping bag is used, which is a little heavier. Both are combined when sleeping in a colder wet environment, down to zero degrees Celsius. If temperatures reach zero degrees Celsius in a dry environment a down winter sleeping bag is used, since it is lighter than the combination of the summer sleeping bags. Finally, if temperatures reach sub-zero, the winter bag is combined with one of the summer bags, again depending on humidity in the environment of choice (Scramble, n.d.). Important for them is durability, packing weight, and having enough space inside the sleeping bag to be able to lay inside it when inside a second sleeping bag.

The final type of use is family camping. For these users camping is no longer the means to achieve an end; hiking, or the festival, but rather the goal itself. The family spends their time at the camp site, usually multiple days, or weeks in a row. The car is parked next to, or near the site, and they sleep in a large and heavy tent, or caravan. Weight does not matter, since all transportation is done by car. There is plenty of space for storing the gear in transport with a roof box, and trailer, being often brought along to get all they want to bring, to the camp site. Comfort is the main decisive factor in choosing a sleeping bag. Features that improve comfort, and ease of use are seen as beneficial, and can add value for these users.

4.2.3 User opinions on sleeping bags

Although there already are a lot of options for sleeping bags, some unsolved irritations with sleeping bags might still be present among users. Therefore enquiries were made with regular sleeping bag users to find what their irritations with sleeping bags are, and what elements of their sleeping bags they like.

The most mentioned irritation with sleeping bags has to do with rotating when in it. The sleeping bag seems to rotate with its user only partially, thereby causing a restriction, usually around the users torso. The current solution on the market for this problem is the connection with the sleeping pad on the bottom of the sleeping bag. By having the pad in fixed to the bottom of the sleeping bag, the bag can no longer rotate with the user, thus preventing the user from getting constricted in a half rotated sleeping bag. The downside is that the hood of the sleeping bag will also be fixed in one orientation, so lying on one's side will be less comfortable, when the hood is drawn tight. The second issue, that attaching the sleeping bag and pad together solves, is sliding off of the pad during the night. Due to the smooth surfaces on both the sleeping pad and bag, and the usually not completely level ground, people tend to slowly slide off of the sleeping pad during the night. When the bag and pad are attached to one another they can no longer be separated during the night, allowing the user to sleep through the night, without waking up on the cold ground and having to climb back on the pad.

Another often mentioned problem is closing a double zipper, once it has been fully opened (figure 49), either accidentally, or on purpose. Double zippers are used to allow users to open the sleeping bag from the bottom as well, for instance for ventilation, or to stick their feet out. The Nordisk sleeping bag has solved this problem by sewing the bottom of the zipper shut, thus never allowing it to be fully opened (figure 50). However, attaching sleeping bags together is then no longer possible, to allow couples to turn their single sleeping bags into a double one (figure 51). By having a way to stop the user, from accidentally unzipping the zipper fully, the problem of getting the zippers on will be limited to purposefully fully unzipping the sleeping bag, for instance for attaching two bags together. Getting rid of the double zipper completely also solves this problem, and single zippers on two sleeping bags can still be attached to each other. Opening the zipper from the bottom is no longer possible, but a shorter second zipper might solve this problem. Another option is to include a fabric bridge, with press button to catch the top zipper as it is coming down. Opening the button allows the sleeping bags to be zipped together. Finally the zipper can be installed upside down so it cannot be fully opened on the bottom of the sleeping bag.

Another issue for some is that they are unable to spread their legs properly, even in a blanket model sleeping bag. The only current option to achieve this, in most sleeping bags, is by having one leg outside of the sleeping bag. However the models with extra material and elastic around the knee area might provide a little more room. If the elastic is weak enough this might also help the people who prefer to have something between their knees when lying on their side.

Finally, similarly to slipping of the sleeping pad, people tend to lose their pillows. Whether or not they are actual travel pillows, or just a stack of clothing, people have their headrest slip away from between the sleeping bag and pad, or sometimes even out of the hood of their mummies. When choosing to use a stack of clothing, additional problems might be that the headrest is uncomfortably hard against the head. Solutions to this problem do not seem to be implemented in current sleeping bags, though a simple extra pocket, in the back of the hood, will hold any pillow firmly in place inside the sleeping bag. Adding an extra layer of insulation, will also get rid of the hardness of a stack of clothing.

Getting rid of a worn sleeping bag is not always easy for people. Often they end up in a closet somewhere. Some find a second use as bed covers, or are used to block drafts by being tucked under a couch, or bed. When they are finally thrown away they end up with other textile recycling articles, or in regular trash bins, for incineration. Persuasion to hand in a sleeping bag is therefore required for a new design to become fully circular.

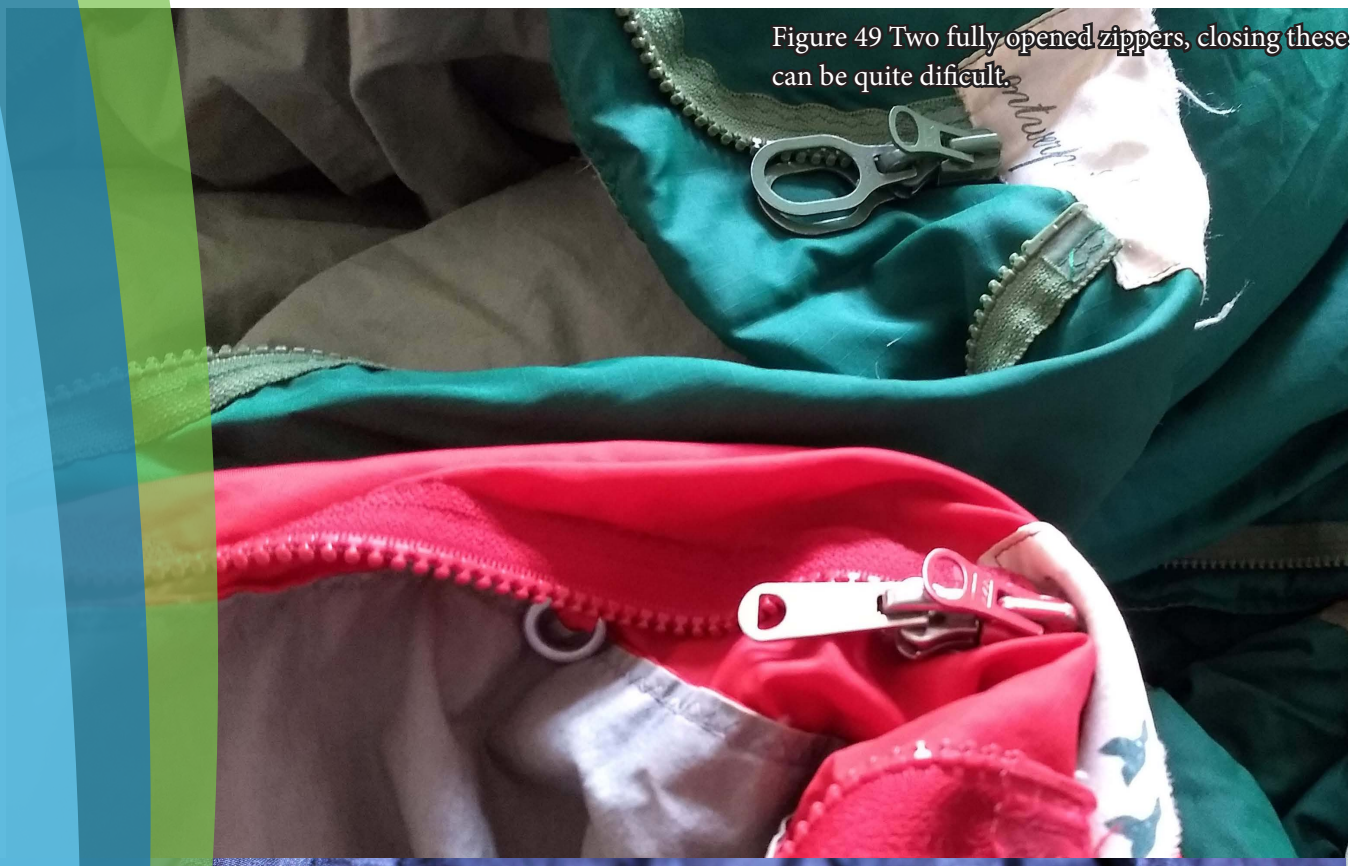


Figure 49 Two fully opened zippers, closing these can be quite dificult.

Figure 50 A lock at the end of a double zipper to prevent it from opening fully.

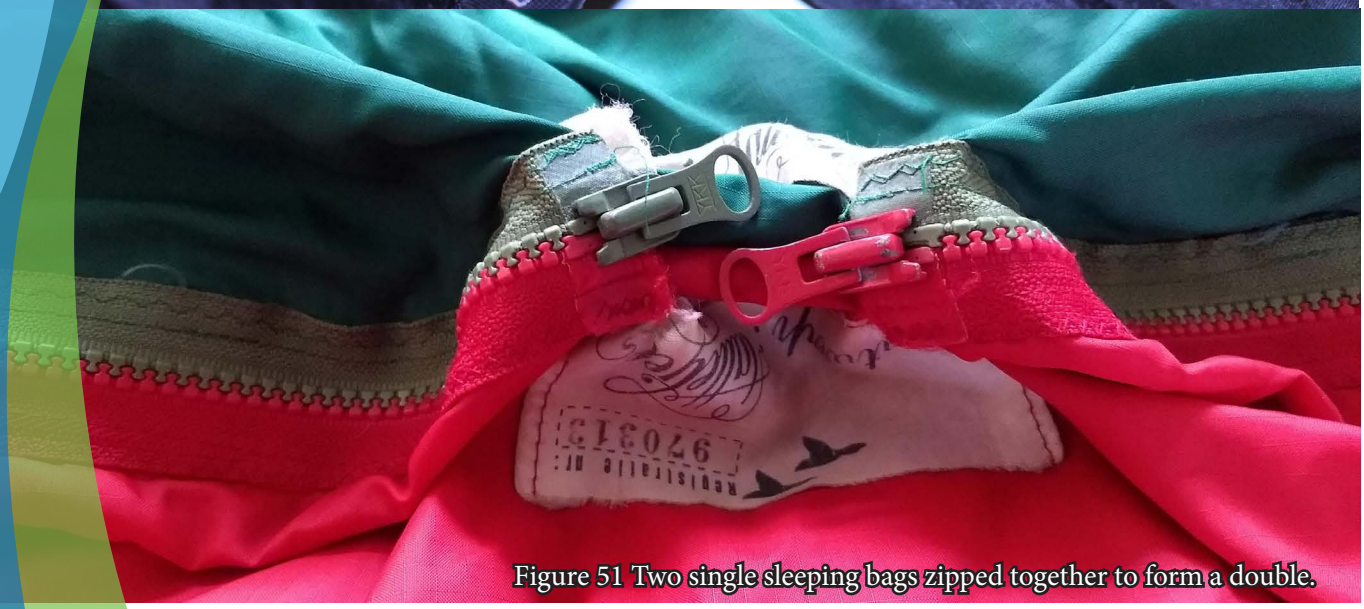


Figure 51 Two single sleeping bags zipped together to form a double.

Figure 52 PDY fibres next to the insulation from the Nordisk sleeping bag.

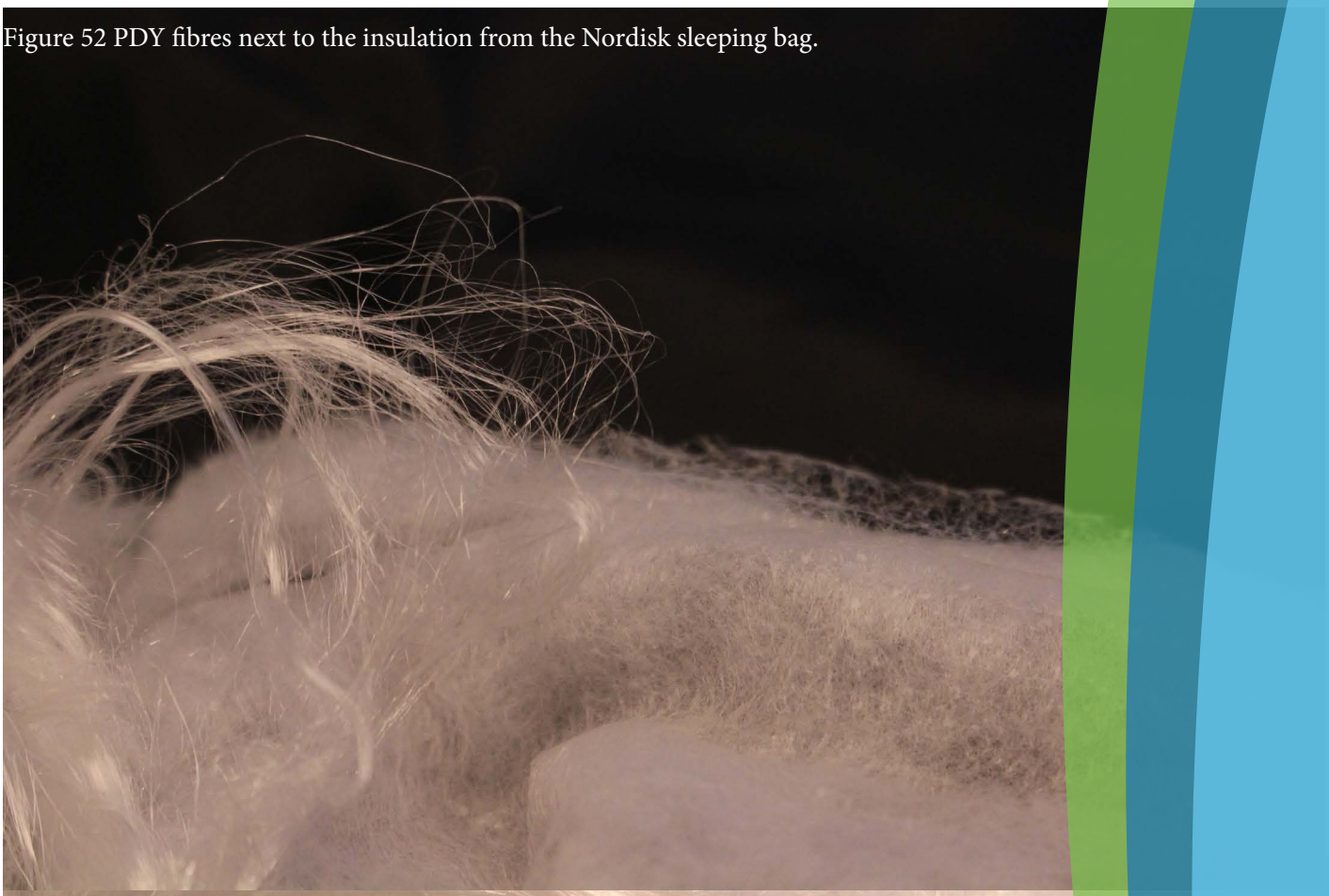


Figure 53 A PDY bird's nest on top of the Nordisk insulation.

4.2.4 Dyneema® in a sleeping bag

When using PDY Dyneema® in a sleeping bag as insulation, enough material needs to be used to ensure the sleeping bag meets the required industry standard EN 23537 for its designed limit and risk temperature ratings.

When directly compared to the insulation in the Nordisk Abel sleeping bag, the fibres in the PDY bird's nest seem thicker and much more aligned than the Nordisk insulation. The insulation in the Nordisk bag cannot be shifted, as if it has been coated to stick together in the shape it does (figure 52). The bird's nest is also a lot thicker and less evenly distributed, than the sleeping bag insulation (figure 53). In order to ensure enough insulation across the entire sleeping bag, without adding too much weight, the bird's nests need to be shredded, or cut down in size, to form a more evenly distributed thinner layer of insulation. This material can then be put in a sleeping bag design with baffles, or needs to be treated to stick together again in this evenly distributed manner, to be used in a similar of-the-roll manner of insulating, like the Nordisk sleeping bag.

Next to using PDY Dyneema® for insulation in the sleeping bag, the outer shell can be made from DFC material, used for tenting that has a lower grade than required, or even offcuts, or waste if large enough to create elements for the sleeping bag with.

The liner will probably not be made from DFC material, since this will likely cause too much perspiration from the user, or not allow enough of the perspiration through, based on the expertise of the application manager for performance fabrics for Dyneema's Flexible Composite department. A different material for the liner thus needs to be found.

The best material for a liner is dependent on the user demands for a sleeping bag. Most common lining materials are nylon, polyester and taffeta, which is a brushed fabric, traditionally made from silk, but nowadays also from polyester. Fleece is sometimes ussed and silk, flanel and cotton offer natural alternatives (Overstock, 2018). In line with the rest of the sleeping bag, a circular material would best suit the design. Within the outdoor equipment world recycled polyester is already being used. In most cases it is made from PET bottles and used for fleece (Textiles Environment Design, n.d.). Patagonia is one of the outdoor companies that is making use of recycled polyester (n.d.-b). They not only use plastic bottles, but also polyester waste of their own, or from products handed back in by users through their worn wear program (Patagonia, n.d.-a).

When a sleeping bag, ends up in recycling facilities it is important that the different materials can be easily separated. Since the sleeping bag is not going to be made entirely from Dyneema®, the polyester needs to be separated from the Dyneema®. This can be achieved based on the density of the materials. Dyneema® is lighter than water and polyester slightly heavier. Therefore the materials can be separated using sink-float methods.

A recycled polyester taffeta has been found on Alibaba (n.d.), that weighs the same as the liner in the Nordisk sleeping bag, which could be used in the sleeping bag to complete the circular concept.

4.2.5 Requirements for a summer sleeping bag

Keep the user warm:

- Block wind,
- Prevent large air pockets,
- Trap stationary air.
    - The filling should retain its thickness over time.
    - The filling should decompress relatively quickly after being compressed.

Prevent the user from getting too hot:

- Offer ventilation options,
- Remove excess heat.

Comply with standards:

- Resist tearing,
- Permeability of water vapour equal to or above 0,45 (dimensionless number),
- Inside length and width mentioned according to measurements performed per Standard EN 23537,
- Mentioning of comfort, limit and risk temperatures according to measurements incompliance with standard EN 23537.
- Safety:
- No solvent present in the sleeping bag, or other irritating chemicals

Circularity of the product

- Made with Dyneema® (fabrication) waste
- Persuade the user to hand the sleeping bag in after use
- In term be (partially) made from old handed in Dyneema® sleeping bags

Wishes for a sleeping bag

Prevent the user from getting stuck when rotating in the sleeping bag

Prevent accidentally fully opening of the zipper

Offer more room for legs to spread

Prevent the user from sliding of the sleeping pad

Keep the users pillow in place

Wishes for different groups:

Summer camping:

- Lightweight
- Compressible into a small volume

Durable

Festival:

- Ease of entry and exit
- Comfortable
- Cheap

Modular camping:

- Lightweight
- Compressible into a small volume
- Durable
- Inside space to fit a second sleeping bag

Family camping:

- Comfortable
- Luxury appearance
- Creature comfort feature additions

5 Implementation

After the concept direction is known, and all types of use and their wishes are determined, the next step is implementing the concept idea into a design proposal. Since multiple wishes need to be satisfied, to make the design proposal suitable for the multiple contexts of use, optimizing for one of them will likely leave others unsatisfied. Therefore a different approach is taken. One that is called satisficing. Satisficing is the process of tweaking parameters of the design to satisfy multiple wishes. The goal is to make the design well enough for all wishes, and then improve, rather than optimizing for one wish, and see what else can be achieved for the others.

5.1 Satisficing for different users

For a sleeping bag design proposal to combine the different types of use, a base shape must be chosen that fits all types of use. This means comfort for the family campers, and festival goers, whilst still being lightweight, and low volume, for the summer, and modular campers. Based on these wishes, the blanket model can be discarded for being too heavy, whilst the tight-fitting sarcophagus mummy is discarded for being not comfortable enough. This leaves the mummy and the little heavier, though comfortable egg-shaped mummy. Out of the two the better option seems to be egg-shaped mummy, since it offers a little more room for the modular campers to fit their second sleeping bag as well. This will be the base to which adaptations will be made to suit extra wishes for all parties.

Construction of the sleeping bag, with baffles, or insulation from the roll, is highly dependant of the way the insulation material can be prepared. If possible insulation from the roll is preferable, since it does not require extra fabric for the baffles and still helps insulate even the seems. The outside pattern for the baffles, or the baffle look when insulated from a roll, is less important for most users. A pattern that is more complicated looking, might attract the family camper a little more, but will likely also be more expensive.

The zipper of the sleeping bag is important for all users, since it determines ease of access, but also contributes to the weight of the sleeping bag. Furthermore, it is a possible source of annoyance, when it gets stuck, or is hard to get on properly, after accidentally fully opening it. the location of the zipper can also help offer additional features, such as the ability to put the feet outside of the sleeping bag, or attach two sleeping bags together to form one sleeping bag for two people. A regular double zipper down the side of the sleeping bag, is the standard for most sleeping bags. It is cheap in construction, since it is sewn in a straight line. It is easy to get in and out of the sleeping bag, and can be used to connect two sleeping bags with zippers on opposing sides. More complicated designs, such as S-shaped zippers, will increase zipper length, and thus weight, but also construction costs, since they are harder to sew. Shorter zippers will mean a lighter pack, but also a more complicated entry process and no ability to combine two sleeping bags. Therefore the standard side double zipper is chosen. It brings, however, the irritation of accidentally fully opening the zipper, when unzipping quickly. A solution to this problem is found, and will be used on this sleeping bag. The zipper will be installed upside down. This means it can only be fully opened on the top, rather than the bottom. Quickly opening the sleeping bag, from top to bottom, will therefore no longer result in an accidentally fully unzipped sleeping bag.

To allow zipping two sleeping bags together, there must be sleeping bags with the zipper on different sides. Otherwise one sleeping bag wil lay upside down to accomodate the zippers matching. Furthermore the zippers need to be mirrored, so that there will be a zipper for the top and one for the bottom, when combining two sleeping bags.

The hood on the sleeping bag is kept, to suit users on the colder nights, and to offer a more comfortable base for the head than the sleeping pad, when not cinched tight.

Figure 54 The RagBag that allows you to donate something old after you have bought something new. A label on the inside of the compression bag for the sleeping bag, will follow the same function to persuade people to send their sleeping bag back, free of charge, after they are done with it.

5.1.1 Multiple implementation variants?

At this point in the design, the sleeping bag could be considered done. It has all the elements a sleeping bag needs, and adding extra features will increase the weight of the bag from this point forward, as well as the price. Therefore a choice needs to be made whether or not to add extra features. Possibly sell this variant, and use it as an adaptible base to add different implementation variants, to cater to each of the different users more effectively. On the other hand this requires bringing more than one sleeping bag to market, and since the sleeping bags are very similar, this means they will most likely be each others biggerst competition. Therefore options will only be added through further comparing them against, and adapting them to the wishes of all the different usegroups.

The largest user irritation is not yet solved by this design. Rotating oneself stuck in a sleeping bag is an irritation for many and can be solved by attaching the sleeping bag to the pad. this is usually done through a large pocket on the bottom of the sleeping bag, that fits the pad. This solution not only solves the problem of constriction whilst rotating, but also prevents the user from sliding of the pad. However, a large pocket adds a lot of fabric, which not only adds weight, but in the case of DFC, can also get quite expensive. Therefore, it will be replaced by a couple of strips of fabric, that offer a similar function with less material.

The final addition to the sleeping bag will be a pocket on the inside. It has been used in many sleeping bags to offer a space for that little head torch, but has mixed reactions by users. This pocket will serve a different purpose however, and is therefore located in a different place: the hood. This pocket will provide a spot for clothes or a travelling pillow to prevent it from slipping away during the night. Since the bottom of the sleeping bag is attached to the pad, the orientation of the hood will remain the same over the course of the night. This makes for a great place to offer that final addition for creature comfort. The pocket will not have a zipper, since it may irritate the user of the sleeping bag. It will thus only consist out of a little extra liner fabric. The gain in weight is minimal, yet the added functionality will be appreciated very much.

5.2 Collection strategy for the sleeping bag

In a circular economy it is important that products get collected after use, to enter one of the loops towards reuse, whether directly, or after (re)processing. In chapter 2.3.2 several methods of collection have been elaborated. Now that the application is known, a collection strategy has to be chosen for this design.

Since this application does not easily allow, acces and performance models, options of motivating the user to hand their old sleeping bag back in are preferred. The waste stream of old sleeping bags is quite small, thus a separated regular waste stream is not possible. This only leaves options that require active action from the user. He has to be encouraged to hand the sleeping bag back in, either by making it easy for him, or by offering something in return, for instance a discount on the purchase of a replacement. Because sleeping bags usually last a long time, it is likely that the offer of a discount will be forgotten. It can be argued that it can better be offered as an option, when buying a new sleeping bag. This will be similar to trading in your old car, when buying a new one, and will lead to similarly mixed brands being handed in.

The best option therefore seems making it easier for them to hand the sleeping bag in, whilst also keeping them aware of this possibility. This will be done by adding resend packaging information on the inside of the compression bag. Allowing users to mail their sleeping bag in its compression bag to the manufacturer, free of charge. They can then repair the sleeping bag, or reuse its materials. By seeing the resend label when using the sleeping bag, the user is kept aware of the possibility of returning the sleeping bag after use. This return feature is inspired by the RagBag from Swedish brand ‘Uniforms for the dedicated (figure 54), that do the same with shopping bags. They allow people to donate something old when they buy something new to the charity they like (Pendrill, 2016). Based on the questionnaire among outdoor equimpent users (2.5.1), Convenience is key to get as many users as possible to hand in their old gear after use. By providing them with the shipping label, they only have to put the sleeping bag in the mail, which they can even do without leaving their home, by simply handing the bag with the resend label on the outside to the package deliverer, when they receive a package themselves (NOS, 2019).

5.3 Prototyping of the design proposal

A prototype of the proposed design has been made, to test the assumptions made regarding the functionality of the chosen materials. The outer shell and the insulation in the prototype, are made with the same material that is envisioned for the final design. The outer shell is Dyneema® Flexible Composite fabric, and the insulation is PDY Dyneema®, out of which the decalin has been removed. The liner is re-used from the Nordisk sleeping bag. The pattern for the sleeping bag is taken from the Nordisk sleeping bag as well, since this will help combining the liner, with the other elements. Chosen is to use simple baffles to create the prototype, since it is not directly possible to stitch the insulation to the outer fabric, as envisioned for the design.

The panels from the Nordisk sleeping bag were pinned to the shell fabric, which could then be cut. The front and rear panels consist of two pieces, to optimise fabric use, based on the width of the roll, as can be seen in figure 55. After the panels had been cut, the pieces were taped together to form the full front and rear panels. Next the lining was sewn to the front and foot piece, on three sides, leaving the side for the zipper open. The baffles were created by sewing the lining to the outer fabric in horizontal bars. Before the rear panel was sewn to the lining, the pillow pocket was attached to the lining in the hood. The opening of this pocket was placed on the side, with the pocket continuing past the opening to prevent the pillow from accidentally sliding out during the night. The top and bottom of the pillow pocket are attached to the fabric together with the baffling. The rear panel and lining were sewn together at the same time they were sewn to the front panel. The baffles were then sewn, in such a way that they matched the baffles of the front panel. The sleeping bag was filled with insulation based on the surface area of each baffle. This way an even distribution is assured. The insulation for each baffle was spread out to the size of the baffle before filling (figure 56), to prevent cold spots during use. The baffles were sewn closed by attaching the zipper. Finally, the straps to attach the sleeping bag to the sleeping pad were attached to the back of the sleeping bag.

Next to the full-sized sleeping bag, three small pockets have been made to compare the insulation of the PDY material to the insulation of the Nordisk sleeping bag. The pockets fit around a PET-bottle of half a litre, that is used for the comparison. Two of the pockets were made with the Dyneema® Flexible Composite fabric. One with baffles similar to the full-sized prototype. The other with the insulation attached to the outer shell with the special DFC tape. The final pocket was made from the combined outer shell and insulation of the Nordisk sleeping bag for the comparison.

5.4 Testing the prototype

Both the full-sized prototype and the small pockets have been tested. The sleeping bag by using it for one night, and the small pockets to compare the cooling pattern, when placed around a bottle of warm water.

5.4.1 The full-sized sleeping bag

The full-sized sleeping bag was tested by sleeping in it for a full night. It was placed on a sleeping pad, and the pillow pocket was filled with a sweater, similar to camping conditions. In order to test summer camping conditions in the winter, the test was performed inside, in a room that was estimated to be around 16° C.

During transportation in a compression bag, the insulation material started clinging together and thereby losing its even distribution, which can be seen in figure 57. This allowed for more areas with little to no insulation, that might become cause for cold spots.The first observation during the test was that the outer shell material makes a slight crackling sound, when moving inside the sleeping bag. It did not influence the sleep over the course of the following night, but it might influence users. The pillow pocket was spaced at the correct place in the sleeping bag, and kept the rolled-up sweater in place well. The pillow remained where it was expected, which is usually not the case when camping in the experience of this user. The sleeping bag was on the large side, due to its measurements being taken from an extra-large example. Nevertheless falling asleep was no problem. Halfway during the night, after a toilet break, the sleeping bag had gone quite cold. The decision was made to continue the night in the sleeping bag, but under a knitted wool quilt. The rest of the night was passed sleeping comfortably. In the morning, the likely cause of the cold became clear. The insulation had clung together even more, and formed little spheres in each baffle, as shown in figure 57. This has likely, slowly happened over the course of the night due to the motion, or rotation of the user inside the sleeping bag. By no longer covering the person inside properly, the material did nothing in terms of insulation. Although the envisioned design has a different method of distributing the insulation, it is important to make sure the insulation remains distributed evenly.

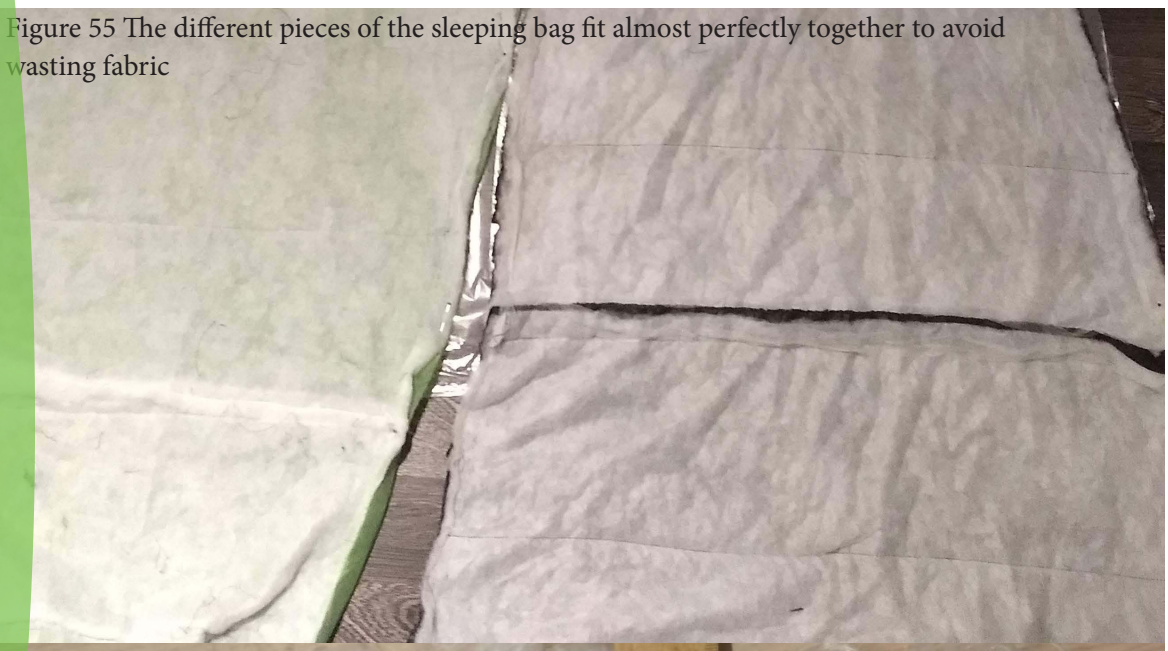


Figure 55 The different pieces of the sleeping bag fit almost perfectly together to avoid wasting fabric

Figure 56 The insulation of the sleeping bag is spread before pu into the baffles

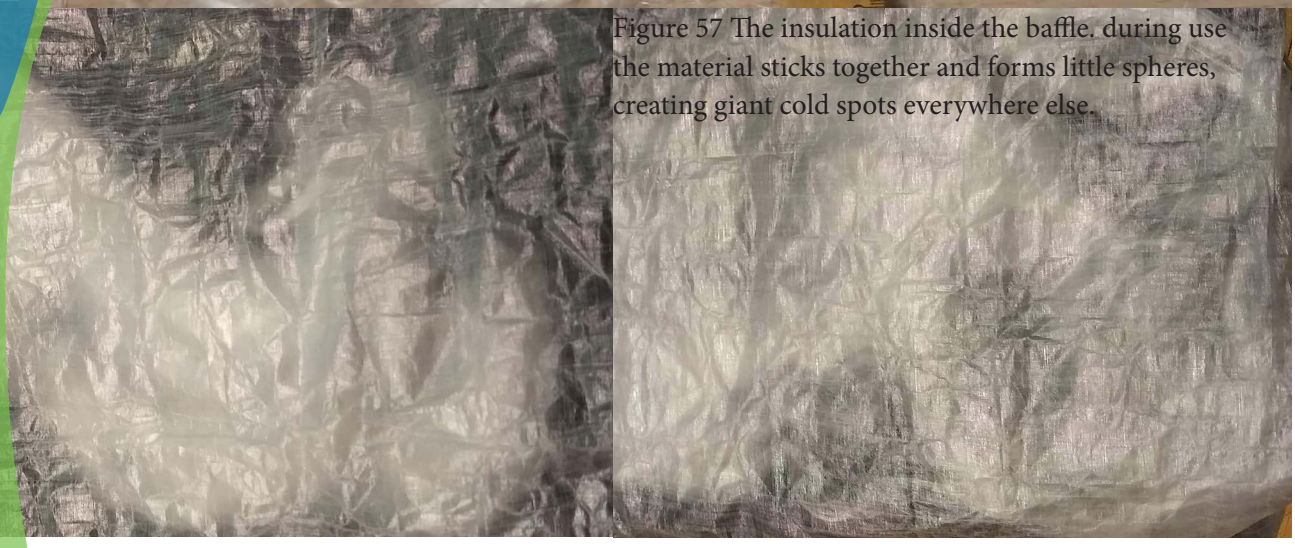


Figure 57 The insulation inside the baffle. during use the material sticks together and forms little spheres, creating giant cold spots everywhere else.

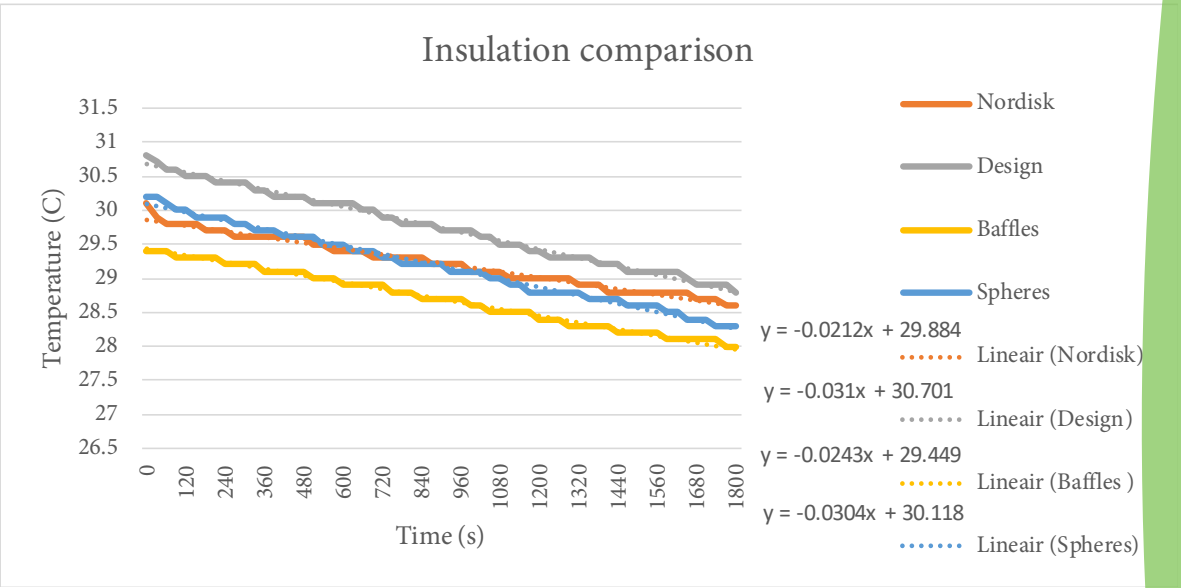


Figure 58 The results of the comparison test between the different shapes of insulation and their tangents.

Thermal resistance posture 1 $R_c(1)$ $m^2 \cdot K/W$	**Extreme temperature** T_{ext} °C	**Limit temperature** T_{lim} °C	**Comfort temperature** T_{comf} °C
0,500	+5,0	+14,2	+17,2
0,540	+2,8	+12,7	+15,9
0,580	+0,6	+11,2	+14,6
0,620	–1,5	+9,7	+13,3
0,660	–3,7	+8,1	+12,0
0,700	–5,8	+6,6	+10,7
0,740	–7,9	+5,1	+9,4

Figure 59 Part of the thermal resistance table of standard ISO 23537 for comfort, limit, and extreme temperature ratings of sleeping bags

5.4.2 Comparing the insulation

The insulation of the sleeping bag was also compared directly to that of the Nordisk sleeping bag. The small pocket sewn from the Nordisk outer shell and insulation, and the two pockets sewn from the DFC with PDY insulation were compared by measuring the drop of temperature in a warm water bottle. The temperature of the water inside the bottle was noted every 30 seconds for half an hour, for each of the pockets. The pocket with the baffles was tested twice, once with the insulation material properly spread, and once with the material compressed into balls, to simulate the situation during the second half of the sleep test. The raw data for this comparison can be found in appendix IV.

In order to compare results evenly, the difference in temperature between tests needs to be minimal. The temperature of the environment was around 22°C for all four tests. At the start of the tests the aim was to get the water temperature inside of the bottle close to 30°C. This temperature differed between 29,4°C for the baffles to 30,7°C for the envisioned design. The tests were performed without lining material, but in order to create the baffles, the final pocket has two layers of outer shell material. The results can be seen in figure 58.

Conclusion

Following from the graph a comparison can be made between the different pockets. Adding a linear trendline for each of the tests, yields a comparable function value (also figure 58). These could then be compared to each other. By reverse engineering the thermal resistance of the Nordisk sleeping bag, through standard ISO 23537 (figure 59), the comfort, limit and extreme temperature for the envisioned design can be determined.

The function values between the baffle pocket and the pocket following the envisioned design, differ quite a lot. The baffles seems to do better than the envisioned design, even though it will likely have more cold spots. This could be due to two reasons. The first being that it has a second layer of fabric, thus is a little thicker. The second reason is that these tests show a small part of an inverse exponential relation between temperature and time. The test only reveals the tangent of the full graph at the selected temperature. The difference of this one and a half degree might be enough to be a large influence.

From the thermal resistance table the Nordisk sleeping bag, likely has a thermal resistance of 0,620 m^2K/W. Comparing its function value to the other pockets leads to values of 0,424 m^2K/W for the envisioned design and 0,541 m^2K/W for the baffle pocket. These would result in Comfort temperatures of +19,8°C for the envisioned design and +15,9°C for the baffles. However, since this test only shows a small section of the entire graph, with a high risk of errors, it is recommended to test a full scale prototype of the envisioned design according to the thermal resistance test as defined in the ISO 23537 standard.

5.5 Value proposition

An important factor for the success of any new product is the value it brings to the market. The product should offer a benefit over its competitors. In the case of the proposed sleeping bag, there are several elements that offer such a benefit. These unique selling points in the design of the sleeping bag are; a pocket for a pillow, to keep it from sliding away during the night, and the inverted zipper that opens at the top, to prevent accidental opening. Other features that add value to the design are not unique to this sleeping bag, but offer a benefit over competitors without them nonetheless. The straps on the back to attach the sleeping bag to the sleeping pad, and the roomy egg shape can for instance also be found on other sleeping bags. The chosen materials also offer a benefit to users. The Dyneema® insulation allows people to sleep comfortably, without getting too hot, or too cold. The Composite fabric on the outside is waterproof, breathable, and extremely lightweight. The circularity of the design, offers a way for users to express their care for the environment through the equipment they use, without having to compromise on the quality of this equipment. This can also be a benefit for users to choose this sleeping bag over a competitor.

5.5.1 Competitor pricing

All these benefits, help the desirability of the sleeping bag, but if it is priced too high for the market, potential buyers will still opt for a different model. Therefore a price analysis of the market has been performed, The raw data for this comparison can be found in appendix III. based on the summer sleeping bags for sale at Bever sport. Figure 60 shows the comparison for these sleeping bags based on weight and price. It is clear from this graph, that prices are higher for lighter weight sleeping bags. Also important to note is that the orange marked sleeping bags have a FairWear certificate, stating that all people working on their production have had fair working conditions and fair pay (Fair Wear Foundation, 2017). Noting from the graph this can result in higher sales prices, than similarly weighted competitors. However there seem to be other reasons for diverting from the trend. Offering extra-large models might be a reason to ask more, whilst not being able to insulate users at the same temperatures as competitors appears to be a reason to offer the sleeping bag for less. Therefore the sleeping bags have also been compared on their comfort temperature and their price, as is shown in figure 61. This graph does not show a clear correlation between the two. Both the cheapest, and the most expensive sleeping bag, even have the same comfort temperature rating. A third and final comparison between weight and comfort temperature, has also been performed. It can be seen in figure 62. It stands to reason, more insulation means more weight, but also a lower comfort temperature. This is partly depicted by the trendline in the graph. However there are other factors that also heavily influence the weight of a sleeping bag. The shape also determines the amount of material, and thereby the weight. A blanket model weighs more than a mummy for instance, and a sleeping bag for a larger user also needs more material than a small one. The chosen materials also influence the weight; down sleeping bags are lighter than synthetic ones, and the shell and lining fabrics have different weight as well.

Based on the comparison of the competition, weight seems the most important factor for determining the price of a sleeping bag.

5.5.2 Sales price of the design

Based on the comparison of the competition, a sales price for the Dyneema® sleeping bag can be determined. By comparing the weight of the envisioned design with the discovered trend and the additional benefits the design offers, a sales price can be determined. In order to determine the weight of the final sleeping bag, the materials that will be used in the final design need to be compared to those in the prototype. The only material that is really different between the two is the lining fabric. By measuring the weight of a small leftover piece of the lining used in the prototype, its weight has been determined to be 70g/m^2. The recycled polyester taffeta, that will be used in the final design can be found as light as 70g/m^2 as well. Therefore the weight of the prototype can be used to determine the sales price of the final design. The prototype weighs just over 680 grams, without stuff sack. For the combined weight an estimation of 700 grams is used, At this point in the graph small weight differences do not seem to make a large difference for the sales price, therefore this estimation can be made.

Looking at the graph comparing weight and price, the trendline suggests a sales price of €100. Competitors in this specific weight range all seem to be cheaper however. They cost between €65 and €89 per sleeping bag. The extra price for this sleeping bag compared to these similarly weighing competitors, needs to prove worth the value for potential customers. Compared to these competitors, the proposed design offers more features. Both the pillow pocket and the sleeping pad holder are extras over the competition, that justify the higher price.

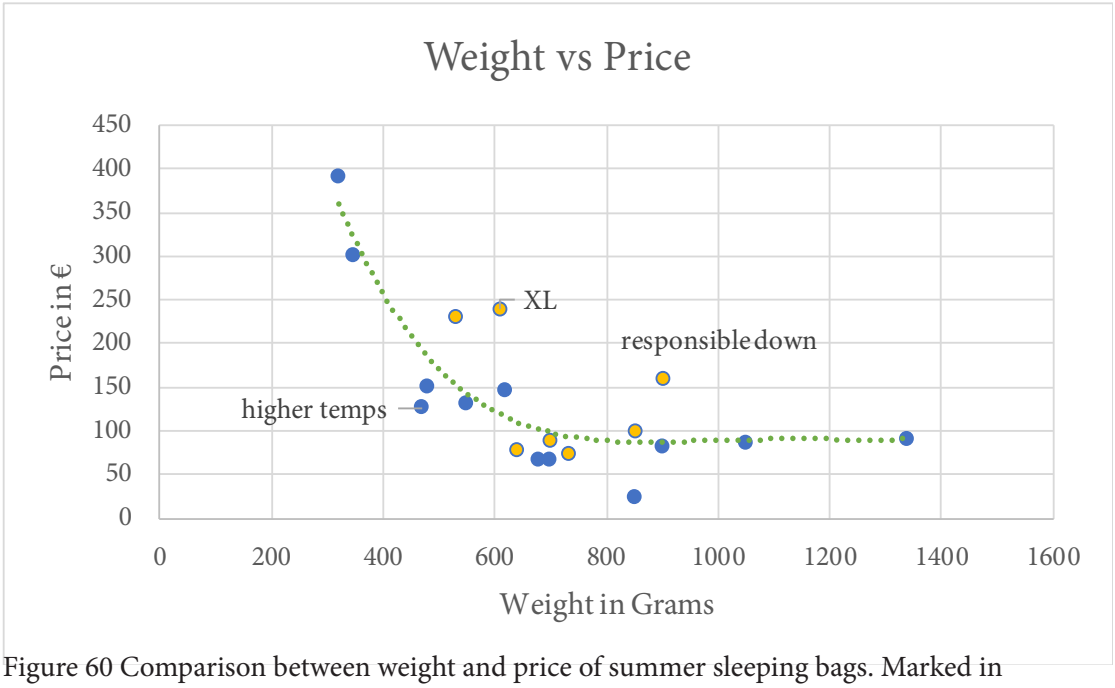


Figure 60 Comparison between weight and price of summer sleeping bags. Marked in orange are the sleeping bags that are made in accordance with the fear wear foundation

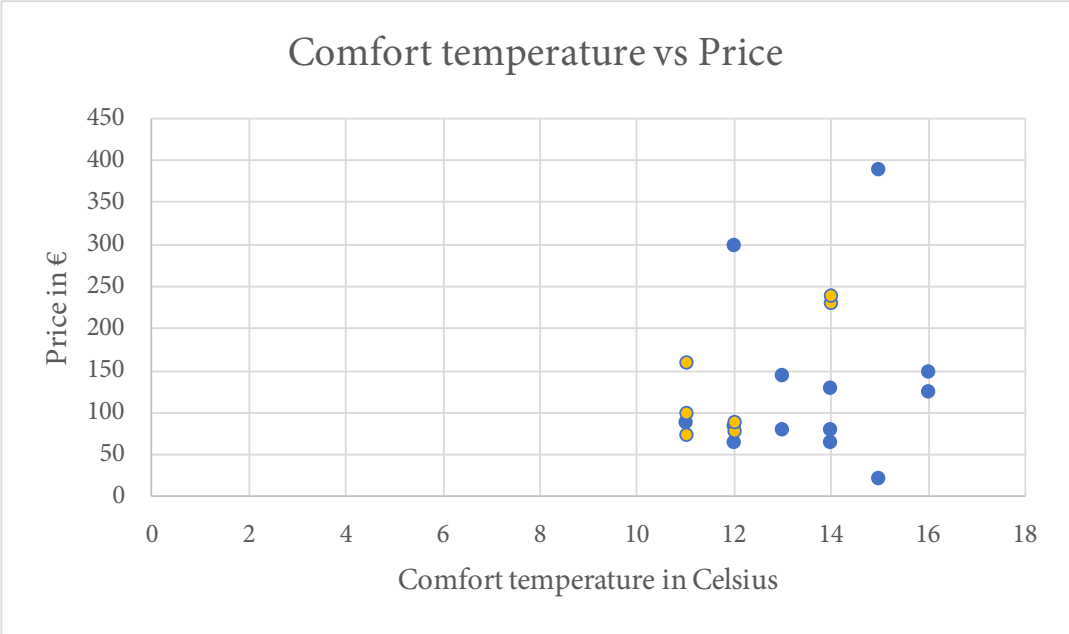


Figure 61 Comparison between comfort temperature and price of summer sleeping bags. In orange the fear wear foundation sleeping bags.

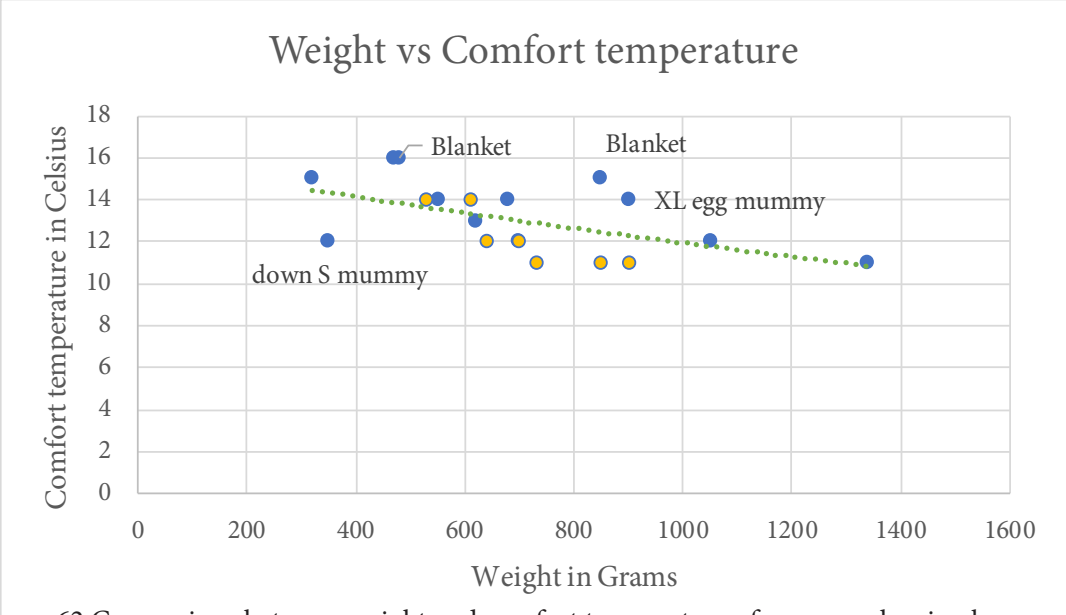


Figure 62 Comparison between weight and comfort temperature of summer sleeping bags. In orange the fear wear foundation sleeping bags.

Figure 63 the estimated production and material costs for making the designed sleeping bag.

5.5.3 Cost price of the design

6 Recommendations

At this stage in the design process, not everything is certain yet. A lot of decisions still need to be made that are of influence on whether or not the product will be produced. Recommendations provided in this chapter give an insight into steps to be taken, whilst also reflect on the process so far to offer improvements for use of these techniques in future projects.

6.1 Design evaluation

The outline for a new sleeping bag design has been set in this report. There is a lot to be done still, however. Most tests performed in project have been relatively small, to discover whether or not it is possible to achieve the desired end. For instance removing the solvent from the PDY material. Industrialisation of this process is not yet considered, but very important for the possible implementation of PDY in a sleeping bag. Other tests were done to provide an indicative value for the final design, such as the temperature rating. Inconsistencies might have affected such a test, and other design elements might also influence the temperature rating. Therefore it is recommended to do a full thermal resistance test on the design, according to the ISO 23537 standard. The sleeping bag should also be tested for the other elements defined in this standard, such as water vapour permeability.

Industrialisation of all processes, required to create this sleeping bag design, still has to be examined. Most important is the spreading of the insulation and assuring it remains well distributed during use. The feasibility of a sleeping bag, that makes use of this PDY material is dependent of the possibility of realising and industrialising this insulation distribution.

The design currently consist out of a list of design elements, that are brought together in a prototype based on the shape of a competitor. This base shape needs to be created, specific for this design. Opportunities to further improve on reducing offcuts arise, and should be taken to reduce use of the expensive DFC outer shell material.

Viability of the design currently hinges on the costs of the B-graded DFC fabric. If it turns out using this material results in an unviable product, alternative shell materials need to found. The possibility of using recycled polyester is a sound option, but it degrades the branding value for Dyneema®.

Next to these insecurities, there are also elements that can already be of value, or even increase the estimated sales price. The pocket for the pillow inside the hood of the sleeping bag, is an innovation in the sleeping bag industry that solves a well-known issue for campers. Being the only sleeping bag that offers a solution for the problem of losing a pillow during the night, might boost sales and can possibly allow the selling price for the sleeping bag to be raised above the currently estimated €100. Research among the target audience can likely quantify this.

6.2 Circular Economy

The design is doing quite well, from a circular perspective. It makes use of materials that are currently incinerated or that have been recycled. In order to be fully circular, however just using recycled materials is not enough. After use the product needs to be re-introduced into the cycle, preferably in as small a circle as possible. Offering a hand-in opportunity for users, by allowing them to send their sleeping bag back to the manufacturer after they are done with it, provides an opportunity for collection. However this way it is still possible for people to end up hanging on to the sleeping bag, whilst they are done using it. Better, would be to give the user an even stronger incentive to hand their sleeping bag in after use, either by having a (financial) reward, or otherwise financial stake for the user. Access models require a complete overhaul of the industry, and are therefore, currently, not yet desirable. A case study into this direction can be performed to find out about the requirements, both corporate and social for an access model for sleeping bags to become a viable option.

Collection of the sleeping bags is in itself not yet circular either. The products need to be re-introduced to use, preferably in as small a circle as possible. Existing systems such as the “Patagonia Worn Wear” initiative are a great way of achieving this. Users hand their old Patagonia gear in for worn wear credit, with which they can buy “new” second hand gear through the worn wear web shop. The gear they handed in is examined for resale through the worn wear web shop, or dismantled and its materials recycled for use in new gear (Patagonia, n.d.-a). Joining this initiative for this sleeping bag design, assures it is used until fully worn out, and after that recycled. The polyester lining can be recycled into new polyester material, and the Dyneema® material can for instance be used for heat pressing solutions as researched by F. Rutten (2019) for his graduation project.

The chosen design direction requires the PDY material to be shredded, which was determined to be a very undesirable direction, due to the wear on shredding equipment and degradation of the material. During this project this turned out to be the only way of using the bird's nest material for the ideas found. The decision was then made to use the material, even though it was an undesirable way of using the material, rather than going for different material and keep incinerating the bird's nests. In the end, making use of the material is an improvement over incineration, though it might not be the most desirable process to use this material.

6.3 CVD

The context variation by design approach taken in this project ensured a wide vision at all times during the project. It acted as a constant reminder, that there are always more possibilities when taking a step back. To a certain extend this helped overcome dead ends, such as the mosquito net. Using this broad vision on all the contexts also allowed for the wide spectrum of created ideas. It set a broad base from which to build into multiple directions. Even when the design direction was narrowed down to designing a summer sleeping bag, having worked to get a broad vision before defining this direction, contributed to keeping the vision for this design broad. Thereby steering to define multiple contexts of use, that were included in deciding, which elements to include in the design and which to leave out. Estimated is that this would not have been the case when a different design approach was taken.

In this specific project, choosing to start with market contexts as large as they were, seems in hindsight not useful. Within the contexts of marine shipping and outdoor equipment, a lot of differentiation is already present, resulting in a narrow view of a large market, with the risk of making too many assumptions. One of these contexts would have been enough to find useful connections, which in this project might have turned out too broad and therefore less insightful. In the end insights gained from the marine context, although showing the re-use of lines is very prevalent, were not used in developing the ideas.

Combining insights for the circular economy with the insights for the context of application proved very useful in painting a picture of problem areas and opportunities, which might otherwise have been harder to find. They ensured an eye was kept on the circular requirements, without always stating them as restrictions.

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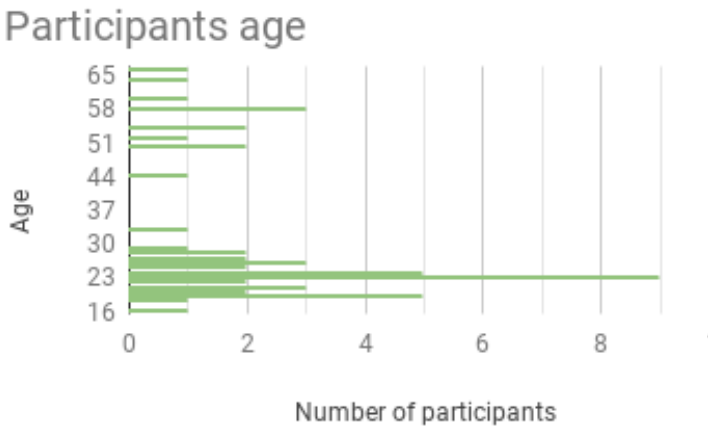
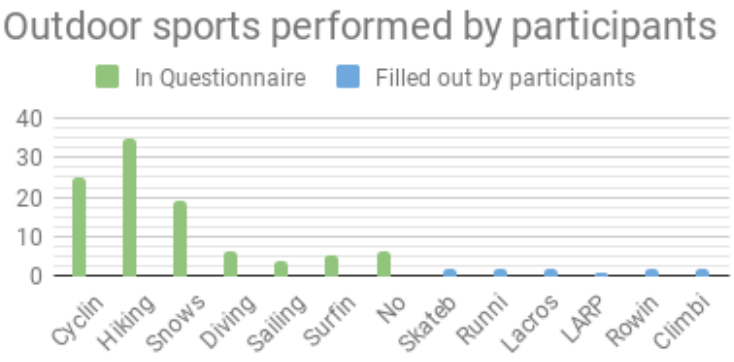
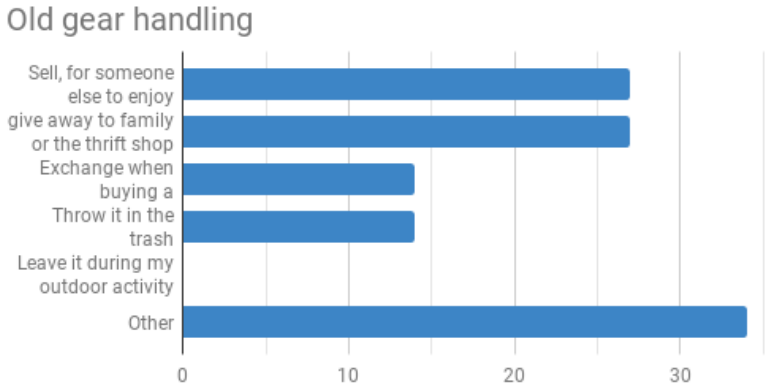
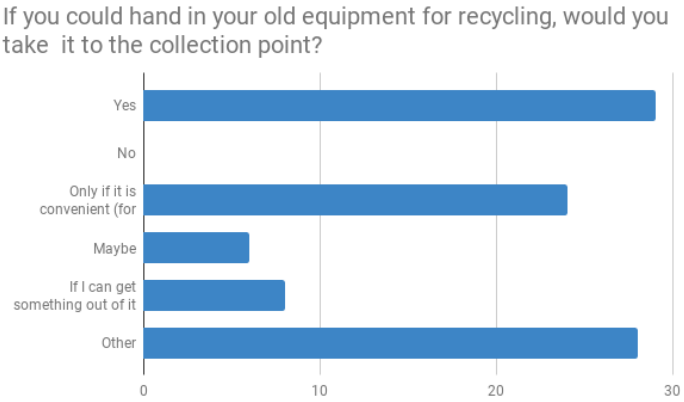
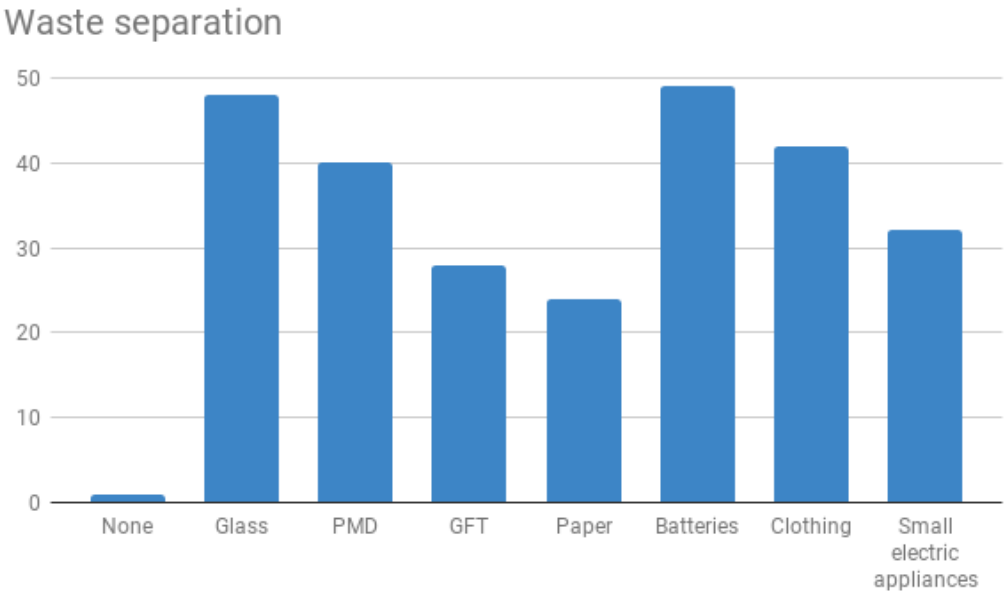
Appendix I Outdoor sports questionnaire results and responses





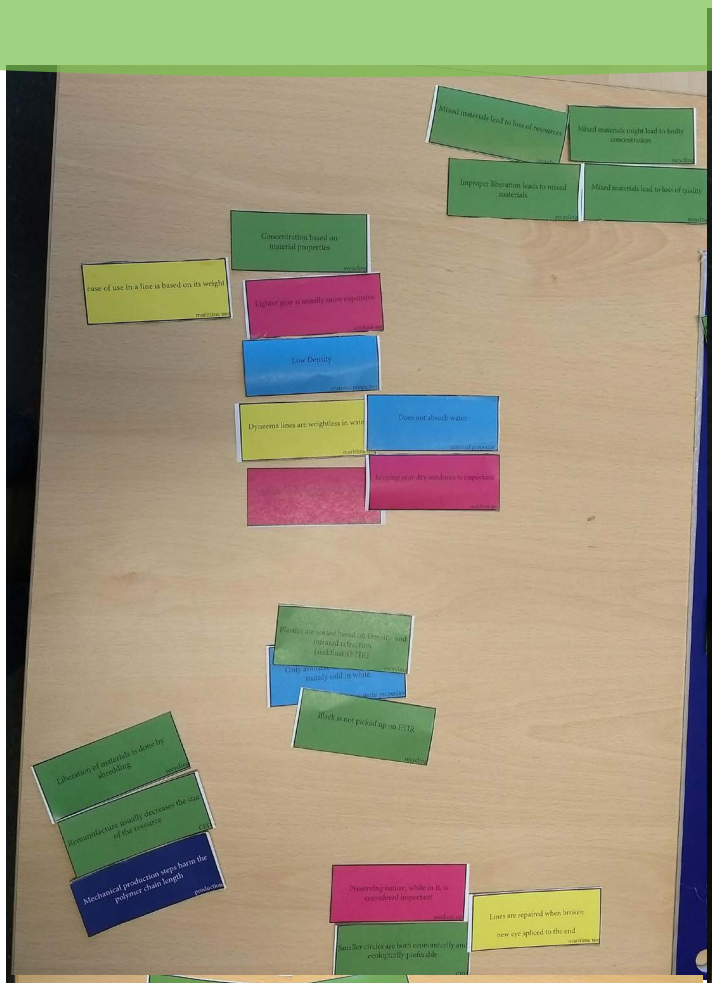


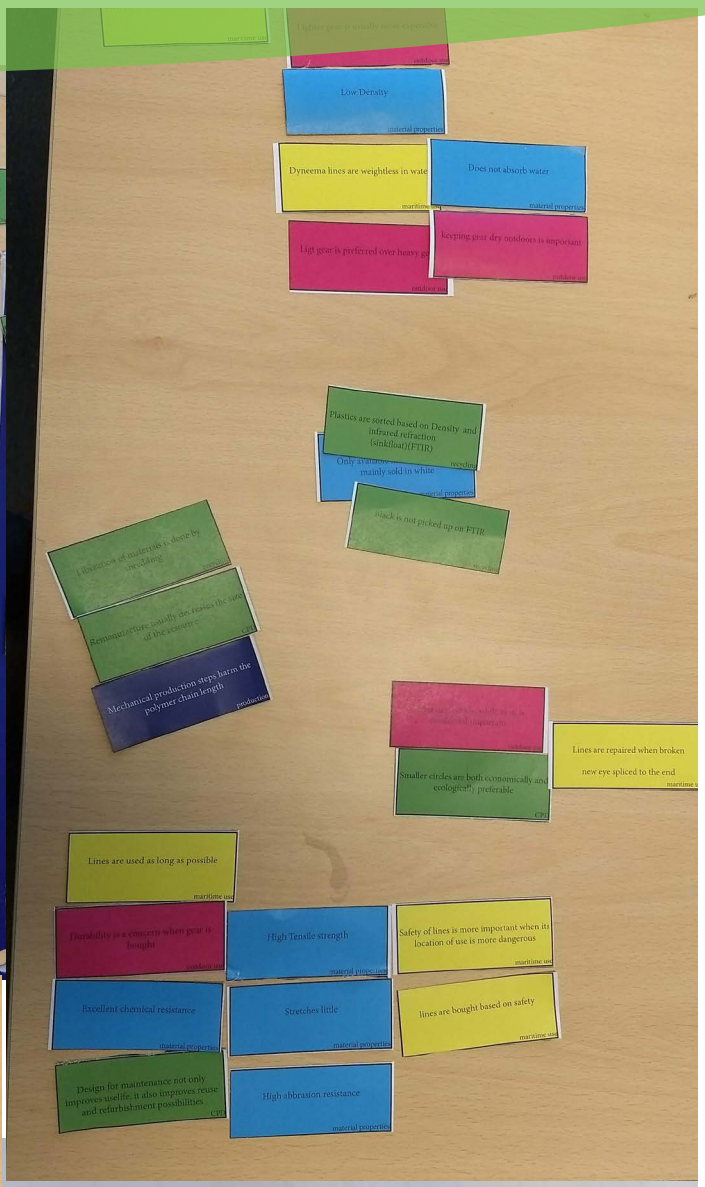


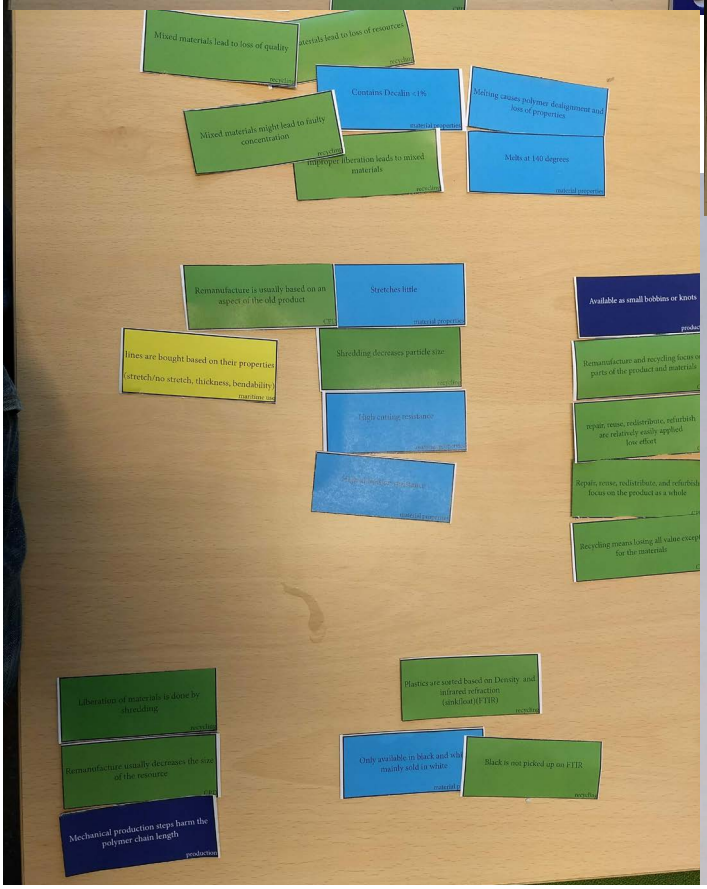


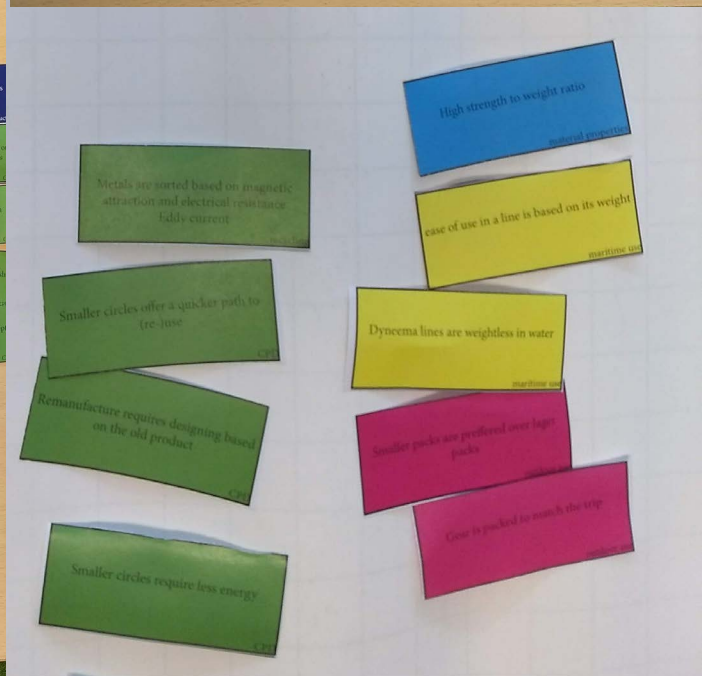
Timestamp	What is your gender?	What is your age?	What outdoor sports do yo	Do you have your own ge	If your gear needs to be r	If you could hand in your	Do you care about the en	Which waste do you separate?
10/29/2018 17:39:44	Male	16	Cycling, Snowsports (skiir	Some	Exchange when buying a	Yes	Yes	Glass, Plastic Metal and Drinkcartons, Clothing (bin or collecting bags), Batteries, Small electric appliances, Greens and compost (GFT), Paper
10/31/2018 13:51:03	Male	18	I do not do outdoor sports	Yes	Sell, for someone else to	Yes	Yes	Glass, Plastic Metal and Drinkcartons, Clothing (bin or collecting bags), Batteries, Greens and compost (GFT)
10/31/2018 13:34:21	Female	19	Hiking and walking, Cyclir	I rent/ loan gear	Sell, for someone else to	Yes	Yes	Glass, Plastic Metal and Drinkcartons, Clothing (bin or collecting bags), Batteries, Small electric appliances, Greens and compost (GFT)
10/31/2018 13:37:54	Female	19	I do not do outdoor sports	No	give away to family or the	Maybe	Yes	Plastic Metal and Drinkcartons
10/31/2018 13:39:37	Female	19	Hiking and walking, Cyclir	Some	Sell, for someone else to	If I can get something out	Yes	Glass, Clothing (bin or collecting bags), Batteries, Greens and compost (GFT)
10/31/2018 13:42:05	Male	19	longboarden	Yes	Sell, for someone else to	Yes	Yes	Glass, Plastic Metal and Drinkcartons, Clothing (bin or collecting bags), Batteries, Small electric appliances
10/31/2018 13:49:26	Male	19	I do not do outdoor sports	Yes	Sell, for someone else to	Yes	Yes	Plastic Metal and Drinkcartons, Paper
10/31/2018 13:36:31	Female	20	rowing	No	give away to family or the	Yes	Yes	Glass, Clothing (bin or collecting bags), Batteries, Greens and compost (GFT), plastic
10/31/2018 21:59:00	Female	20	Hiking and walking, Cyclir	No	give away to family or the	Only if it is convenient (for	Yes	Glass, Plastic Metal and Drinkcartons, Clothing (bin or collecting bags), Batteries, Small electric appliances, Greens and compost (GFT), Paper
10/29/2018 17:35:33	Female	21	Hiking and walking, Snow	Yes	Sell, for someone else to	Only if it is convenient (for	Yes	Glass, Plastic Metal and Drinkcartons, Clothing (bin or collecting bags), Batteries, Small electric appliances, Greens and compost (GFT)
10/31/2018 13:04:07	Female	21	Hiking and walking, Cyclir	Yes	Sell, for someone else to	If I can get something out	Yes	Glass, Plastic Metal and Drinkcartons, Batteries, Small electric appliances
10/31/2018 13:32:43	Male	21	Snowsports (skiing and sr	Yes	Sell, for someone else to	Only if it is convenient (for	Yes	Plastic Metal and Drinkcartons, Clothing (bin or collecting bags), Batteries, Greens and compost (GFT), Paper
10/29/2018 17:32:21	Male	22	Snowsports (skiing and sr	Some	Sell, for someone else to	Yes, If I can get somethin	Yes	Glass, Plastic Metal and Drinkcartons, Clothing (bin or collecting bags), Batteries
10/31/2018 13:16:22	Female	22	I do not do outdoor sports	No	Sell, for someone else to	Only if it is convenient (for	Yes	Glass, Plastic Metal and Drinkcartons, Clothing (bin or collecting bags), Batteries
10/29/2018 16:59:53	Male	23	I do not do outdoor sports					
10/29/2018 17:33:45	Female	23	Hiking and walking, Cyclir	Yes	Exchange when buying a	Only if it is convenient (for	Yes	Glass, Plastic Metal and Drinkcartons, Clothing (bin or collecting bags), Batteries
10/29/2018 19:53:37	Female	23	Hiking and walking, Snow	Yes	Sell, for someone else to	Only if it is convenient (for	Yes	Glass, Plastic Metal and Drinkcartons, Clothing (bin or collecting bags), Batteries, Small electric appliances
10/31/2018 12:58:31	Male	23	Cycling	Some	Sell, for someone else to	Only if it is convenient (for	Yes	Glass, Batteries, Small electric appliances
10/31/2018 13:45:34	Male	23	Cycling, Snowsports (skiir	Some	Sell, for someone else to	Yes	Yes	Glass, Clothing (bin or collecting bags), Batteries, Greens and compost (GFT), I don't have the ability to separate waste in the netherlands, but in my country i used to separate th
10/31/2018 13:47:37	Male	23	Hiking and walking, Cyclir	Some	Sell, for someone else to	Yes	Yes	Glass, Clothing (bin or collecting bags), Batteries, Small electric appliances, paper
10/31/2018 13:53:32	Female	23	Hiking and walking, Cyclir	Yes	Sell, for someone else to	Yes	Yes	Glass, Clothing (bin or collecting bags), Batteries, Small electric appliances, papier
10/31/2018 13:55:34	Female	23	Hiking and walking, Cyclir	Some	Sell, for someone else to	Yes	Yes	Glass, Batteries, papier
11/2/2018 15:57:59	Female	23	Hiking and walking, Snow	Yes	Exchange when buying a	Only if it is convenient (for	Yes	Glass, Plastic Metal and Drinkcartons, Greens and compost (GFT), Paper
10/29/2018 17:08:23	Female	24	Hiking and walking, Cyclir	Yes	never had to replace old g	Only if it is convenient (for	Yes	Glass, Clothing (bin or collecting bags), Batteries, Small electric appliances
10/29/2018 17:10:14	Female	24	Hiking and walking	Yes	give away to family or the	Yes	Yes	Glass, Plastic Metal and Drinkcartons, Clothing (bin or collecting bags), Batteries, Small electric appliances, Greens and compost (GFT)
10/29/2018 18:02:41	Male	24	Hiking and walking, Cyclir	Yes	I keep it and borrow it to p	Only if it is convenient (for	Yes	Glass, Plastic Metal and Drinkcartons, Batteries
10/29/2018 18:42:17	Male	24	I do not do outdoor sports	Yes	Throw it in the trash, I hav	Only if it is convenient (for	Yes	Glass, Plastic Metal and Drinkcartons, Clothing (bin or collecting bags), Batteries, Small electric appliances, GFT only sometimes.
10/31/2018 13:19:54	Female	24	Hiking and walking, Cyclir	Yes	Sell, for someone else to	Yes, Only if it is convenier	Yes	Glass, Plastic Metal and Drinkcartons, Clothing (bin or collecting bags), Batteries, Small electric appliances, Greens and compost (GFT)
10/31/2018 11:25:47	Male	25	Hiking and walking, LARP	Yes	Sell, for someone else to	Yes	Yes	Glass, Plastic Metal and Drinkcartons, Clothing (bin or collecting bags), Batteries, Small electric appliances, Greens and compost (GFT)
10/31/2018 13:01:17	Female	25	Hiking and walking, Sailin	No	Sell, for someone else to	Yes	Yes	Glass, Plastic Metal and Drinkcartons, Clothing (bin or collecting bags), Batteries, Small electric appliances, Greens and compost (GFT), Paper
11/1/2018 9:43:26	Male	25	Hiking and walking, Snow	Some	Sell, for someone else to	Yes	Yes	Glass, Clothing (bin or collecting bags), Batteries, Greens and compost (GFT), Paper
10/29/2018 18:40:59	Male	26	Snowsports (skiing and sr	Yes	Sell, for someone else to	Yes, is there a reward inv	Yes	Glass, Plastic Metal and Drinkcartons, Clothing (bin or collecting bags), Batteries
10/31/2018 14:03:22	Female	26	Hiking and walking, Cyclir	Yes	give away to family or the	Only if it is convenient (for	Yes	Glass, Plastic Metal and Drinkcartons, Clothing (bin or collecting bags), Batteries, Small electric appliances, Greens and compost (GFT)
11/6/2018 13:16:46	Male	26	Hiking and walking	Yes	Sell, for someone else to	Yes, Only if it is convenier	Yes	Glass, Plastic Metal and Drinkcartons, Clothing (bin or collecting bags), Batteries, Paper
10/31/2018 13:59:06	Male	27	Lacrosse, Track & field	Yes	Sell, for someone else to	Only if it is convenient (for	Yes	Batteries, Small electric appliances
10/31/2018 14:04:55	Male	27	Hiking and walking, Cyclir	Yes	Sell, for someone else to	Maybe	Yes	Glass, Plastic Metal and Drinkcartons, Clothing (bin or collecting bags), Batteries
10/31/2018 13:57:40	Male	28	Sailing	Yes	Exchange when buying a	Only if it is convenient (for	Yes	Glass, Batteries
10/31/2018 14:01:13	Male	28	Hiking and walking, Lacro	Yes	Sell, for someone else to	Only if it is convenient (for	Yes	Glass, Plastic Metal and Drinkcartons, Batteries, Small electric appliances
10/30/2018 10:29:38	Prefer not to say	29	Hiking and walking, Cyclir	Some	give away to family or the	Only if it is convenient (for	Yes	Glass, Clothing (bin or collecting bags), Batteries, Small electric appliances
11/2/2018 14:32:44	Male	33	Cycling, Sailing, Surfing	Some	Sell, for someone else to	Only if it is convenient (for	Yes	Glass, Clothing (bin or collecting bags), Batteries, Paper
11/4/2018 21:28:42	Female	44	Hiking and walking	Yes	give away to family or the	Yes	Yes	Glass, Plastic Metal and Drinkcartons, Clothing (bin or collecting bags), Batteries, Small electric appliances, Greens and compost (GFT), Paper
10/31/2018 22:22:49	Male	50	Hiking and walking, Cyclir	Yes	Sell, for someone else to	Yes	Yes	Glass, Plastic Metal and Drinkcartons, Clothing (bin or collecting bags), Batteries, Small electric appliances, Greens and compost (GFT), Paper
11/3/2018 10:53:19	Female	50	Cycling, Hiking and walkir	Yes	give away to family or the	Yes, Only if it is convenier	Yes	Glass, Plastic Metal and Drinkcartons, Clothing (bin or collecting bags), Batteries, Small electric appliances, Greens and compost (GFT), Paper
11/3/2018 10:51:50	Male	52	Cycling, Hiking and walkir	Yes	Exchange when buying a	Only if it is convenient (for	Yes	Glass, Plastic Metal and Drinkcartons, Clothing (bin or collecting bags), Batteries, Small electric appliances, Greens and compost (GFT), Paper
11/2/2018 21:21:34	Female	54	Cycling, Hiking and walkir	Some	Throw it in the trash	Only if it is convenient (for	Yes	Glass, Plastic Metal and Drinkcartons, Clothing (bin or collecting bags), Batteries, Greens and compost (GFT), Paper
11/8/2018 22:12:25	Male	54	Rowing	No	Repairshop @rowing club	Yes, Only if it is convenier	Yes	Glass, Plastic Metal and Drinkcartons, Clothing (bin or collecting bags), Batteries, Small electric appliances, Greens and compost (GFT), Paper
11/2/2018 19:23:50	Female	58	Hiking and walking	Yes	give away to family or the	Yes	Yes	Glass, Plastic Metal and Drinkcartons, Clothing (bin or collecting bags), Batteries, Small electric appliances, Greens and compost (GFT), Paper
11/2/2018 19:25:05	Female	58	Hiking and walking	Yes	give away to family or the	Yes	Yes	Glass, Plastic Metal and Drinkcartons, Clothing (bin or collecting bags), Batteries, Small electric appliances, Greens and compost (GFT), Paper
11/3/2018 11:19:31	Female	58	Hiking and walking	Yes	Ik breng het naar een ver	Yes	Yes	Glass, Plastic Metal and Drinkcartons, Clothing (bin or collecting bags), Batteries, Small electric appliances, Paper
11/2/2018 19:39:26	Female	60	Hiking and walking	Yes	Throw it in the trash	Yes	Yes	Glass, Plastic Metal and Drinkcartons, Clothing (bin or collecting bags), Batteries, Small electric appliances, Greens and compost (GFT), Paper
11/2/2018 19:33:50	Female	64	Cycling, Hiking and walkir	Yes	give away to family or the	Yes, Only if it is convenier	Yes	Glass, Plastic Metal and Drinkcartons, Clothing (bin or collecting bags), Batteries, Small electric appliances, Greens and compost (GFT), Paper
11/2/2018 19:41:55	Male	66	Hiking and walking	Yes	Throw it in the trash	Yes	Yes	Glass, Plastic Metal and Drinkcartons, Clothing (bin or collecting bags), Batteries, Small electric appliances, Greens and compost (GFT), Paper
11/3/2018 12:31:03	Male		Cycling, Hiking and walkir	Yes	Throw it in the trash	Yes	Yes	Glass, Plastic Metal and Drinkcartons, Clothing (bin or collecting bags), Batteries, Small electric appliances, Greens and compost (GFT), Paper

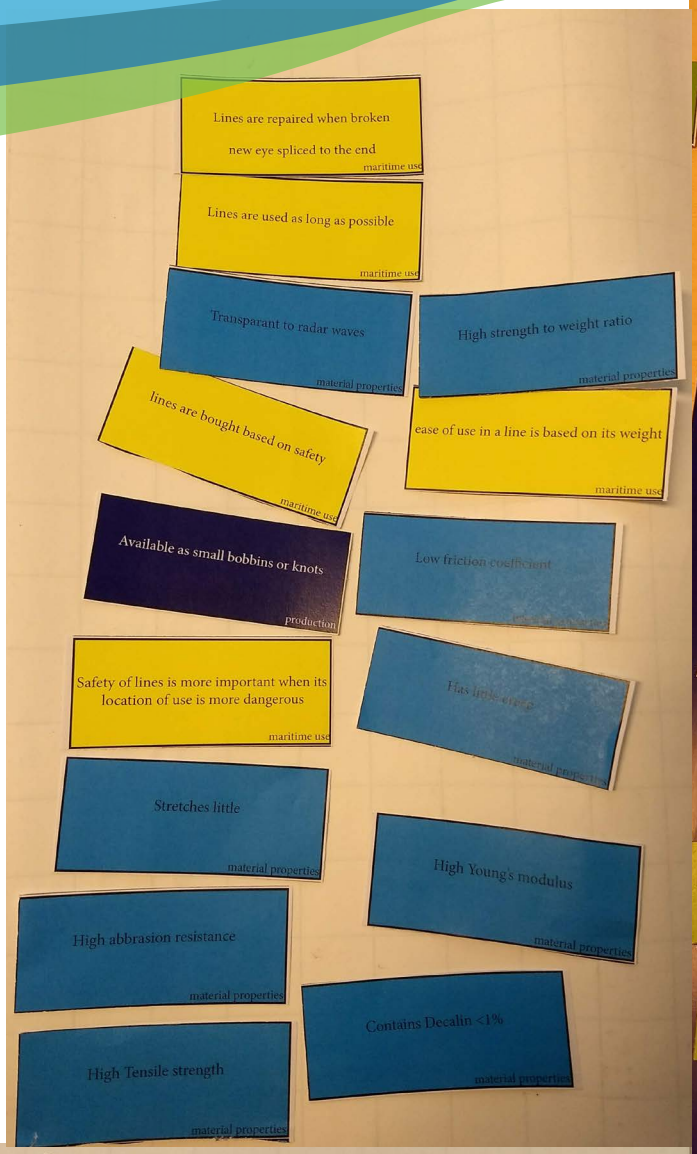
Appendix II Clusters resulting from the shared insight session

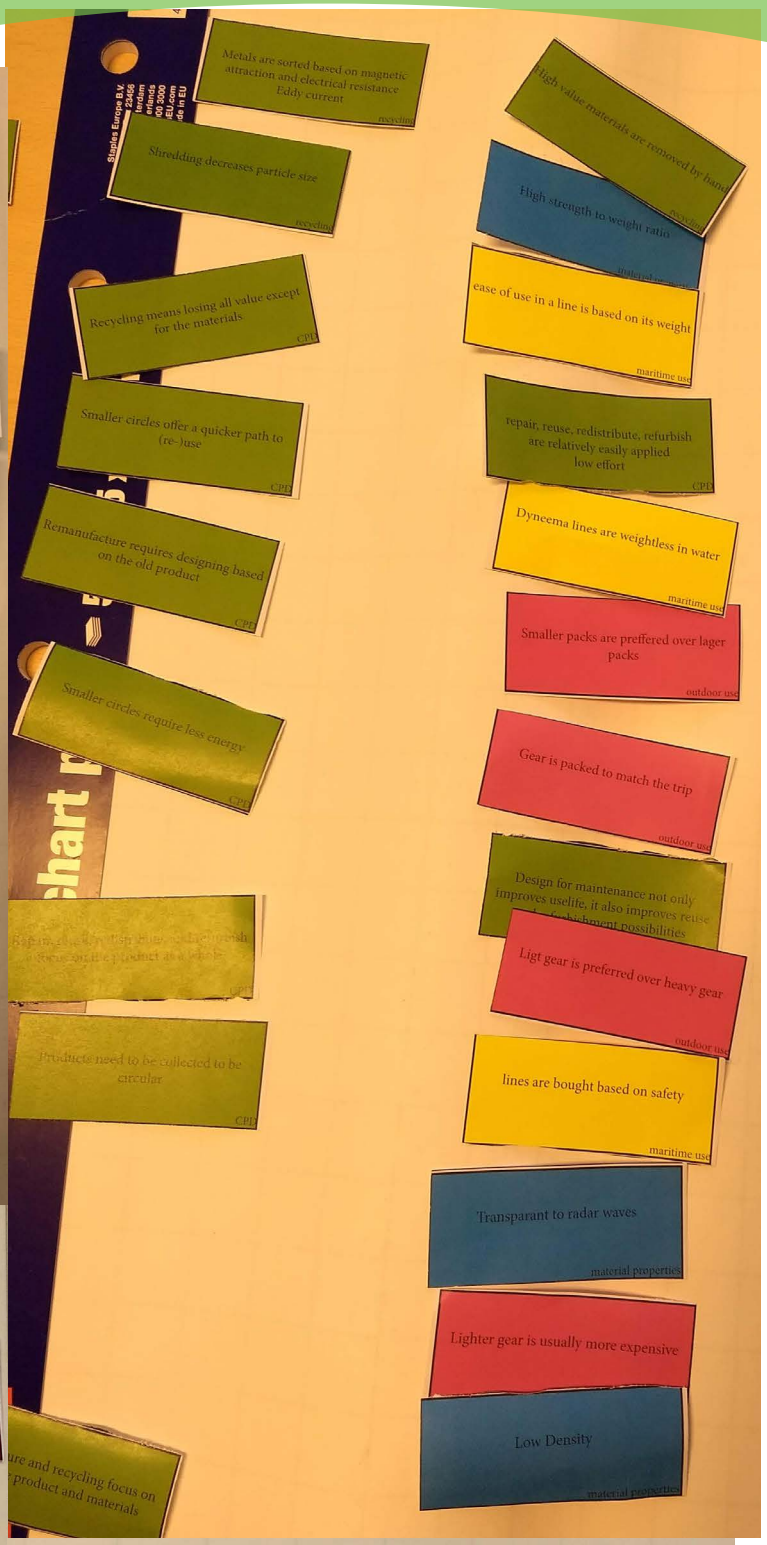


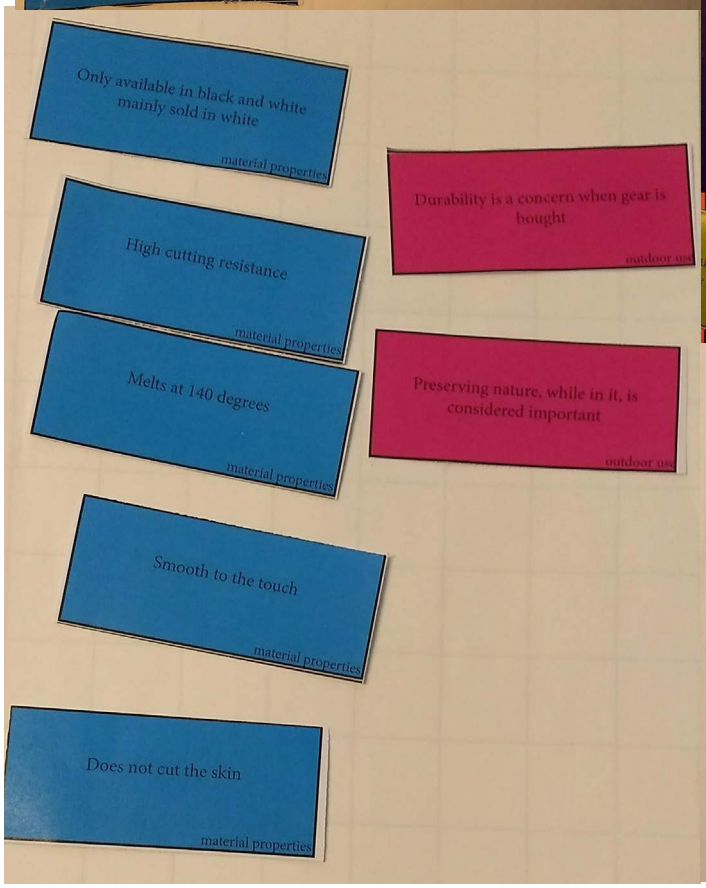


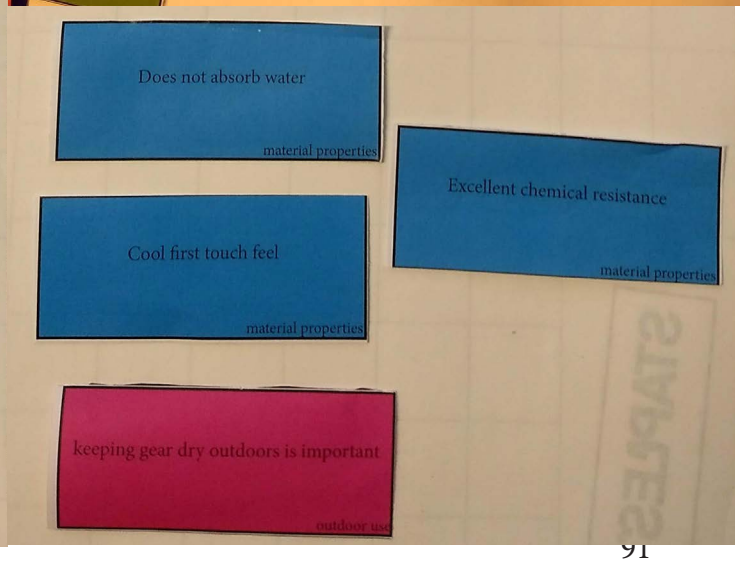





Lines are repaired when broken
new eye spliced to the end
maritime use
Lines are used as long as possible
maritime use
Transparant to radar waves
material properties
High strength to weight ratio
material properties
lines are bought based on safety
maritime use
ease of use in a line is based on its weight
maritime use
Available as small bobbins or knots
production
Low friction coefficient
Safety of lines is more important when its location of use is more dangerous
maritime use
Has little creep
material properties
Stretches little
material properties
High Young's modulus
material properties
High abbrasion resistance
material properties
Contains Decalin <1%
material properties
High Tensile strength
material properties

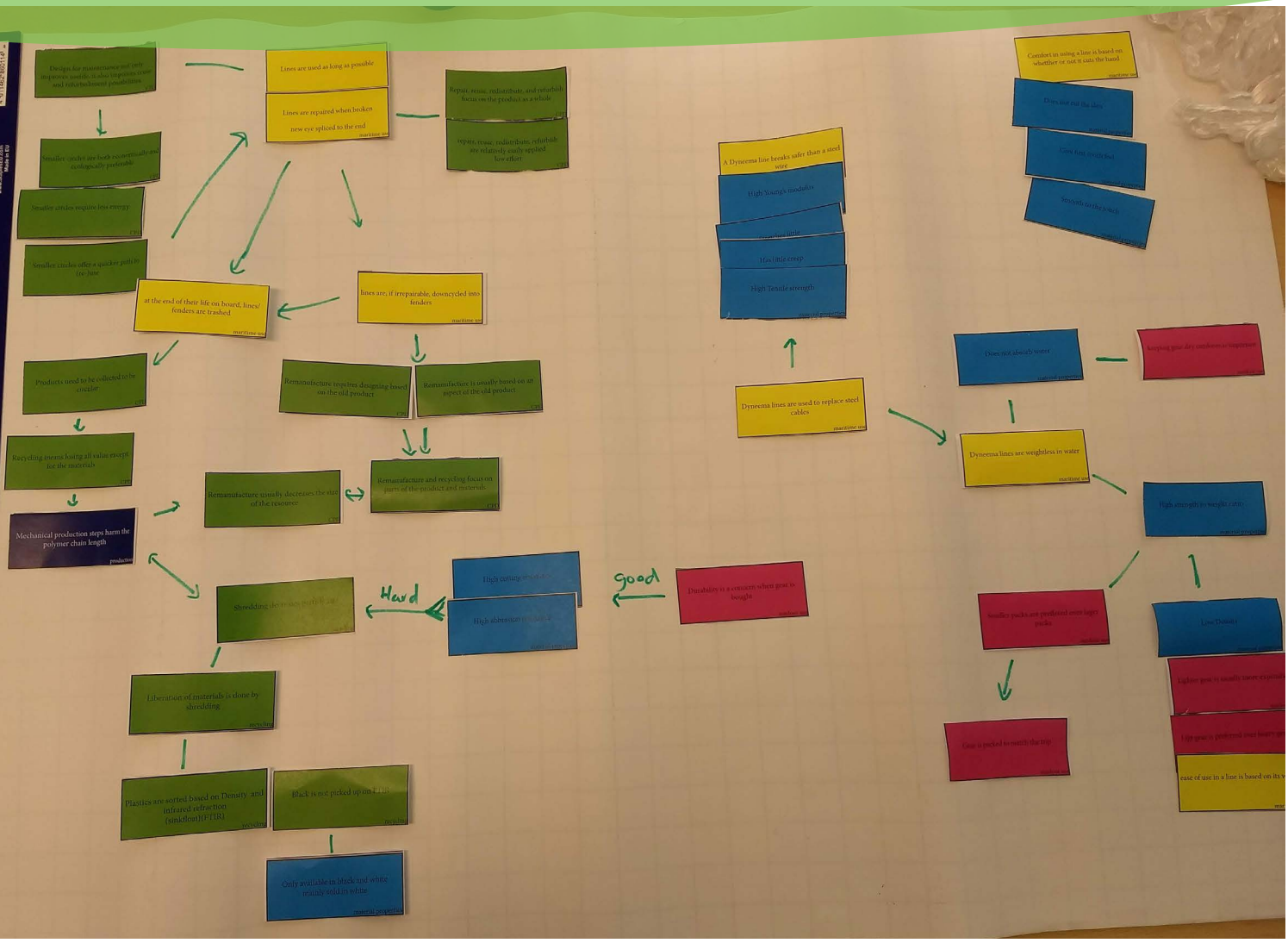

Metals are sorted based on magnetic attraction and electrical resistance Eddy current
recycling
Shredding decreases particle size
recycling
High value materials are removed by hand
recycling
High strength to weight ratio
material properties
Recycling means losing all value except for the materials
CPL
ease of use in a line is based on its weight
maritime use
Smaller circles offer a quicker path to (re-)use
CPL
repair, reuse, redistribute, refurbish are relatively easily applied low effort
CPL
Remanufacture requires designing based on the old product
CPL
Dyneema lines are weightless in water
maritime use
Smaller packs are preffered over lager packs
outdoor use
Smaller circles require less energy
CPL
Gear is packed to match the trip
outdoor use
Design for maintenance not only improves uselife, it also improves reuse
Ligt gear is preferred over heavy gear
outdoor use
Products need to be collected to be circular
CPL
lines are bought based on safety
maritime use
Transparant to radar waves
material properties
Lighter gear is usually more expensive
Low Density
material properties

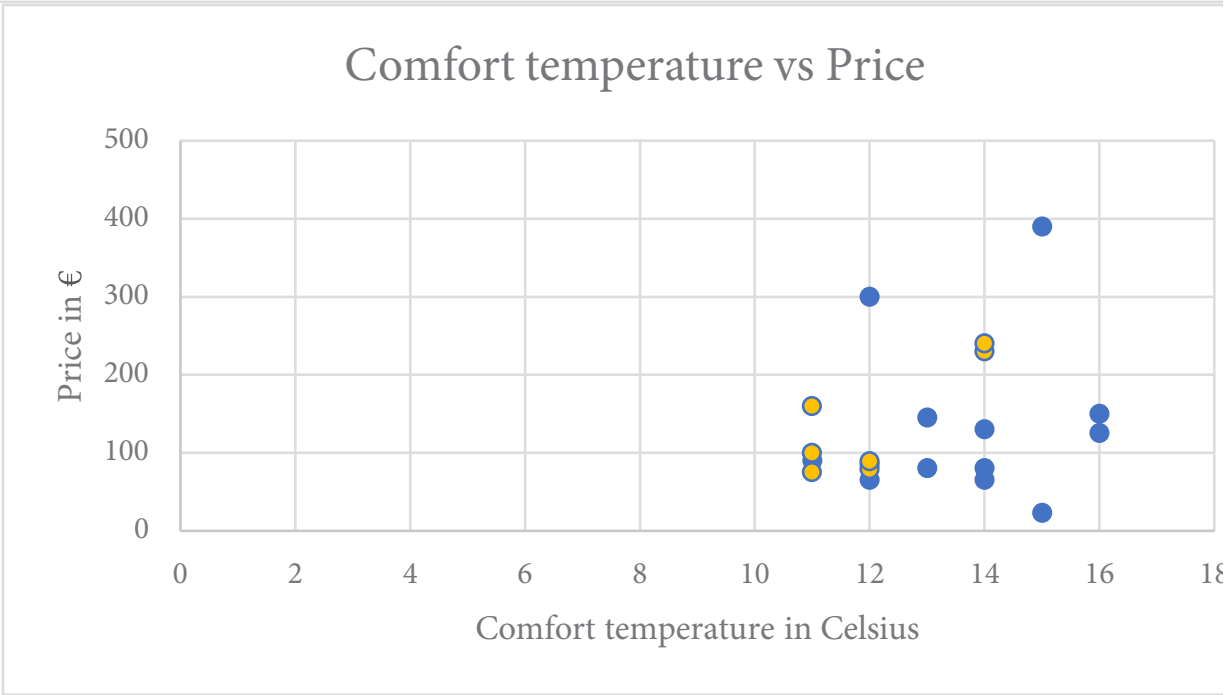

Only available in black and white mainly sold in white
material properties
Durability is a concern when gear is bought
outdoor use
High cutting resistance
material properties
Melts at 140 degrees
material properties
Preserving nature, while in it, is considered important
outdoor use
Smooth to the touch
material properties
Does not cut the skin
material properties


Does not absorb water
material properties
Excellent chemical resistance
material properties
Cool first touch feel
material properties
keeping gear dry outdoors is important
outdoor use

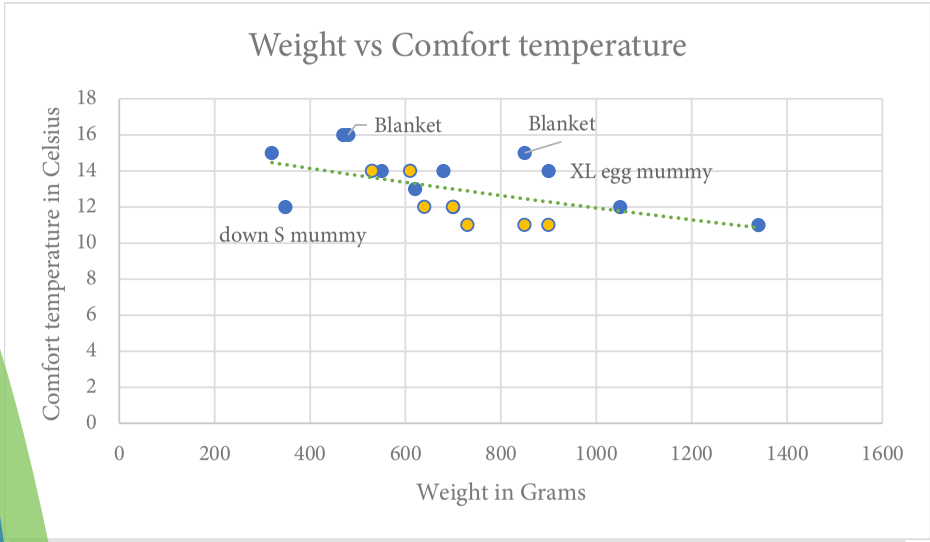
Appendix II Clusters resulting from the shared insight session

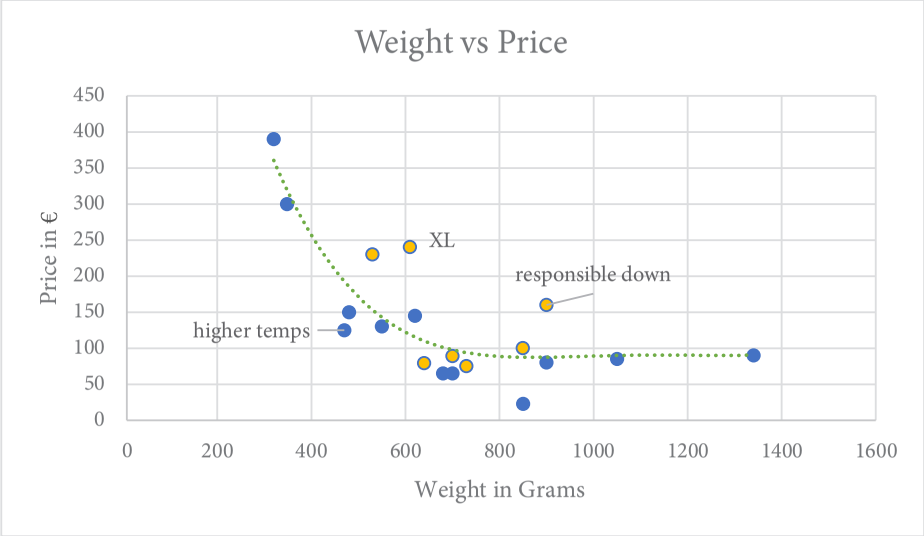
Appendix III summer sleeping bag comparison





Naam	Gewicht	comfort te	limit temp	prijs	binnentijk	Buitentijk	isolatie	model	lengte	breedte		avarage comfort limit
Camp gear	850	15		23	170T polye	170T polye	synthetisch	Blanket	190	75		
ayacucho l	680	14	11	65		Nylon	synthetisch	mummy	210	75		12.5
Lafuma act	700	12		65	50D polyes	50D polyes	Synthetisch	mummy	213	80		
Vaude Siou	730	11	7	75	50D polyes	50D polyes	synthetisch	mummy	210	75	Fair wear foundation	9
Nordisk Ca	550	14	10	130	30D Nylon	30D Nylon	synthetisch	egg Mumn	200	73		12
Mammut (	640	12	8	79	Polyester	Nylon	synthetisch	strakke mummy		78	Fair wear foundation	10
ayacucho lite	1200B	13	9	80	Polyester	polyester	synthetisch	Blanket	220	80		11
Vaude Nav	1050	12	8	85	50D polyes	50D polyes	synthetisch	Blanket	220	80		10
Mammut M	700	12	8	89	Polyester	Nylon	synthetisch	strakke mummy		78	Fair wear foundation	10
Lafuma cot	1340	11	5	90	Katoen	Katoen	synthetisch	Blanket	200	90		8
Jack wolfsk	850	11	7	100	50D Polyes	50D polyes	synthetisch	mummy	205	75	Fair wear foundation	9
fjällräven F	470	16	13	125	20D polyes	20D nylon	synthetisch	mummy		80		14.5
fjällräven F	620	13	9	145	20D polyes	20D nylon	synthetisch	mummy		80		11
bever deke	480	16	13	150	Pertex Mic	Pertex Mic	dons	Blanket	227	83		14.5
Vaude Che	900	11	6	160	Polyester	polyester	dons	mummy	220	80	Fair wear f responsibl	8.5
sea to sum	348	12	8	300			dons	mummy	185	73		10
Jack wolfsk	530	14	10	230	nylon	nylon	synthetisch	mummy	215	78	Fair wear foundation	12
yeti Passio	320	15	12	390	nylon	Nylon	dons	mummy	225	83		13.5
jack wolfsk	610	14	10	240	nylon	Nylon	synthetisch	mummy	225	85	Fair wear foundation	12
Nordisk ab	900	14	10	80	brushed pc	195T polye	synthetisch	egg Mumn	230	88		12





Appendix IV Results insulation temperature comparison.

Time	Nordisk	Design	Baffles	Spheres
0	30.1	30.8	29.4	30.2
30	29.9	30.7	29.4	30.2
60	29.8	30.6	29.4	30.1
90	29.8	30.6	29.3	30
120	29.8	30.5	29.3	30
150	29.8	30.5	29.3	29.9
180	29.7	30.5	29.3	29.9
210	29.7	30.4	29.3	29.9
240	29.7	30.4	29.2	29.9
270	29.6	30.4	29.2	29.8
300	29.6	30.4	29.2	29.8
330	29.6	30.3	29.2	29.7
360	29.6	30.3	29.1	29.7
390	29.6	30.2	29.1	29.7
420	29.6	30.2	29.1	29.6
450	29.6	30.2	29.1	29.6
480	29.6	30.2	29.1	29.6
510	29.5	30.1	29	29.6
540	29.5	30.1	29	29.5
570	29.4	30.1	29	29.5
600	29.4	30.1	28.9	29.5
630	29.4	30.1	28.9	29.4
660	29.4	30	28.9	29.4
690	29.3	30	28.9	29.4
720	29.3	29.9	28.9	29.3
750	29.3	29.9	28.8	29.3
780	29.3	29.8	28.8	29.2
810	29.3	29.8	28.8	29.2
840	29.3	29.8	28.7	29.2
870	29.2	29.8	28.7	29.2
900	29.2	29.7	28.7	29.2
930	29.2	29.7	28.7	29.1
960	29.2	29.7	28.7	29.1
990	29.1	29.7	28.6	29.1
1020	29.1	29.6	28.6	29.1
1050	29.1	29.6	28.5	29
1080	29.1	29.5	28.5	29
1110	29	29.5	28.5	28.9
1140	29	29.5	28.5	28.9
1170	29	29.4	28.5	28.8
1200	29	29.4	28.4	28.8
1230	29	29.3	28.4	28.8
1260	29	29.3	28.4	28.8
1290	29	29.3	28.3	28.8
1320	28.9	29.3	28.3	28.8
1350	28.9	29.3	28.3	28.7
1380	28.9	29.2	28.3	28.7
1410	28.8	29.2	28.3	28.7
1440	28.8	29.2	28.2	28.7
1470	28.8	29.1	28.2	28.6
1500	28.8	29.1	28.2	28.6
1530	28.8	29.1	28.2	28.6
1560	28.8	29.1	28.2	28.6
1590	28.8	29.1	28.1	28.5
1620	28.8	29.1	28.1	28.5
1650	28.8	29	28.1	28.4
1680	28.7	28.9	28.1	28.4
1710	28.7	28.9	28.1	28.4
1740	28.7	28.9	28.1	28.3
1770	28.6	28.9	28	28.3
1800	28.6	28.8	28	28.3

	gewicht		outdoor temp	
			start	end
petfles	25.5			
water	433.5	nordisk	21.7	22
nordisk	11	design	22	22
design	11.5	baffle	22	22.2
baffle	12.6	sphere	21.3	21.6