DESIGNING WITH ELEPHANT GRASS BASED BIOPLASTIC

Romy Zwetsloot - Master thesis - Delft University of Technology -July 2020

Graduation Committee
Chair: Prof. dr. A.R. (Ruud) Balkenende
Department: Sustainable Design Engineering

Mentor: Ir. M.F. (Martien) Bakker
Department: Sustainable Design Engineering

Company Mentor: F. (Fredric) Petit
Function: CEO of Vibers

Author
Romy Denise Zwetsloot
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MSc. Integrated Product Design
Faculty of Industrial Design Engineering
Delft University of Technology

EXECUTIVE SUMMARY

The company Vibers makes bioplastic from elephant grass, which has a positive effect on the environment. The crop grows perfectly on the Dutch soils, so the material is locally attuned. There are low fertilizer and pesticide requirements, which makes the crop relatively environmentally friendly (Lewandowski, Clifton-Brown, Scurlock & Huisman, 2000). The elephant grass has a high absorption of CO_2. This material sounds promising, and therefore, research is done on the unique qualities of this material: what fitting application areas of the material are, and what questions arise when designing with this material. The project definition is as follows: exploring the possibilities of designing with elephant grass based bioplastic.

During the first phase of this research the unique qualities of this bioplastic are explored and they are connected to application areas that fit the material. While doing this analysis, a method is designed that can be used for exploring the unique qualities of a new material. The Vibers bioplastic has the unique quality that it is bio-based and biodegradable, and due to its look and feel, users link it directly to a sustainable material. The elephant grass fibres have captured a large amount of CO_2 from the air. Also they add stiffness to the material. With this unique quality, a structured way of opportunity finding is used in order to identify the right fit for the material.

In the second phase of the report the method 'research through design' is used to explore the material further while designing two concepts of a veranda bench. The veranda bench is chosen to continue the project with since the unique qualities of the material add value to the product. Also this application has multiple conflicting requirements, which can lead to interesting design questions. The goal of this exploration is not to design the best veranda bench, but to get to know the material better, and to set up design guidelines for designing with Vibers bioplastic. During the design process several design questions arose that needed to be answered in order to design with this material. Answering those questions gave insights in the strength, production, UV resistance and end-of-life scenarios of the material.

In the conclusion of this research, the findings are converted to design guidelines and recommendations. The design guidelines are meant to help designers that want to use this material. They explain the following: (1) The material should add value to the product. (2) The material has environmental benefits. (3) The material has a sustainable look and feel that should be used. (4) How production depends on the desired end-of-life scenario of the product. (5) What plastic the material is comparable to. (6) What the end-of-life possibilities are with this material. (7) That the material does not change colour in UV exposure. (8) How different percentages of elephant grass can change the material. (9) That the material is fit for durable and timeless design. (10) That the material is fit for modular design.

The recommendations are meant to help Vibers develop their material. Firstly, a method is explained that they can use for exploring new materials. Secondly, a recommendation is given on what application areas are fit for their material. Thirdly, a to-do list is made, which explains what questions have not been answered in this thesis and thus need follow-up research. Lastly, the writer gives advice on how transparency is key to a more sustainable world.

ACKNOWLEDGEMENTS

Sustainability is a topic that always attracted me. While searching for small things to change in my materialised behaviour, I explored that it is rather difficult to 'do the right thing'. Discussions like: "is it better to buy a cucumber with or without plastic packaging?" kept me busy, and inspired me to dive into this interesting topic.

When Jeroen Verbrugge, whom I know from my internship at FLEX/design, told me about Vibers, I was convinced. The Vibers website made a great first impression and I immediately knew I wanted to do a graduation project for this company. Luckily for me they were enthusiastic about my proposal, and so the project started. I learned a lot during the last five months about the sustainability topics that inspire me so much. I therefore want to thank my colleagues at Vibers, especially Fredric Petit, for helping me during the project. Although it was a stressful time for business in which sales needed to grow, you were always available for my questions and to give advice.

Furthermore, I feel honoured that my chair Ruud and mentor Martien wanted to guide me through this project, and therefore I want to thank them. It was not an easy topic since the end goal of the project was never known until a few weeks before the green light. However, there was always a great teamwork during our meetings, in which you helped me finding the right direction to go in, which resulted in this structured thesis.

There are more people who supported me the last five months.

I want to thank everyone who participated in a creative session that I organised, for giving me their time and great ideas.

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And lastly, Mom, Dad, Suus and Jannick; you are my perfect family. Thanks for being around.

Enjoy Reading!

TABLE OF CONTENT

APPROACH

Here a short overview of the different methods used during this project is given.

Main method (figure 1)

The goal of this research was to explore the bioplastic developed by Vibers. The approach of this research consist of two phases. In the first phase research is done on the material composition, material properties, use phase, and recovery. Because the material is still being developed, the Wishful thinking method is used to tweak material properties and come up with the 'preferred material'. Within the four analysis topics is discovered what the qualities of the material are. Those qualities are noted in a grey box after each section. Together those form the uniqueness of this material.

In the second phase, the material is explored within the application of a veranda bench. Two concepts are established for which requirements are set up. Those requirements result in design questions of properties that are still unknown about the material. Answering those questions gives design guidelines which can be used when designing with Vibers plastic.

The result of this research is split in two conclusions. The first is about how to design with vibers plastic. The possibilities and restrictions of the material are discussed and an approach for designing with vibers plastic is explained. The second conclusion is a recommendation for Vibers in explaining which application areas are suitable for the material, what the preferred material properties for future materials are, and what a good approach can be to gain knowledge about future materials.

Material Driven Design (MDD)

In the Material Driven Design method (Karana, Barati, Rognoli & Zeeuw van der Laan, 2015), a material is the starting point of the design process. The goal is to design a product that fits the material well and provides a specific material experience. The first step of the MDD method, in which an understanding of the material is gathered, is used during the exploration phase of the material. The technical and experiential characterisations are found by internet research, quick tinkering tests and a small user research.

Wishful thinking (WT)

If there was the freedom to change all material properties and design a 'perfect' bioplastic, how would this material look? Vibers keeps innovating their material, and when other material properties are preferred, they try to incorporate those in a new granulate. Therefore, it is valuable to take this 'preferred material' into account as if they are already making it. The preferred material properties are determined by looking for the failure points of the current material in different applications.

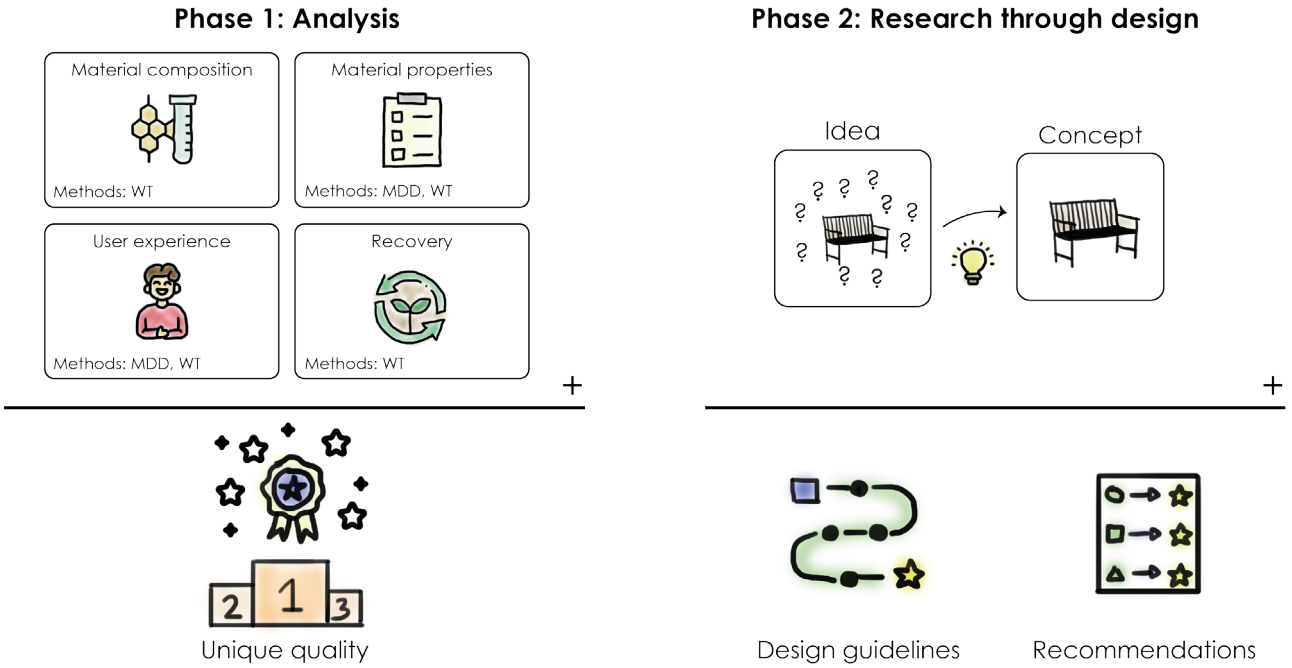


Figure 1. Visualisation of the main method for this research

Creative sessions

Creative brainstorm sessions are held in order to find suitable application areas for the material. Interesting in this method is that there is the possibility to let other people focus on the problem for a while, and the problem can be tackled from different angles. The book 'Road map for creative problem solving techniques: organizing and facilitating group sessions' from Heijne and Van Der Meer (2019) is used to prepare the sessions. In total seven creative sessions are held, in which a total of 20 people participated in finding application ideas.

Research through design

When using the method Research through design, a concept design is made with the goal to gain as much knowledge about the material as possible (Stappers & Giaccardi, n.d.). It is important to keep in mind that in the end the concept design is not the most valuable. Instead it is the material exploration that is valuable. Knowledge gaps are filled from which the information is needed for designers who want to use this material in their design. All actions performed during this method need to have a purpose on exploring the material. Therefore, aesthetics and visual prototypes are less useful in this research, while technical aspects and functional prototypes are valuable. With this rather new and unknown material there are a lot of knowledge gaps that need to be filled before designing with it. This method explores which gaps are there and finds answers to them.

INTRODUCTION

In this section an introduction is given on the company Vibers, the elephant grass crop they use in their bioplastic and the current produced products with Vibers bioplastic.

The company Vibers started with founder Jan-Govert van Gilst in 2010, who wanted to contribute to a more sustainable world. Wageningen University & Research pointed him in the direction of elephant grass, a crop that absorbs a large amount of CO_2. This appeared to be a great base for paper and bioconcrete. After widening the scope he found out that the material was also fit to make bioplastics. Nowadays the company has grown to 10 employees, and they are still making, selling and innovating all three products. In this project research is done about their bioplastic. The other Vibers biomaterials, paper and concrete, are left out of scope.

Vibers does not have its own soil or machinery to create the plastic, and they don't sell products to consumers. They buy the elephant grass from farmers in The Netherlands. The crop can be harvested once a year and the yield is brought to a company that grinds it to flakes. Those flakes are processed into plastic granulate by another company. This granulate is fit to be used for injection moulding, extrusion and thermoforming of products. Vibers sells this granulate to buyers that are interested in making plastic products with their bioplastic. An overview of all stakeholders Vibers deals with is shown in figure 2.

It is a challenge for Vibers to find buyers since the material is rather unknown. They are being contacted by a lot by people who are enthusiastic about their material. However, most of them don't buy the product in the end. At Vibers those contacts are called 'cheerers'. Only a minority of the contacts will become 'buyers'. Following up on 'cheerers' costs a lot of time and has only little helpful result. Since one year they decided to actively search for 'buyers'. At the moment they are searching for connections in the following branches: consumer products, luxury packaging, furniture and some business-to-business branches like displays, points of sale and in-store signage. Since Vibers doesn't design or sell products themselves, it would be most valuable for them to find applications that already exist, and in which only the material can be replaced. However when a non-existing application appears to be the right fit for Vibers, this doesn't necessarily mean that it is not reasonable, since it could be an application for the future.

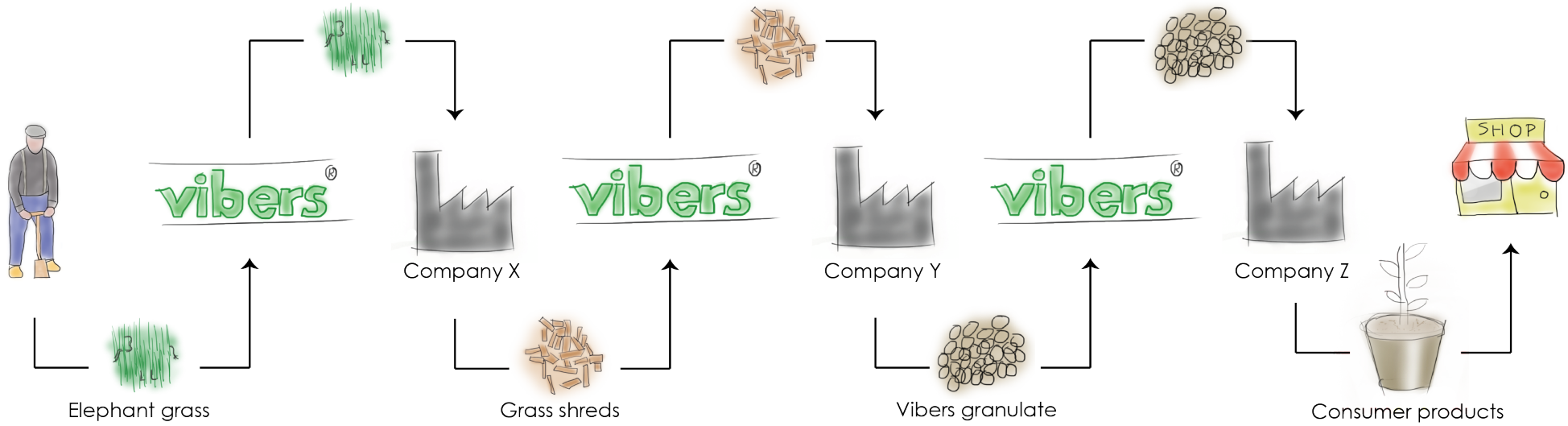


Figure 2. Stakeholders for Vibers

Elephant grass crop

The origin of the elephant grass crop lays in east Asia. In the 1930's the crop was introduced in Europe. There are different varieties of the crop with various names. The genotype 'Miscanthus x giganteus Greef et Deu' was observed to have exceptional growth with yields to 20 tonnes dry matter ha/year.

Miscanthus appears to have a wide range of applications: "Fibres to replace cotton in clothing, paper, animal feed, packaging material, raw material for bioplastics and biofuels" (Wageningen University & Research, n.d.(b)). The crop grows in very diverse conditions and is efficient in the use of natural resources. It grows on a wide variety of grounds, from sandy to clayey soils. The optimal pH value of the soil is 5.5 to 7.5 (Cradle-Crops, n.d.). It is able to grow on marginal land that is not fit for food production (Wageningen University and Research, n.d.(d)). The minimum temperature for the crop to activate photosynthesis is 6°C (Cradle-Crops, n.d.). During the grow period it would be ideal to have a precipitation of 700 to 900mm. Lower precipitations could have a negative influence for the yield. After a long period of dryness, in which the crop paused growing, it will continue to grow after rainfall (Cradle-Crops, n.d.)

Figure 3. Elephant grass crop

The crop grows perfectly on the Dutch soils, so the material is locally attuned. Once planted, the crop grows about 15 to 20 years. New shoots are formed annually. During the first year, the crop can grow to a height of about 1 to 1.5 meters long and a diameter of about 10 mm. The crop will after about four years reach a length of about 3 to 3.5 meters (Cradle-Crops, n.d.). Because of its high length it is often called elephant grass (figure 3). The harvest happens annually in late winter or spring when the stems are dead (Christian, Riche & Yates, 2008).

Existing products from Vibers material

Vibers has been investigating four different branches of products. The consumer products which are currently being sold are: flower pots, plates, kitchen containers, lunch boxes and bowls (figure 4). Furthermore they have one client that buys their material for sale displays. The current products are made with a granulate with a low heat distortion temperature. Therefore, the kitchen products like the bowls, plates and lunch boxes turned out to deform in the dishwasher, or when exposed to heat from food. Although it is arguable that consumers should listen to the instructions, it is not very consumer friendly. Therefore these might not be the best applications. The flower pots and sale displays are however a good purpose for the material.

The end-of-life scenario of the current Vibers products is incineration, since there is no recycling process for biodegradable plastics. Vibers bioplastic could be recycled into the same bioplastic, only this will not happen without a collection system. However, business-to-business products, which are designed to return to the manufacturer, can be shredded and used with the virgin material. For business-to-consumer products, confusion could occur about where to dispose the product, since it is made from plastic. By throwing the product in the plastic recycling bin, the plastic recycling process gets polluted. Consumers are missing a guide of how to dispose those products.

Figure 4. Products with Vibers material

PHASE 1. ANALYSIS

In the first phase of the research, the material is analysed on four topics: material composition, material properties, user experience, and recovery. This exploration is done by literature research, material tests and user tests. The three plastic granulates that Vibers makes, are taken into account in this research. Since Vibers keeps innovating their material, also a fourth ‘preferred granulate’ is discussed in each section. For every section a conclusion is drawn of what the quality of the material is for that topic. Those are noted in a grey box after each section. Together those qualities form the uniqueness of the material.

SECTION 1. MATERIAL COMPOSITION

In this first section of phase 1, the material composition of the Vibers plastic is explored. First the composition of the three current granulates is examined, after which a preferred granulate is discussed. The following question is asked here: “If there was the freedom to change all material properties and design a ‘perfect’ bioplastic, what would this material look like?”

1.1 Current material composition

Vibers manufactures three different granulates which differ in composition materials (figure 5).

All three granulates are bio-based materials. The European standard EN 16575 defines bio-based as 'derived from biomass' (European Committee for Standardization, 2014). The material needs to be (partly) derived from renewable, natural sources. The raw materials are derived from biomass, for which renewing the source happens in a relative short period of time. Renewing the source for fossil fuels takes millions of years, so it is not considered as bio-based (figure 6).

The three granulates all contain the material elephant grass. The contribution in of elephant grass in the material is confidential, and can be found in the confidential appendix. The use of elephant grass has a positive effect on the environment. The elephant grass crop grows perfectly on the Dutch soils, so the material is locally attuned. There are low fertilizer and pesticide requirements, which makes the crop relatively environmentally friendly (Lewandowski, Clifton-Brown, Scurlock & Huisman, 2000). Like all vegetation, the crop absorbs CO_2 while growing. Vibers states however, that this crop absorbs four times as much CO_2 as a European forest (Vibers, n.d.). When such a material is used in products that are endlessly recycled after use, the CO_2 is captured for ever. This is however with the requirement that it isn't incinerated after use since this will release the CO_2 again.

Granulate 1 (figure 5) is made with elephant grass, potato starch, polylactide (PLA), and a coupling agent. Interesting in this composition is that the coupling agent, which name can be found in the confidential appendix, is not a bio-based material. The coupling agent is a biodegradable plastic, made from fossil fuels. Its material properties are similar to those of low density polyethylene and it is used as a substitute material for PE foils for its high elongation at break (30-40%) (Polymer Properties Database, n.d.). This coupling agent is used in bioplastics like PLA as a toughening agent and to make the material more flexible (Rijksdienst Cultureel Erfgoed, n.d.).

Granulate 2 (figure 5) is made with elephant grass in combination with a high temperature PLA. The high temperature PLA has a crystallization process after cooling down, which means that it gets a higher heat resistance than regular PLA (Luminy, n.d.).

Granulate 3 (figure 5) is made from elephant grass and bioPE. BioPE is chemically exactly the same as traditional PE, and has therefore the same material properties as PE. The difference between the two is that bioPE is made from a renewable source, and PE from a fossil fuel based source (Wageningen University and Research, n.d.(c))

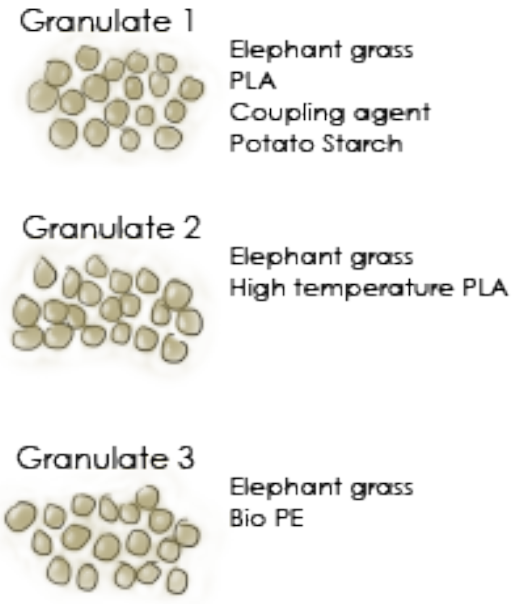


Figure 5. Material composition of the current three granulates

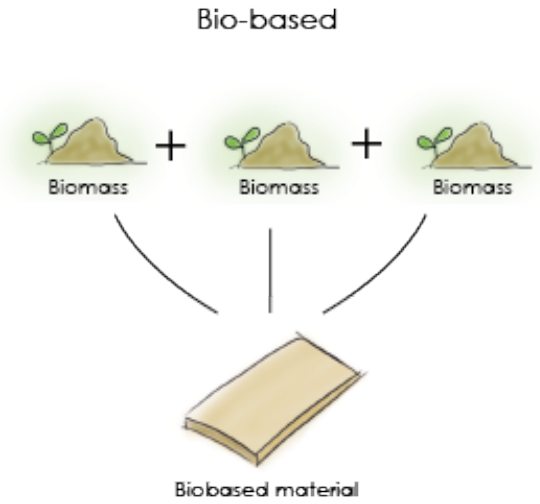


Figure 6. Explanation bio-based

1.2 Preferred material composition

If there was freedom to change all material properties and design a 'perfect' bioplastic, how would this material look? The preferred material is determined by looking for the failure points of the current material (figure 7).

All three granulates contain an amount of elephant grass, which is less than preferred. Vibers sells the material as if elephant grass is the main component in the material, however it appeared not to be. It is preferred to have a higher contribution of elephant grass since the crop has a very positive effect on the environment. Since both granulate 1 and 2 contain PLA, an analysis is done on compositions with PLA. Research has shown that PLA composites with 30% to 40% of natural fibre reinforces the material (Oksman, Skrifvars, Selin, 2003). Therefore, the assumption is made that a contribution of 40% elephant grass is possible (figure 8). To predict the influence of a higher percentage of elephant grass, the mechanical properties of PLA and PLA with 30% of natural fibre are analysed using CES EduPack (Granta Design Limited, 2019), a software with a big material database. The natural fibre is a short fibre cellulose material, which seems comparable to elephant grass fibres. From this comparison it can be concluded that a higher percentage elephant grass results in a lower tensile strength, a higher Young's modulus and a higher impact strength. Most thermal properties like maximum service temperature and melting temperature stay about the same.

Lastly, to create a truly sustainable material, the material needs to be minimally completely build up from bio-based materials. Granulate 1 is build up with a coupling agent which comes from a non-renewable resource. The preferred granulate will not contain this material.

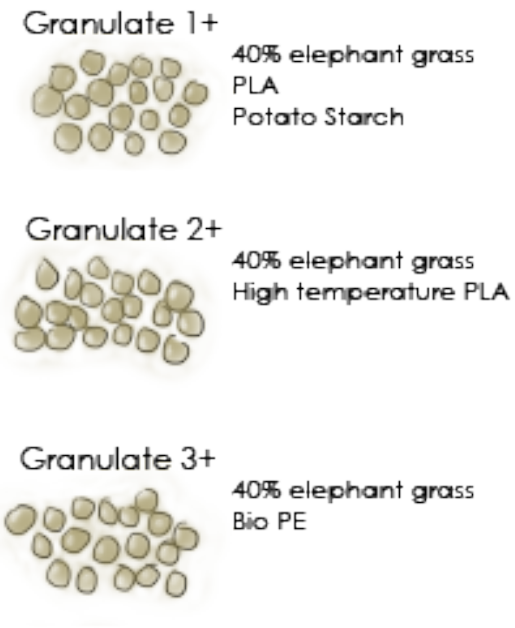


Figure 7. Material composition of the preferred material

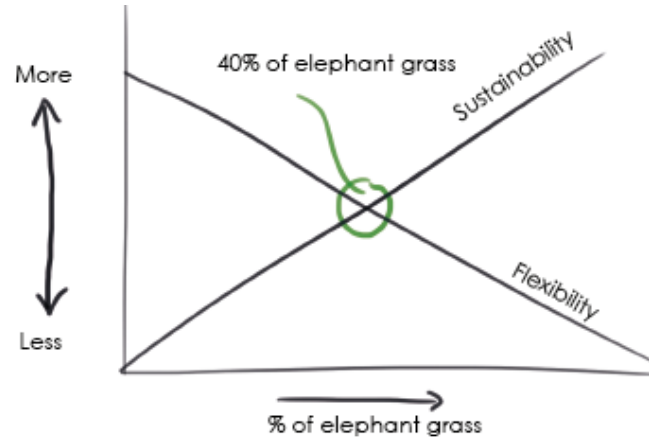


Figure 8. Sustainability vs. material properties

VIBERS QUALITY
The preferred Vibers granulates are bio-based, which means that no non-renewable resources are used for making this material.

The preferred Vibers granulates contain 40% elephant grass. Using this grass in a material has big positive effect on the environment when the product is not incinerated after use, due to the high possibility of capturing CO_2, no fertilizer and pesticide requirements and the possibility of producing it locally.

SECTION 2. MATERIAL PROPERTIES

In this section the material properties of Vibers plastic are examined. Firstly an overview of all material properties of the current Vibers granulate is made. Since Vibers is open to new variations on the material, some material properties need to be changed to come to the 'preferred material'. A comparison with other plastics is made with both current and preferred materials. This comparison is done with the material database of CES EduPack (Granta Design Limited, 2019).

2.1 Current material properties

The three Vibers granulates differ in material properties that can be found in table 1. Not all properties are known and therefore, a few quick tinkering tests are done. Granulates 2 and 3 were still in production during this research. Therefore the tinkering tests are done only with granulate 1. Samples of 1.7mm and 0.3mm thickness are used.

Bending: the 1.7mm thick injection moulded material breaks as soon as it starts to plastically deform and feels therefore rather brittle. The thin sheet material of 0.3mm thickness deforms plastically first and breaks when it is bend a few times.

Tearing: the 0.3mm thick sheet material is easy to tear. It feels like it tears naturally into one direction, due to the fibres that are inside. It is however not possible to make a straight tear as seen in figure 9. This applies to tearing in both directions. Straight tearing is only possible after bending the material first and then tearing it on the bending line.

Figure 9. No straight tearing

Heat: when the material is exposed to hot water or air, the material gets very weak and is easily deformable. This is due to its maximum service temperature of 50°C degrees. After heating in water several times the material gets a white skin (figure 10). This is probably because the starch dissolves in the water. This does not happen when heating with hot air.

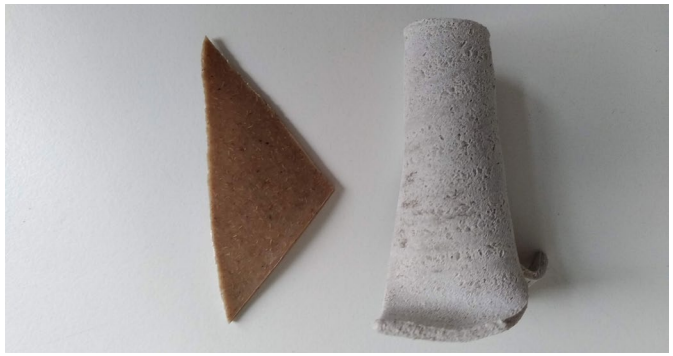


Figure 10. White scale after heating several times compared to a unheated piece.

Smell: the material has a very specific smell that is not good comparable to any other smell. Its scent can be smelled from about 10cm distance.

Fire: when the material is exposed to fire it quickly reacts by burning (figure 11). The smell was comparable with burning a normal plastic.

Figure11. Burned piece of material

Table 1. Material properties of the three Vibers granulates, PP and PLA.

Material	Granulate 1	Granulate 2	Granulate 3	PP	PLA
Official name	Vibers BP06022212IM en BP06022214IM	Vibers BP CTS0230 IM	Vibers BP CTS0233 IM	Polypropylene	Polylactide
Developed for	Injection Moulding[1]	Injection Moulding[2]	Injection moulding[3]	Both[4]	Both[4]
Bio-based carbon content		75%[2]	95%[3]		
Ingredients	Elephant grass, starch, PLA, Pbat[1]	Elephant grass, high temp PLA[2]	Elephant grass, bio PE[3]		
Maximum service temperature	50°C[1]	110°C [2]	n/a[3]	100 - 115°C[4]	43.9 - 56.9°C[4]
Costs per kg	€ 3.75[1]	€ 6.5[2]	€ 3.25[3]	€ 1.19 - 1.23[4]	€ 2.42 - 3.18[4]
Young's modulus	3000MPa[1]	3100MPa[2]	1845MPa[3]	896 - 1550MPa[4]	3310 - 4580MPa[4]
Tensile strength	32MPa[1]	47MPa[2]	26MPa[3]	27,6 - 41,4MPa[4]	47 - 70MPa[4]
Tensile stress at break	32MPa[1]	20MPa[2]	24MPa[3]		
Tensile strain at tensile strength		5,70%[2]	7,50%[3]		
Tensile strain at break	2.5%[1]	14%[2]	16%[3]		
Flexural modulus	3000MPa[1]		1745MPa[3]		
Flexual strength	55MPa[1]				
Flexual strain at break	3.0%[1]		No break[3]		
Flexual stress at 3,5% strain			25MPa[3]		
Notched impact strength		3.5kj/m^2 [2]	2.2kj/m^2 [3]		
Impact strength		38kj/m^2 [2]	36kj/m^2 [3]		
MFI (170*C/2,16kg)	10*g/10min[1]				
MFR (190*C/2,16kg)		25 - 30g/10min[2]	13 - 15g/10min[3]		
T melt	>150°C[1]	>155°C[2]	130 - 140°C[3]		
Density	1.25g/cm^3 [1]	1.37g/cm^3 [2]	1.07g/cm^3 [3]	0.89 - 0.91g/cm^3 [4]	1.24 - 1.27g/cm^3 [4]
Bio-based	Yes[1]	Yes[2]	Yes[3]	No[4]	Yes[4]
Biodegradable	Yes[1]	Yes[2]	No[3]	No[4]	Yes[4]

(1). (Vibers, 2020a)
(2). (Vibers, 2020b)
(3). (Vibers, 2020c)
(4). (Granta Design Limited, 2019)

2.2 Preferred material properties

If there was the freedom to change all material properties and design a 'perfect' bioplastic, how would this material look? The preferred material properties are determined by looking for the failure points of the current material in different applications.

The material properties of the preferred material will be based on the composition of granulate 2+ (figure 12) since this looks the most promising for a broad range of applications. This granulate is rather strong and stiff, and has a high maximum service temperature. The material will become rather brittle since the coupling agent is left out and more elephant grass is added. There could be applications in which this would be a benefit. However, this could also be a restriction in design freedom. For sustainability reasons that have to do with the durability of the product, many consumer products nowadays need a non-brittle material that can withstand an impact. Research can be done to add other toughening agents. It would be preferred to get a fracture toughness of about the same as PC and ABS, which is about $2{,}1*10^6$ MP√m(Granta Design Limited, 2019)

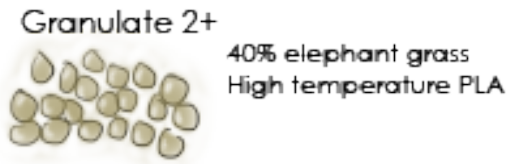


Figure12. Composition of granulate 2+.

2.3 Comparison of Vibers bioplastic with regular plastics and bioplastics

It is valuable to compare the Vibers granulate to regular plastics and other bio-based materials since materials with similar properties could have suitable examples of applications. The comparison is done with CES EduPack (Granta Design Limited, 2019). This programme has a database of many materials and their material properties. The properties of the Vibers granulates are added in order to compare it to other plastics. The materials are compared for their stiffness, maximum service temperature, tensile strength and density. The database 'Level 2 Sustainability' is used for its large amount of polymers and bioplastics.

Figure 13 to 16 show plots of the materials in CES EduPack, including the three Vibers granulates. A striking result is firstly the low maximum service temperature of granulate 1, which means that the material is deformable at a rather low temperature. This could give an interesting added value in a deformable product. However this could also be a difficult restriction while designing. Secondly, when looking at the strength and stiffness of the materials, granulate 3 is rather weak and flexible compared to other plastics. Granulate 1 and 2 are comparable with each other in terms of stiffness. They have a relatively high Young's modulus in comparison to other plastics. The tensile strength of granulate 1 and 3 are rather low compared to other plastics, and granulate 2 has a medium tensile strength compared to others. Table 2 shows an overview of the three granulates and a simplification to 'low', 'medium' and 'high' of the results of the comparison.

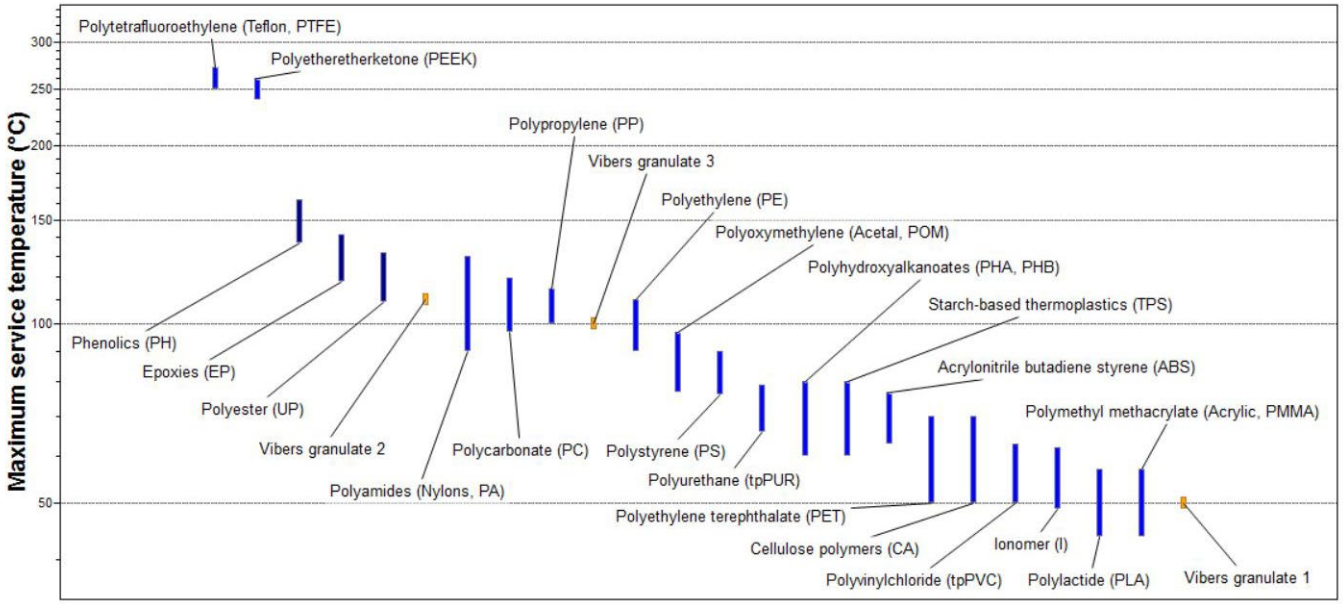


Figure 13. Maximum service temperature of the three Vibers granulates compared to other plastics

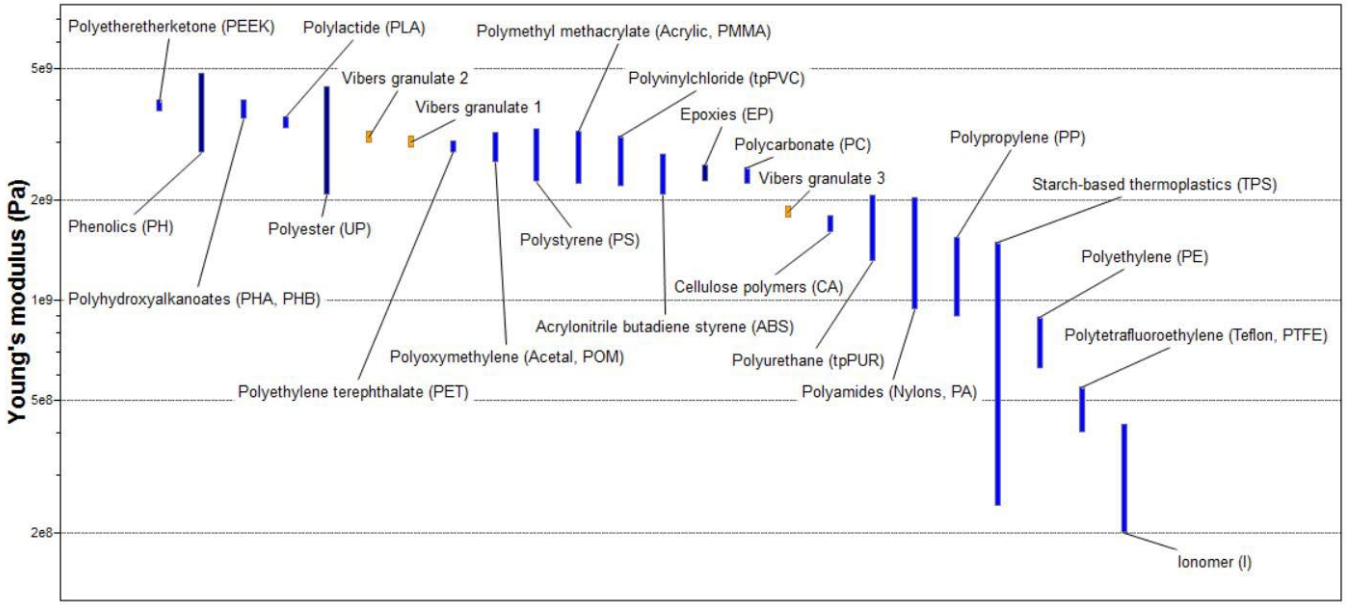


Figure 14. Young's modulus of the three Vibers granulates compared to other plastics

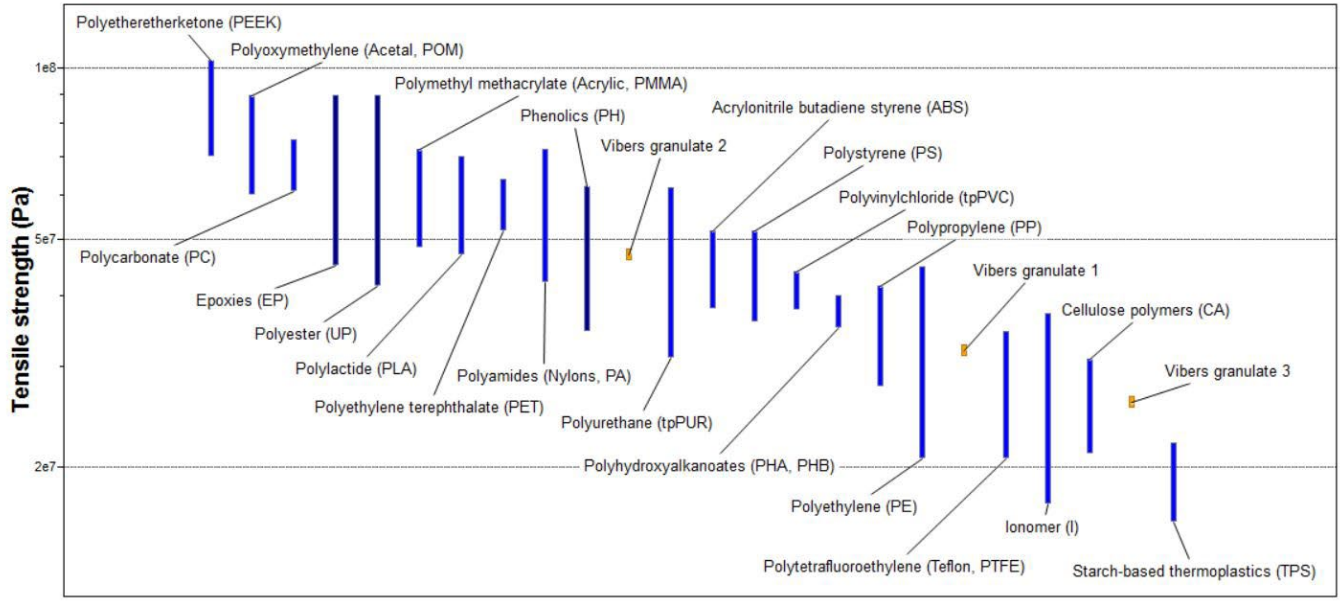


Figure 15. Tensile strength of the three Vibers granulates compared to other plastics

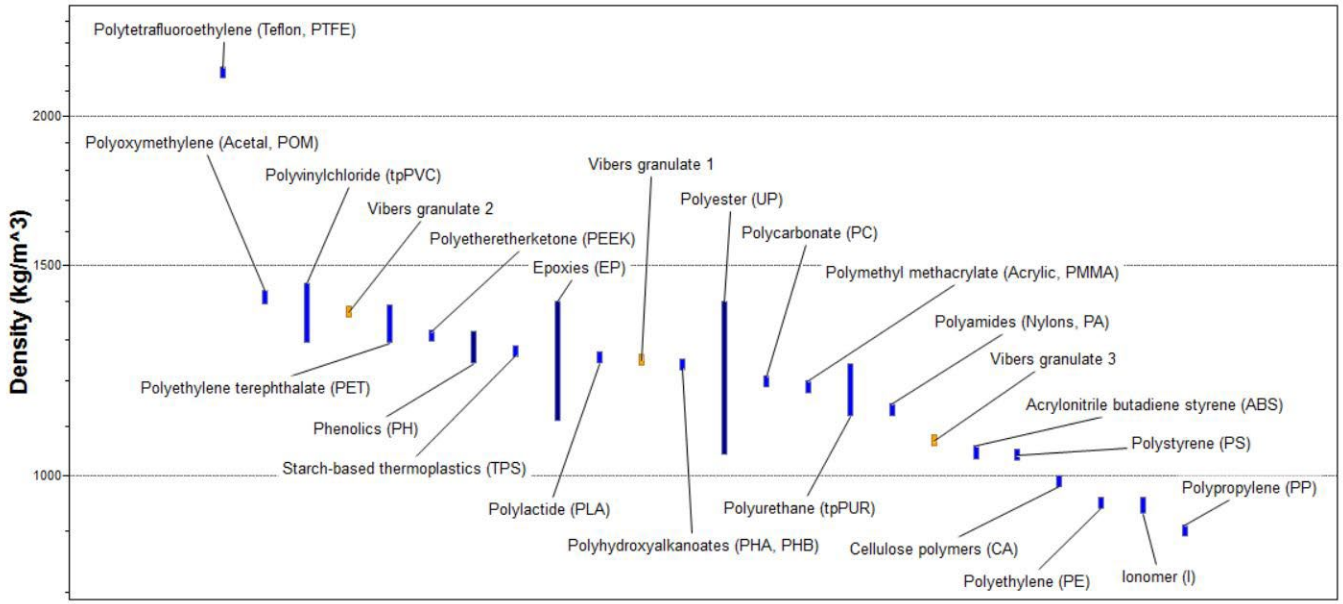


Figure 16. Density of the three Vibers granulates compared to other plastics

Table 2. Comparison of material properties of the three Vibers granulates with other plastics

	Granulate 1	**Granulate 2**	**Granulate 3**
Young's modulus	Medium	Medium	Low
Tensile strength	Low	Medium	Low
Density	Medium	High	Low
MST	Low	High	High
Price	High	Super high	High

Interesting about the comparison in CES EduPack, is that it is possible to find out as what plastic the Vibers granulates look like. Vibers bioplastic could then be used as a substitution. To find a perfect substitution fit, more material properties are needed to compare. However an estimation is done using the known material properties: tensile strength, Young's modulus and maximum service temperature.

Table 3 shows the materials that have comparable material properties. For all three granulates there is no plastic that has similarities in all three material properties. The most resemblance are found in PLA for granulate 1, PVC and PLA for granulate 2 and CA and PE for granulate 3.

Table 3. Comparison of material properties of the three Vibers granulates with other plastics

	Young's modulus	***Tensile strength***	***Maximum service temperature***
Granulate 1	UP, PET, POM, PS, PMMA, PVC, PLA	PTFE, I, PE, PP, PUR	PLA, PMMA, I
Granulate 2	UP, PET, POM, PS, PMMA, PVC, PLA	PUR, ABS, PVC, PA, PLA	PA, PC, PP
Granulate 3	CA, PUR, PA	CA, I PTFE, PE, PP	PE, PP, PC, PA

Legend
UP: Polyester
PET: Polyethylene terephthalate
POM: Polyoxymethylene
PS: Polystyrene
PMMA: Poly(methyl methacrylate)
PVC: Polyvinyl chloride
PTFE: Polytetrafluoroethylene / Teflon
I: Ionomer
PE:Polyethylene
PP: Polypropylene
PUR: Polyurethane
PLA: Polylactic acid / Polylactide
ABS: Acrylonitride butadiene styrene
PA: Polyamide
PC: Polycarbonate
CA: Cellulose polymers

VIBERS QUALITY:
- Elephant grass vibers adds stiffness to the material.

SECTION 3. USER EXPERIENCE

This section explores the experience people have regarding the material. A small user test is conducted in order to find the experiences with the material. The goal of this test was to find out how people perceive the material. Afterwards a preferred user experience is made-up in which the qualities are discussed.

3.1 User experience test

Test setup

The test is done with 10 participants, 4 male, 6 female. They were students from Delft University of Technology with different study backgrounds. The test took place at a table in a public space with sufficient light. The participants were shown a sample of the material, with a non recognisable shape. They first had some time to look at the material sample, and then they could touch it.

The participants were asked five questions about their experiences:
- What do you think of this material compared to other materials?
- How would you describe the material?
- Is there something about the material you like/ dislike?
- How does it smell?
- How does it sound?

Afterwards the participants needed to rate the material on the following aspects (Parisi, Rognoli, Sonneveld, 2017):

Hard	o o o o o	Soft
Smooth	o o o o o	Rough
Matt	o o o o o	Shiny
Reflective	o o o o o	Non reflective
Cold	o o o o o	Warm
Elastic	o o o o o	Non elastic
Transparent	o o o o o	Intransparent
Tough	o o o o o	Flexible
Strong	o o o o o	Weak
Light	o o o o o	Heavy

Results

The test results can be seen in appendix 2. With the result of the test, the questions from the paper about the Material Driven Design method (Karana et al., 2015) are answered:

- What are the unique sensorial qualities of the material?
Most users thought the material was very soft and smooth. 'I want it to become a usage object because I want to feel it.' - participant
Most users thought it had a sustainable appearance, due to the brown colour, the non-plastic appearance, the visible fibres and the natural look. It looked recycled, which therefore gave a positive impression.

- What are the most and the least pleasing sensorial qualities of the material (according to users)?
Most pleasing: it feels smooth, soft, matt, not sticky. It has a nice structure, not too smooth. It is light, strong but soft. The structure uneven. It doesn't look cheap. You won't throw it away after using it once.
Not pleasing: it is rather brittle and the edges are sharp.

- Is the material associated with any other material due to its similar aesthetics?
Mostly people that had no background information about the material were not sure about the material category it belongs to. Most of them didn't think it looked like plastic. Without touching, it had the appearance of cardboard or compressed paper. When touching the material they got confused since it was much stronger than cardboard.

- How do people describe this material? What kind of meanings does it evoke?
People described the material by its brown colour, the soft and smooth feel, and the fact that there are small 'pieces' in the material that you don't feel when you touch it. Terms as recycled, compostable, and biodegradable were used to describe the material.

- Does it elicit any particular emotions—such as surprise, love, hate, fear, relaxation, etc.?
During the interview people were mostly unsure since they were trying to figure out what kind of material it was. When after the interview they were told that it was bioplastic made from elephant grass, they were surprised, excited and interested.

- How do people interact and behave with the material?
No special interactions with the material were observed.

- Hoe does the material smell?
Most users had a hard time placing the smell. None of them thought the smell was bad. However one person wouldn't drink out of a cup made of this material, for that reason. Furthermore people thought it smelled musty and odd. Some thought of coffee or coffee biscuits. It did give an biological / sustainable feeling after smelling it.

Rating the material on the aspects of Parisi, Rognoli and Sonneveld (2017)*:*
The participants agreed on the following terms: the material is smooth, matt, non reflective, non elastic, intransparent and light. The other terms were rated in the middle, or had a big variety in ratings.

Conclusion

From the small user test is concluded that people don't immediately recognise the material as a plastic. It is however directly clear that it is a sustainable material. Terms as recycled, bio-based and compostable are used to describe the material. There are many sensorial qualities regarding the structure of the material.

3.2 Preferred user experience

A pleasing sensorial quality that the participants experienced was the brittleness of the material, which caused sharp edges after breaking the sample. When the material has a higher toughness, the material would feel less like it is possible to break in al brittle way.

A positive experience is that the material is not directly perceived as plastic. However for the recovery phase it would be valuable to already have some sort of feeling of how the material can be recycled. When an application is found, the material experience should be adjusted in a way that it is better visible how the material should be recycled.

The test participants thought the material smelled a bit weird and biological. For some applications this could be beneficial since it shows the consumer that it is a sustainable material. However in most of the applications the sustainability is already shown by its looks, and therefore it is preferred that the material has a natural smell.

VIBERS QUALITY
The quality of the Vibers material in terms of user experience, is the natural and sustainable look and feel to the material, which makes is directly clear that there is something special to the product.

SECTION 4. END-OF-LIFE

This chapter elaborates on the possible end-of-life scenarios for the Vibers bioplastic. Firstly the terms biodegradable, compostable, incineration and recycling are described, since those are often used in the wrong context. Afterwards the current end-of-life scenarios and the preferred end-of-life scenarios are drawn.

4.1 Clarifying end-of-life terms

Biodegradable

Only Vibers granulate 1 and 2 are biodegradable. "Biodegradable materials are materials that can be broken down by micro-organisms (bacteria or fungi) into water, naturally occurring gasses like carbon dioxide and methane, and biomass." (Van den Oever, Molenveld, Van der Zee & Bos, 2017) (figure 17). A biodegradable material will only degrade under specific conditions. This strongly depends on temperature, presence of micro-organisms, presence of oxygen and water (Van den Oever et al., 2017). It is not clear what those conditions are for the Vibers materials.

It should be avoided that the Vibers products end up in nature, since degrading mostly takes a long time. It will, just like other plastic products, contribute to 'the plastic soup'. However when the material accidentally does end up in nature, for example when it leaks out of the production system, it is less harmful than when this happens to a non-biodegradable material. Non-biodegradable plastics break down in micro plastics, meaning it gets more difficult to remove the plastic from nature. Vibers plastic eventually breaks down into CO_2 and water, that will then be used by plants in the ecosystem.

Compostable

"Composting is the accelerated degradation of heterogeneous organic matter by a mixed microbial population in a moist, warm, aerobic environment under controlled conditions." (Song, Murphy, Narvan & Davies, 2009) (figure 17). The process produces compost, water and CO_2. The European EN 13432 standard requires that compostable waste breaks down for at least 90% under industrial composting conditions within 12 weeks (Oaks, 2019). The Vibers plastics are not compostable because they are not able to break down this quick.

Incineration

"Incineration is a waste treatment technology, which includes the combustion of waste for recovering energy" (Waste management resources, n.d.) (figure 17). The high temperature process transforms waste into, among other things, heat that are later on used to generate energy from. When Vibers plastic is thrown into the regular waste bin, it will be incinerated, and energy can be recovered from it.

Recycling

"Recycling is the process for converting used materials in to new products for the prevention of producing waste" (Waste management resources, n.d.) (figure 17). This reduces the use of new materials and results in a reduction of energy and pollution of the environment. Vibers plastic can be recycled into the virgin material. However, recycling will only happen when the material is collected. As long as there is no collection system for Vibers plastic, the material can not be recycled.

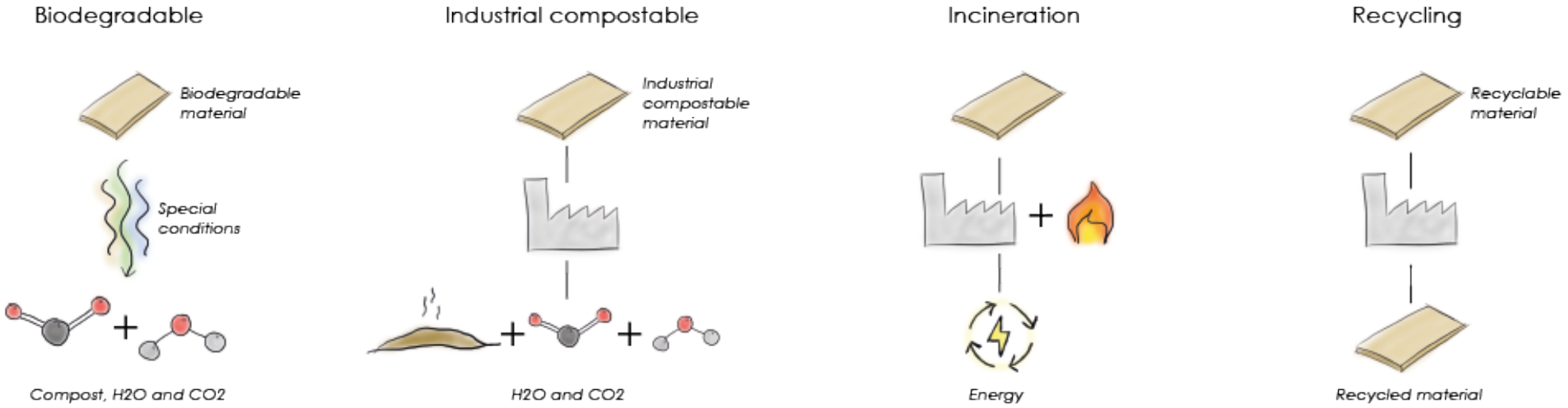


Figure 17. Explaining biodegradable, industrial compostable, incineration and recycling

4.2 Current end-of-life scenarios

The current end-of-life scenario is incineration. However, vibers bioplastic could be recycled into the same bioplastic. This can only happen when a collection system is designed in order to collect the products after use. The material can be shredded and used with the virgin material. Using recyclability in marketing a product should only happen when the collection stream is actually present. Otherwise the products can lead to confusion for the user, since the material has a sustainable look and is said to be biodegradable. Users misinterpret those terms, and many times think it is a compostable material. The dispose phase can therefore be confusing for users.

4.3 Preferred end-of-life scenarios

When looking from a sustainability perspective, the end-of-life scenario should be postponed as long as possible. In figure 18 the butterfly diagram (Ellen MacArthur Foundation, n.d.) is shown. This diagram shows how materials from a product can stay in a closed loop by applying maintenance, reusing, refurbishing or recycling. The closer the material stays to the user, the less negatively impactful it is to the environment. If we want to strive to a more sustainable world, incineration should be postponed as long as possible. Possible solutions for this would depend on the application area.

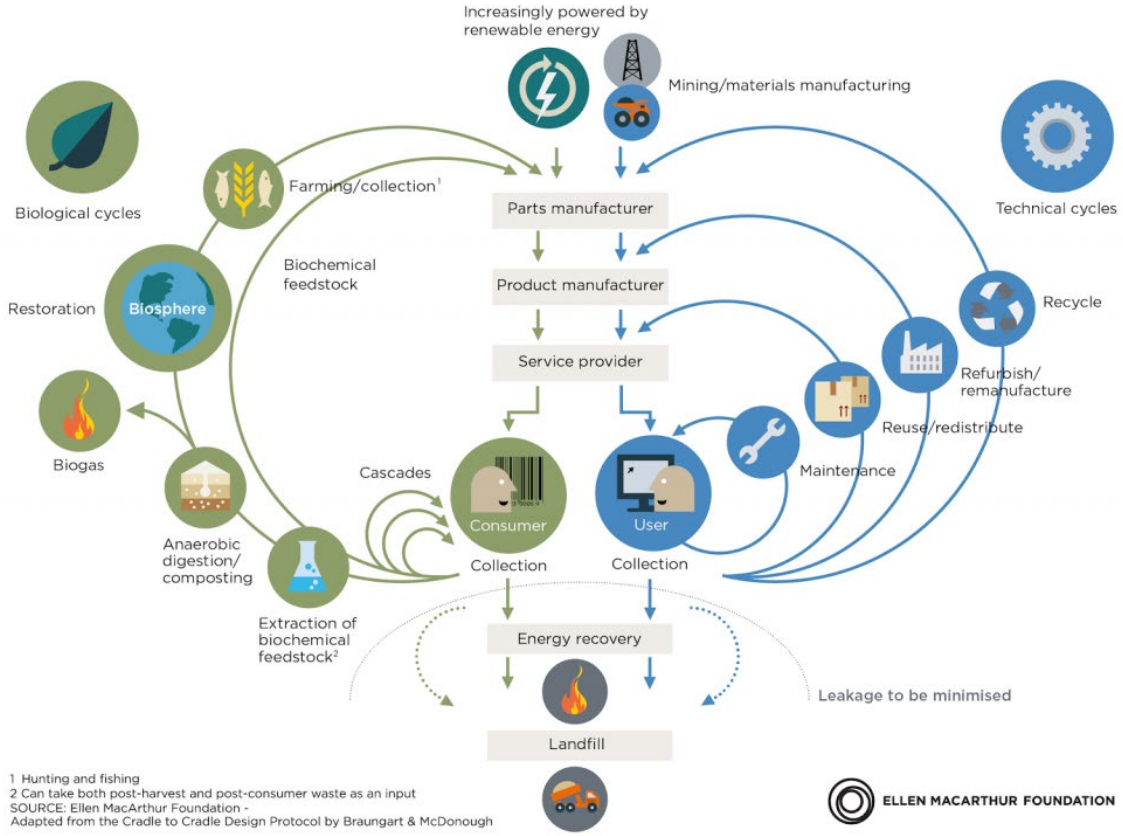


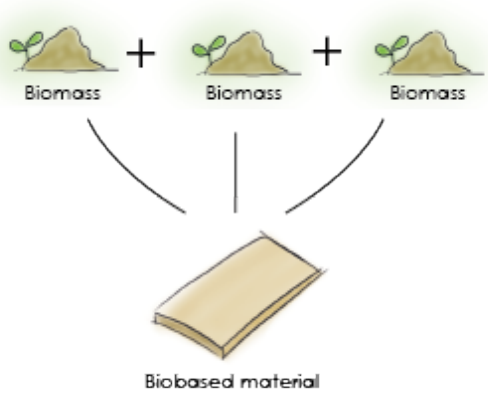
Figure18. Butterfly diagram (Ellen MacArthur Foundation, n.d.)

VIBERS QUALITY

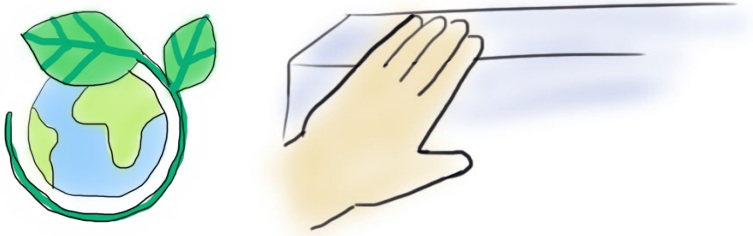
Two of the three Vibers granulates are biodegradable, which is handy for outdoor applications in which small pieces of material can end up in nature.

The material can be recycled, when a collection and recycling stream is designed.

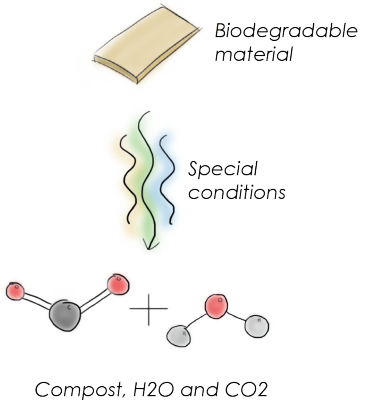
BIO-BASED



SUSTAINABLE FEEL



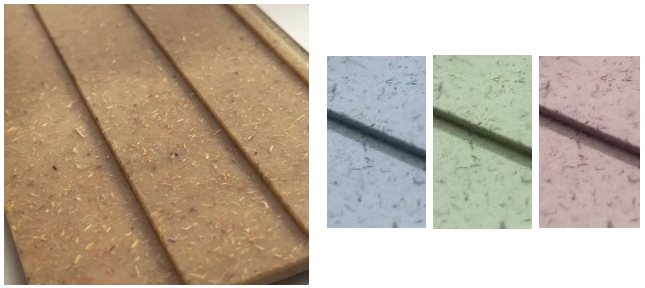
BIODEGRADABLE



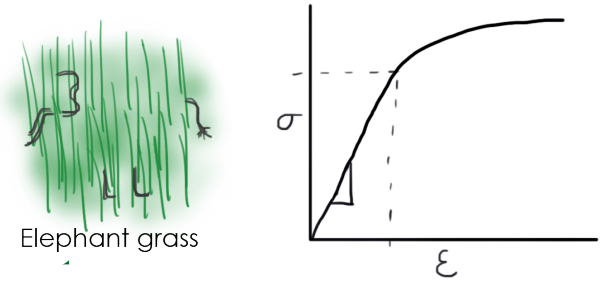
VIBERS UNIQUE QUALITIES

Summarising, Vibers plastic is a fully bio-based and biodegradable plastic. The elephant grass fibres the are used have captured a large amount of CO_2 from the air. Also they add stiffness to the material. It has a look and feel which is directly linked by users to a sustainable material.

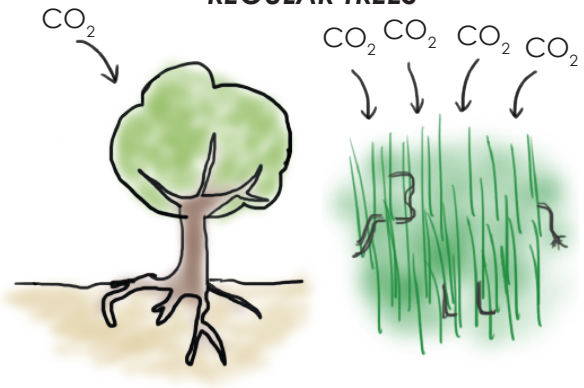
SUSTAINABLE LOOK



STIFFNESS BY ELEPHANT GRASS



4 TIMES AS HIGH CO2 ABSORPTION AS REGULAR TREES



SECTION 5. OPPORTUNITY FINDING

The unique qualities of Vibers material can be used to judge whether or not an application fits the material. In this section several creative brainstorm sessions are held in which ideas are found for applications with Vibers material. Afterwards the ideas are judged by the unique quality of Vibers plastic.

5.1 Creative sessions

Searching for applications was done by organising seven creative sessions on opportunity finding (figure 19), with experts on different sectors. To give structure to those sessions, different sectors were chosen. These topics are an outcome of an earlier individual brainstorm on which sectors could fit this material. Interesting in this method is that there is a possibility to let other people focus on the problem for a while, and the problem can be attacked from different angles. The focus during the sessions was on quantity rather than quality. The participants were instructed that non of their ideas were wrong. This gave a broad range of ideas for applications (appendix 3).

The sessions were as following:

Outcome of CES EduPack comparison: individual brainstorm sessions on my own
The applications that are found while doing the material comparison in CES EduPack (Granta Design Limited, 2019) in section 2.3, are used as a starting point for the first brainstorm session. The goal was to turn the list of applications into ideas.

Furniture sector: creative session with two people
The goal of this session was to find as many ideas as possible in the furniture section. The session plan was as follows: to get into the context, a flower association (Heijne & van der Meer, 2019) was done. Afterwards a quick energiser was performed to start the ideas flowing. Next was a brainstorm on sticky notes to generate as many ideas as possible. Halfway the brainstorm session it was showed how the material reacted to temperature changes.

Deformability with hot temperatures: creative session with four people
The deformability at a rather low temperature is something that could give an interesting added value to a product. In order to find out what product would fit this property, a creative session on this topic was held. The session plan was comparable to the session above.

How to find new products: creative session with seven people
Besides ideas for applications, it was also useful to find ideas on how to do application finding. The outcome of this session was less relevant for the pile of application ideas, but it gave information on how to find more ideas.

A walk through the plastic world: individual brainstorm session on my own
This brainstorm session was held while walking around in the city. While wearing the imaginable Vibers glasses, all products around had to be imagined in Vibers plastic. The goal was to find out which products would be able to exist in the real world.

Medical sector: creative session with three people
The creative session on applications in the medical sector is done with two students with a medical background. The set up of the session was comparable to the session about the furniture sector.

Automotive sector: creative session with three people
The automotive sector was explored during a creative session with three participants. Different aspects in the automotive sector were discussed, such as the production of cars, racing circuits, current transportation and futuristic transport possibilities.

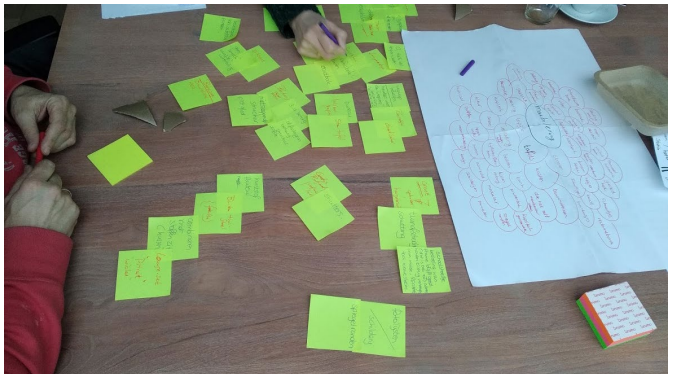
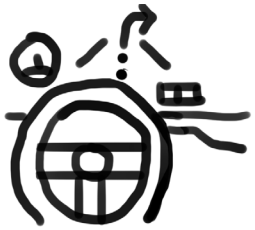


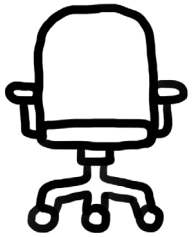
Figure19. Creative sessions

5.2 Judging ideas

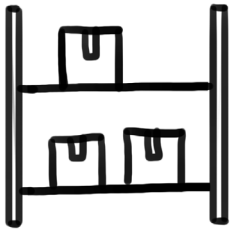
The ideas found in the creative brainstorm sessions are clustered into application areas (appendix 4 and 5). Those areas are judged on one requirement: 'does the unique quality (page 37) of the material add value to the application?' An application fits, when it benefits from all the unique qualities, and not just form a few of them. The judgement can be seen in table 4. The fitting application areas appeared to be:



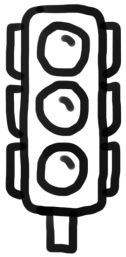
Car interior



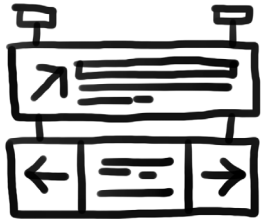
Office furniture



Shop furniture

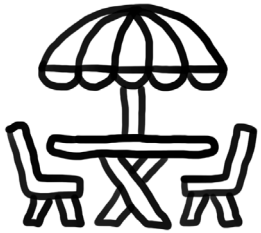


Street furniture



Signage boards

Accessories



Garden furniture

House decoration

Household products

Table 4. Judgement of the application areas on bio-based/ biodegradable and the sustainable look and feel.

Application areas	Bio-based and biodegradable	Sustainable look and feel
Beauty products	x	
Desktop products	x	
Electronic gadgets	x	
Crafting and do it yourself	x	
Household products	x	x
Storage products	x	
Decoration in house	x	x
Building material	x	
Furniture	x	x
Garden furniture	x	x
Street furniture	x	x
Shop furniture	x	x
Signage boards	x	x
Sports products	x	
Toys	x	
Medical appliances		
Fashion	x	x
Car interior	x	x
Model making	x	

5.3 Choice of application

In the next phase, the method Research through design is used to explore the material further by designing a concept product. The choice is made to design a veranda bench from the application area ‘garden furniture’. This is one of the application areas that fits the material when we look at adding value. Of the 10 fitting application areas, the garden furniture appeared to have the most conflicting requirements, like for example the requirement of being durable versus the requirement of standing outside for its lifetime. Those kind of conflicts lead to interesting design questions. Therefore this application is chosen to continue the project with.

PHASE 2. RESEARCH THROUGH DESIGN

The goal of this chapter is to learn more about the design possibilities of Vibers plastic and to find recommendations for the company Vibers. The method 'Research through design' is used to design two concepts of a veranda bench. Those concepts are designed for two different, most opposite situations so that the full width of design requirements can be explored. Those found requirements result in design questions on which the answers are needed in order to design with Vibers plastic.

SECTION 6. SITUATION SKETCHES

When using the method Research through design, it is highly important to keep in mind the goal of making those concepts, which is to learn more about the material, and not to design the best possible bench concept. In order to learn as much as possible, different design challenges are needed. Two concepts are designed in order to generate those different challenges.

Two situations of the use of a veranda bench are sketched in this section (figure 20). In the first situation the bench is designed to be durable, and to be used by the same person for at least 20 years. In situation two the bench is modular so that the looks can change every now and then. This bench will be a rental, and must be returned afterwards so that it can be refurbished or recycled. Firstly the boundary conditions for both benches are discussed. The requirements from the boundary conditions already result in design questions that need to be answered before designing with them. Next the two situations with their specific requirements are explained. The requirements that are found are also converted to design questions.

BOUNDARY CONDITIONS
Focus: mutual design requirements

SITUATION 1
Focus: durability

SITUATION 2
Focus: modularity and rental

Figure 20. The bench used for boundary conditions, and the design of the two benches in situation 1 and 2.

6.1 Boundary conditions for veranda bench

A veranda bench will initially stand in a veranda with much light and where it is protected from rain and wind (figure 21). The veranda itself forms a subtle transition between the garden and the living room. The bench can contribute to this transition by bringing the natural feeling inside. The bench can temporarily be moved to the garden when it is preferred to sit outside.

The following requirements are set as boundary conditions:

Mechanical
- The bench can withstand static vertical loads of 2,000N applied to the seating part.
- The backrest of the bench can withstand a horizontal load of 480N.
- The applied loads can form a deformation of maximum 25mm.
- The bench should not deform permanently.
- Fatigue cannot appear during the lifespan of the bench.

Weather
- The product should withstand UV light with wavelengths between 315-400nm.
- The product should withstand a temperature of 50°C.

Production
- The bench is made (partly) with Vibers plastic.
- The production techniques injection moulding or extrusion are used.

Measurements
- The measurements of the 'Kees Smit' bench in figure 22 are used for this bench (Kees Smit Tuinmeubelen, n.d.).

Figure 22. Measurements of 'Kees Smit' garden bench (Kees Smit Tuinmeubelen, n.d.).

Design questions
1. Which Vibers granulate should be used when designing applications like this?
2. How can a bench from Vibers plastic be strong enough to fit two people?
3. What is the resistance to outdoor conditions like UV, water and temperature differences of the Vibers material?
4. Are there problems that can be caused by fatigue while designing with this material?
5. Is it possible to use different percentages of elephant grass in an application?

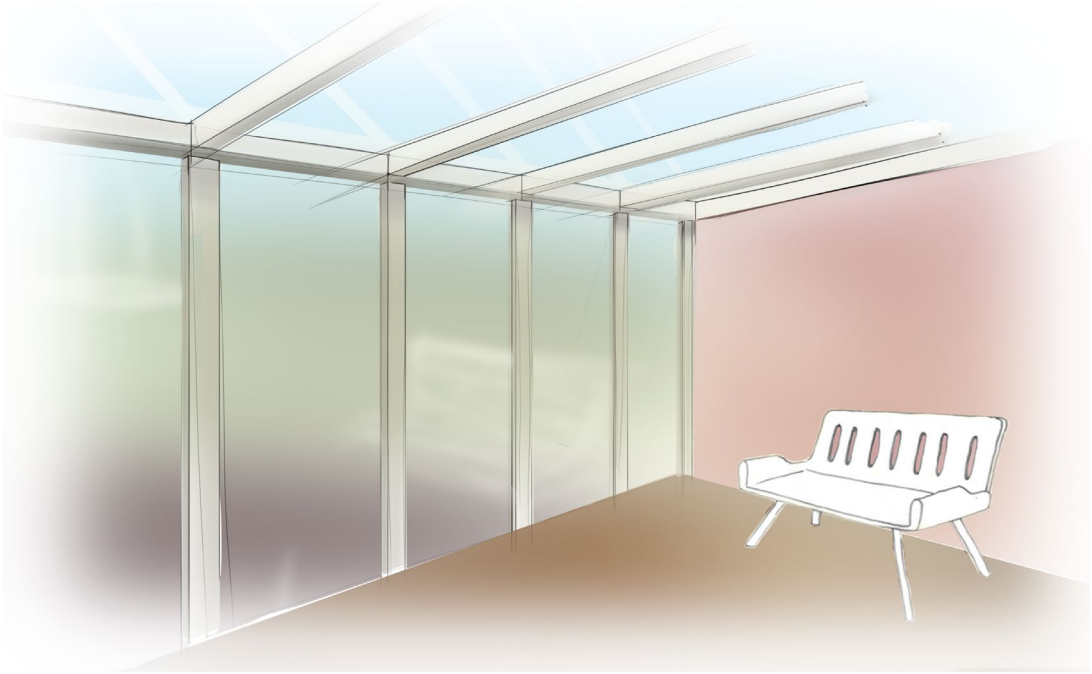


Figure 21. Situational sketch of the veranda bench

6.2 Situation 1: a durable bench

This concept design is focused on designing a durable veranda bench. It is designed to be bought by the user and should last for at least 20 years (figure 23). The material should withstand several weather conditions for when the bench is used in the garden. When the bench is broken, it should be repaired by the user. When the user wants to dispose the bench, it should be returned to the manufacturer so that the materials can be recycled.

The following requirements are set for the durable veranda bench:

Mechanical
- The bench should keep its strength for at least 20 years.
- The bench can be loaded with 2,000N on the seating.
- The backrest can be loaded with 460N.

Weather
- The bench can withstand rain and wind weather conditions.

Production
- The production method injection moulding is used.

User experience
- The bench can be repaired by the user.
- The bench has a timeless design.

End-of-life
- The bench can be recycled at end-of-life.
- The product should be returned to Vibers after use.

Design questions
1. What are the production guidelines for injection moulding with Vibers plastic?
2. Can the material be recycled, and how can you make sure the material is returned instead of disposed?
3. How can the bench be repaired, and can this be done by the user?
4. How can Vibers material be used in a timeless design?

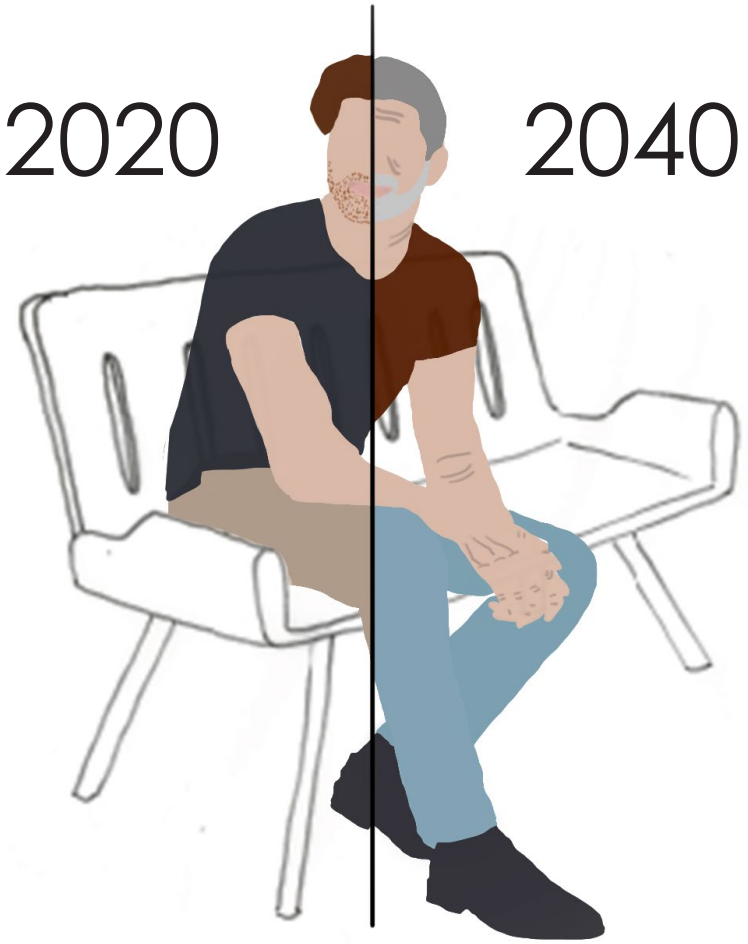


Figure 23. Situation 1. Bench in 2020 and 2040

6.3 Situation 2: a modular rental bench

In this concept the bench is designed to be modular and consists of a frame that carries the weight, and different seatings and backrests that can be attached. The bench is rented per month, and each month there is the possibility to redesign the bench by changing the modular parts (figure 24). The old parts are returned to the manufacturer to be refurbished. Because it is a rented bench, it is expected that people will act less gentle around it, by for example sitting with more than two people on the bench and sitting on the armrests. Unsubscribing from the rental subscription can be done every month. The bench will then be returned to the manufacturer.

The following requirements are set for the rented modular veranda bench:

Mechanical
- The bench is modular.
- The bench can be loaded with 3,000N on the seating .
- The backrest can be loaded with 720N.
- The armrest can be loaded with 800N.

Production
- The production method extrusion is used.

User experience
- The user can (dis)assemble the bench by himself.
- The bench can change to different designs.

End-of-life
- The bench can be refurbished when returned within six years.

Design questions
1. What are the production guidelines for extrusion with Vibers plastic?
2. How can the bench be refurbished?
3. How can a bench frame be designed with Vibers plastic?
4. How would a bench frame from Vibers plastic look like?
5. How can the bench be made modular?
6. What kind of connections can be made of Vibers plastic, and is it possible to let the user assemble those connections?

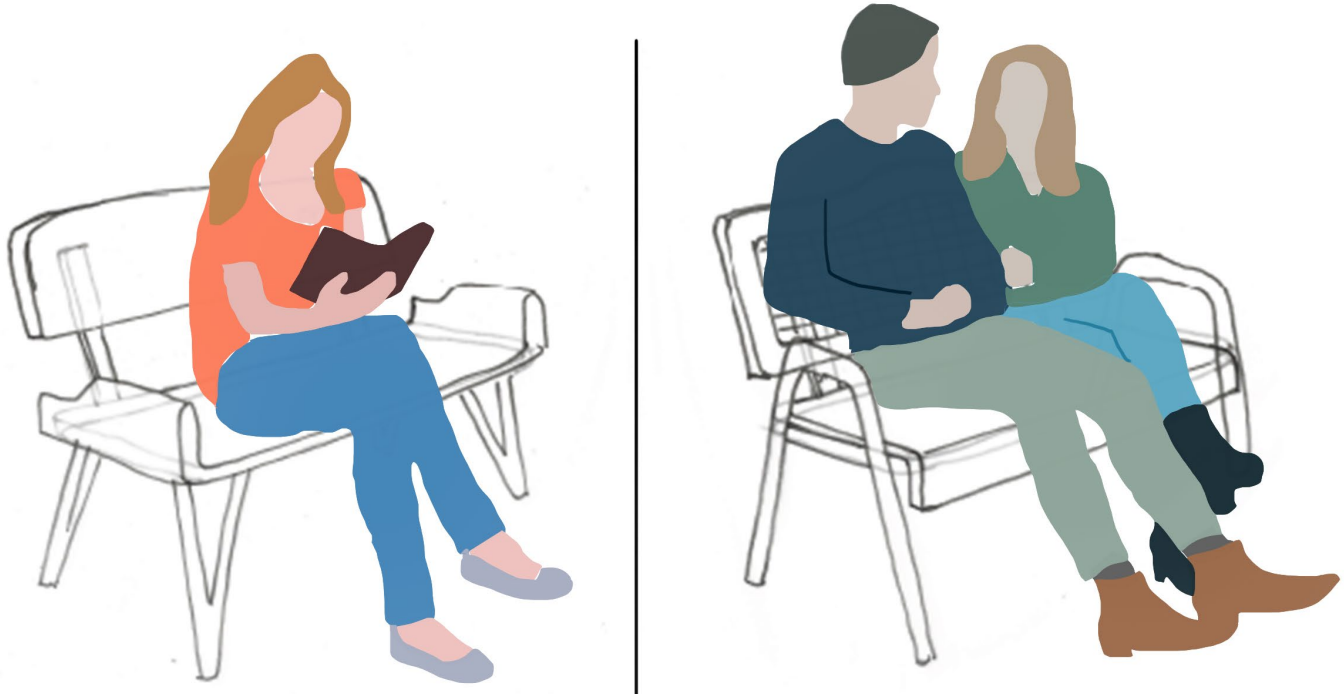


Figure 24. Situation 2. Modular bench

SECTION 7. BENCH DESIGN

This section describes the concept design of the two veranda benches. While designing those, the design questions from section 6 are answered. The elaborated answers can be found in section 8.

SITUATION 1
Focus: durability

SITUATION 2
Focus: modularity and rental

7.1 Bench design for situation 1

For the first situation, a durable bench is designed that lasts at least 20 years. While designing this bench, the design questions that were set in subsection 6 are answered. The elaborated answers on those questions can be found in section 8. An overview of the design process is shown in figure 25. The final bench design is shown in figure 26.

While designing this bench, there was a lot of design freedom since the situation and the material did not leave many requirements for the shape of the bench. The bench is completely made from the preferred granulate that is designed in phase 1. The material has a natural look, caused by the small elephant grass fibres inside. This look could be a perfect fit for the veranda bench since it helps bringing some nature into the veranda.

The bench is designed to be made with structural foam injection moulding (TSG), in which a gas is used to press the material to the walls, and therefore create a hollow part (VMT Products, n.d.). There are no special requirements for this process with this new plastic. A static and dynamic analysis has been executed to determine the thickness of the bench. Since the bench is not repairable, it is designed not to break.

A possible problem while designing this bench was the UV resistance. It is still doubtful what the exact influence of the sun and rain on the material will be. For designing this long lasting bench, more certainty is required. Therefore a protective coating is considered. Using this coating has the consequence that the material can not be recycled sufficiently. In this situation security is chosen, so the protective coating is added.

The conclusion is that this bench could last at least 20 years. However, it is also important to make sure the user doesn't get bored of it. Vibers plastic is fit for timeless design, so the timelessness is taken into account while designing the shape.

Figure 25. Sketches during the design process of the bench for situation 1.

Figure 26. The durable bench design

To conclude, it is possible to design a durable bench with this material that lasts at least 20 years. After this 20 years it will not be possible to recycle the bench completely since a UV resistant coating is used.

7.2 Bench design for situation 2

For the second situation, a modular bench is designed that can be rented by the user per month. While designing this bench, the design questions that were set in subsection 6 are answered. The elaborated answers on those questions can be found in section 8. An overview of the design process is shown in figure 27. The final bench design is shown in figure 28.

The bench is made with the preferred granulate that is designed in phase 1. The material has a natural look, caused by the small elephant grass fibres inside. This look is a perfect fit for the veranda bench since it helps bringing some nature inside.

All modular parts of the bench can be designed with Vibers plastic. The frame is designed for rental conditions, which means that a higher load can be applied than for the bench in situation 1. The frame is made of extruded parts that are connected with connection parts. Extrusion with this material causes extra strength in the beams due to the alignment of the fibres. The frame becomes rather thick, however still a reasonable design is made. The modular seating and backrest can be attached to the bench by the user, using snap fits. This makes it easy to let the user repair the bench when needed. Those snap fits are protected for excessive deflection by making the ribs rather small and adding less elephant grass to the backrest and the seating.

A possible problem while designing this bench was the UV resistance. It is still doubtful what the exact influence of the sun on the material will be. However from a UV test of 1,200 hours with thin samples of granulate 1, is concluded that no weight changes are made and the colour hasn't faded over time. Since this bench is rented, and the possibility of exchanging parts is present, the conclusion is made that for this bench, UV light won't be an issue.

Figure 27. Sketches during the design process of the bench for situation 2.

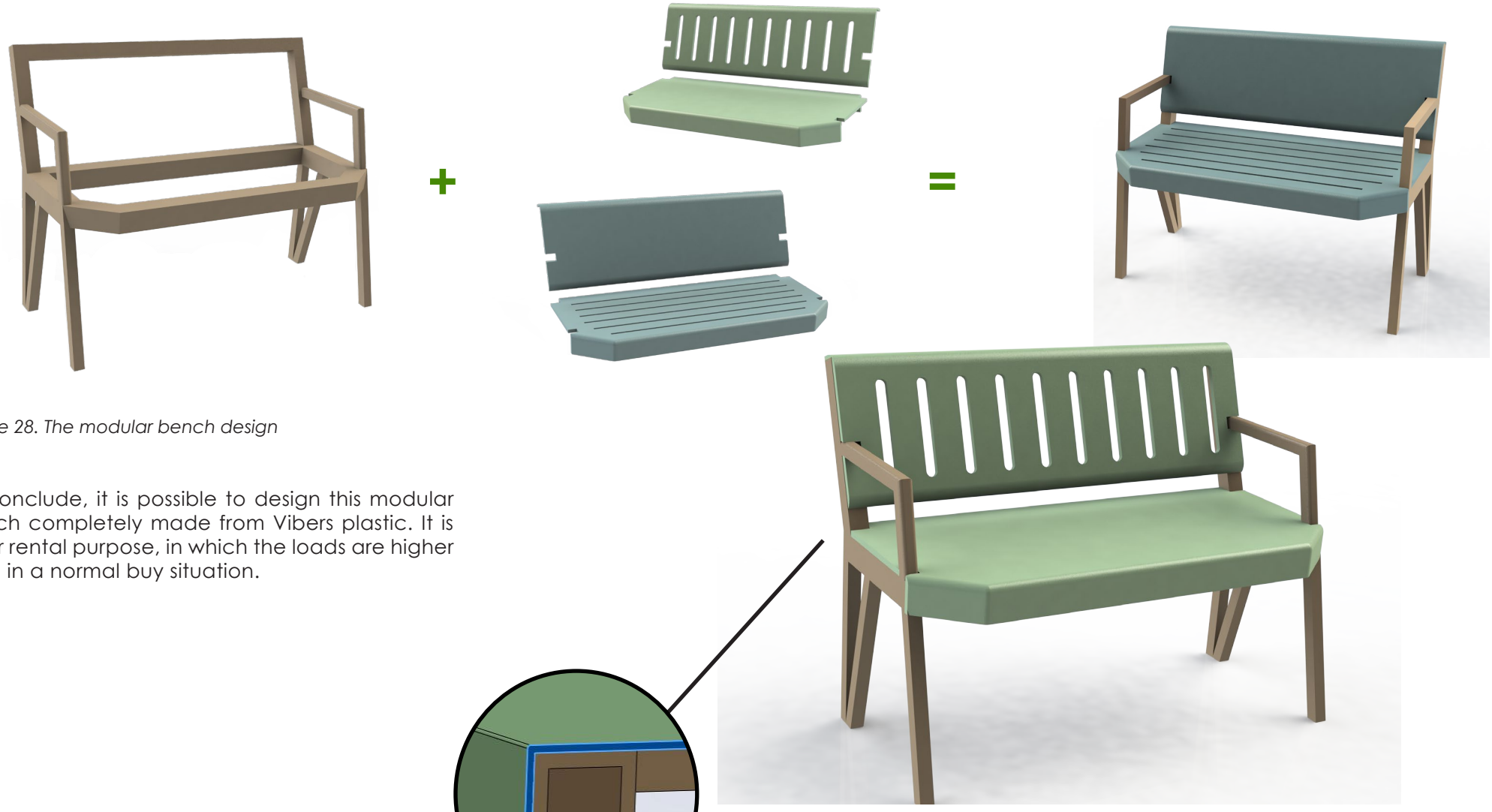


Figure 28. The modular bench design

To conclude, it is possible to design this modular bench completely made from Vibers plastic. It is fit for rental purpose, in which the loads are higher than in a normal buy situation.

SECTION 8. DESIGN QUESTIONS

The situation sketches of section 6 resulted in 14 design questions from which the answers were found during the design of the two veranda benches in section 7. Every design question is treated in this section with its own page. In the top right corner of each page is shown to which benches the question is applicable. The pages result with a conclusion on design guidelines for designing with Vibers plastic and/or a recommendation for Vibers.

The following design questions are answered:

8.1 What would be the material properties of the used Vibers granulate?

8.2 How can a bench from Vibers plastic be strong enough to fit two people?

8.3 What is the resistance to outdoor conditions like UV light, water and temperature differences?

8.4 Are there production guidelines for injection moulding and extrusion with Vibers plastic?

8.5 Are there problems that can be caused by fatigue while designing with this material?

8.6 Is it possible to use different percentages of elephant grass in an application?

8.7 Can the material be recycled, and how can be made sure the material is returned?

8.8 How can the bench be repaired, and can this be done by the user?

8.9 How can Vibers material be used in a timeless design?

8.10 How can the bench be refurbished?

8.11 How can a bench frame be designed with Vibers plastic?

8.12 What would a bench frame from Vibers plastic look like?

8.13 How can the bench be made modular?

8.14 What kind of connections can be made of Vibers plastic, and can the user assemble those?

8.1 What would be the material properties of the used Vibers granulate?

Vibers material has a natural look due to the brown colour and the visible fibres. It is expected that this appearance fits in well within a garden full of nature. When the purpose of this veranda bench is to connect the veranda with the garden, the material helps bringing nature inside. A downside of this rather 'camouflaging' material can be that the bench might not stand out as much as the user wants it to. This can be prevented by making a more exuberant design.

Section 1 to 4 are an exploration of the current Vibers granulates in which the Wishful thinking method is used to find out how the preferred Vibers material would look like. Now that an application is chosen, it is decided that such a desired material is useful, and the material properties for this can be specified (table 5).

The preferred granulate contains 40% elephant grass because of the extra strength and the high sustainability contribution of this material. Furthermore it consists PLA and potato starch, since the granulate must be free of non-bio-based ingredients. The maximum service temperature should be at least 70°C, so that it will not deform in hot sun. The Young's modulus is comparable to that of granulate 1 and 2, which is 3,000MPa. The preferred fracture toughness is around 3MPa√m, which is about the same as the fracture toughness of PLA (Granta Design Limited, 2019). This is important because the bench should not break brittle. At last, the material is biodegradable, so that wear off pieces from the bench, that end up in nature are not very harmful.

Table 5. Material properties of the three Vibers granulates and the preferred granulate

Material	Granulate 1	Granulate 2	Granulate 3	Preferred granulate
Official name	Vibers BP06022212IM en BP06022214IM	Vibers BP CTS0230 IM	Vibers BP CTS0233 IM	-
Ingredients	Elephant grass, starch, pla, coupling agent	Elephant grass, high temp PLA	Elephant grass, bio PE	40% Elephant grass, potato starch, PLA
Maximum service temperature	50°C	110°C	n/a	70°C
Costs per kg	€ 3.75	€ 6.5	€ 3.25	-
E-Modulus	3,000MPa	3,100MPa	1,845MPa	3,000MPa
Tensile strength	32MPa	47MPa	26MPa	30MPa
Tensile stress at break	32MPa	20MPa	24MPa	-
Tensile strain at tensile strength		5.70%	7.50%	-
Tensile strain at break	2.5%	14%	16%	-
Notched impact strength		3.5kJ/m²	2.2kJ/m²	-
Impact strength		38kJ/m²	36kJ/m²	-
Fracture toughness				3MPa√m
Density	1.25g/cm³	1.37g/cm³	1.07g/cm³	-
Bio-based	Yes	Yes	Yes	Yes
Biodegradable	Yes	Yes	No	Yes

HOW TO DESIGN WITH VIBERS PLASTIC
Make use of the material properties of the preferred granulate, but keep in mind that the material could be innovated when other properties are needed.

RECOMMENDATIONS FOR VIBERS
Explore this new preferred granulate.

8.2 How can a bench from Vibers plastic be strong enough to fit two people?

Load situation

Normal use: the maximum load on the bench is 2,000N. The load on the backrest is about 480N, derived from the article (Goossens, Snijders, Roelofs & Van Buchem, 2003). The maximum deflection in this situation can be 25mm.

Static load calculation

The effect of the static forces on the bench are calculated, so that the thickness of the material can be decided globally. A simplified version of a bench is drawn (figure 29). The needed moment of inertia is calculated to prevent buckling in the legs (formula 1) and to prevent the seating (formula 2) and backrest (formula 3) from deflecting more than 25mm (figure 30). The moment of inertia's are respectively 52,308mm^4, 960,000mm^4 and 207,650mm^4. Translating this to a bench structure, the legs could be hollow beams of 35x35mm with thickness of 3mm, the seating could be made out of beams of 65x65mm with thickness of 7mm and the backrest out of beams of 47x47mm with thickness of 4mm. A SolidWorks model is made to visualise those measurements (figure 31). The weight of the model is 17kg.

$$Pcr = \frac{\pi^2 \cdot E \cdot I}{(K \cdot L)^2}$$

Formula for 1

$$\varepsilon = \frac{P \cdot L^3}{48 \cdot E \cdot I}$$

Formula 2

$$\varepsilon = \frac{-P \cdot L^3}{3 \cdot E \cdot I}$$

Formula for 3

Dynamic load calculation

The deflection for the dynamic situation in which a person sits down on a bench is calculated. The velocity at moment of touching the bench is estimated to be 0.5m/s. The weight of the upper-body is about 62% of the bodyweight (Plagenhoef, Evans & Abdelnour, 1983), which is about 50kg. The following formula is used in which Δmax is the deflection of the bench:

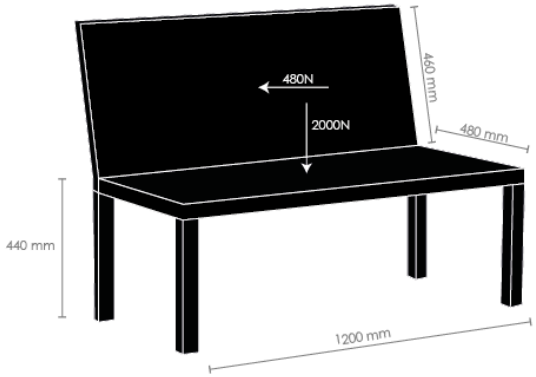


Figure 29. Simplified frame with forces and measurements

$$ExternalEnergy = InternalEnergy$$

$$W \cdot (h + \Delta max) = \frac{1}{2}\left(\frac{48 \cdot E \cdot I \cdot \Delta max}{L^3}\right) \cdot \Delta max$$

In this equation the gravitational acceleration is used instead of the seating velocity. To include the seating velocity, there is calculated at what height the velocity is 0.5m/s with the following formula:

$$PotentialEnergy = KineticEnergy$$

$$m \cdot g \cdot h = \frac{1}{2} \cdot m \cdot v^2$$

This height is used in the first equation to calculate the deflection for a bench with beams of 65x65mm with thickness of 7mm. The deflection appeared to be about 20mm, which is sufficient.

Pcr = critical load
E = Young's modulus
I = moment of inertia
K = buckling constant
L = length
ε = deflection
P = Load
W =Weight
h = height
Δmax = maximum deflection
m= mass
g = gravitational constant
v = velocity

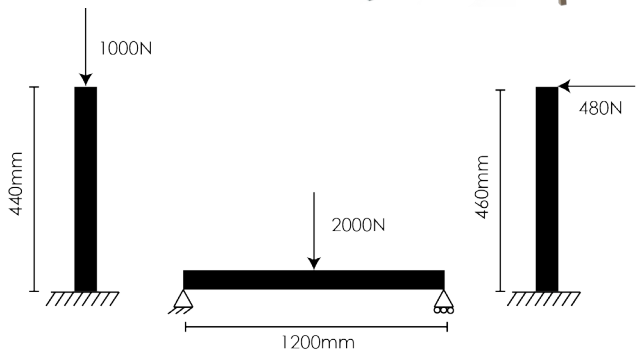


Figure 30. Visualisation of (1) buckling in the legs, (2) deflection in the seating and (3) deflection in the backrest.

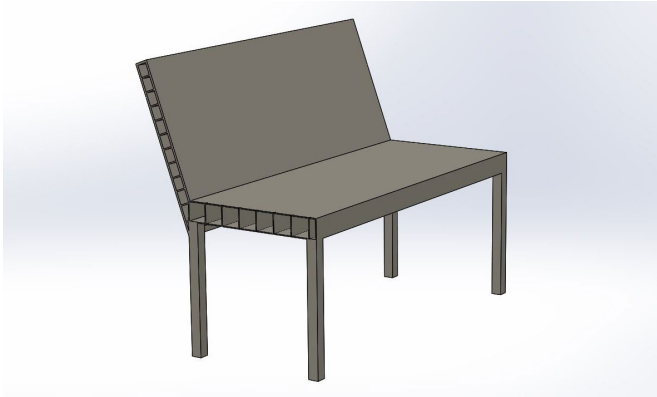


Figure 31. Construction of simplified bench in SolidWorks

HOW TO DESIGN WITH VIBERS PLASTIC

It is possible to design a bench that is strong enough for two people to sit on, based on the static and dynamic analysis that is done. A simplified bench would be rather robust and weights about 17kg.

RECOMMENDATIONS FOR VIBERS

The yield strength of the materials needs to be determined, in order to determine whether the material deforms plastically.

8.3 What is the resistance to outdoor conditions like UV, water and temperature differences?

Users might let the bench standing outside every now and then. Therefore, research is done on how the bench would react to sunlight, and if other weather conditions can cause damage. The question is answered by literature research and a UV test.

Weathering conditions of PLA

Since granulate 1 consists for a large part of PLA, the degradation process of PLA is examined. A paper on the effects of UV, temperature and humidity on the degradation of PLA is used to find information about the degradation process (Copinet, Bertrand, Govindin, Coma & Couturier, 2004). The conclusion about the changing mechanical properties is rather interesting for this research. It appeared that the PLA sample had a decrease of 50% of the elongation at break, it was observed after 15 weeks at 30°C and after 3 weeks at 45°C. The influence of UV light was that it has an enhancing effect on the degradation process (Copinet et al., 2004). In another paper the weather conditions of a PLA/Lignin composition is compared with PLA. Lignin is a natural glue that trees and grasses give their stiffness and flexibility (Wageningen University & Research, n.d.(a)). Accelerated weathering was executed at 30 °C and 60% humidity, artificial light of a mercury lamp with light intensity 39 mW cm^{-2}, for 600 hours. This paper concludes that adding Lignin to PLA results in a lower decrease of mechanical properties like Young's modulus and impact strength during the weathering test (Spiridon, Leluk, Resmerita & Darie, 2015) (figure 32). Elephant grass as well contains Lignin. Therefore it is expected that the Vibers granulate will degrade less fast than regular PLA. Both papers did not include information about how this accelerated weather conditions relate to a normal weather situation. Also the experiments are done with thin material films, for which the effects of weathering will be much higher than

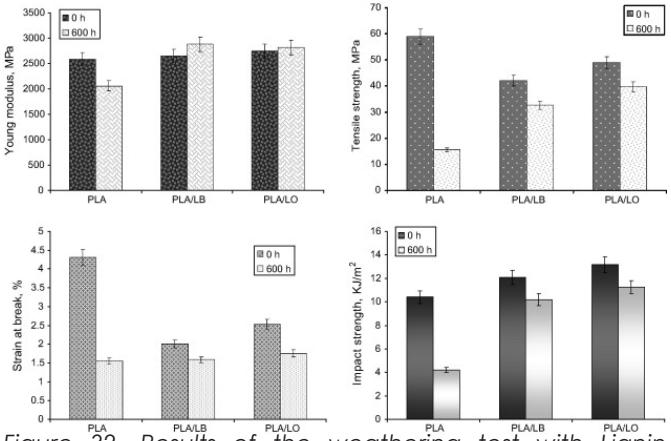


Figure 32. Results of the weathering test with Lignin (Spiridon, Leluk, Resmerita & Darie, 2015).

for a thicker material. Therefore no conclusion can be drawn yet about how long it takes until weather conditions have influence the strength and the looks of the bench.

UV test of Vibers granulate 1

Besides the literature research, a UV test is done with samples of Vibers granulate 1. Thin films are put under a UV lamp for 6 weeks. The UV lamp has a wavelength of 365nm, which means that its UV-A light. Light at this wavelength can go through glass, and causes discolouring of materials. Every week one sample is removed from the lamp and stored in a dark place. The weight of the samples is measured weekly. After 6 weeks the colour of the samples is compared (figure 33). The elaborated results of the test can be found in appendix 6. The conclusion of the test is that the weight of the material decreases when it is exposed to UV light. However, when the exposure to UV light is stopped, the weight increases again to about its original value. Furthermore the material does not fade colour when exposed to sunlight for a long time.

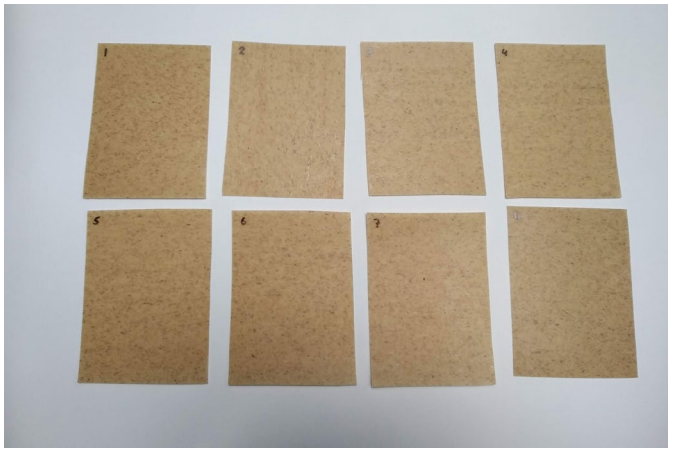


Figure 33. Comparison of the samples from the UV test.

When more security of UV and rain resistance is needed in a product, an option is to use a coating which protects the material against those conditions. However, this would negatively influence the recyclability of the material. A balanced choice should be made.

HOW TO DESIGN WITH VIBERS PLASTIC

From the UV test is concluded that the material won't discolour by UV-A light for 1200 hours.

When designing an application for outdoor use, a weathering test needs to be done.

RECOMMENDATIONS FOR VIBERS

Do a weathering test with Vibers plastic and examine how quick the material properties change. Recommended material properties to examine after weathering: tensile strength, Young's modulus, material looks, material feel.

8.4 Are there production guidelines for injection moulding and extrusion with Vibers plastic?

The bench will be designed for injection moulding or extrusion production methods. Research is done on how the basic plastic design rules can be applied to those production methods, using bioplastics instead of regular plastics.

Basic design rules for bioplastics
For designing an injection moulded or extruded product with bioplastics, many of the basic plastic design rules can be applied. Frederic Petit, CEO of Vibers, explained how the design rules for draft angles, sink marks and knit lines can one on one be applied in designing with bioplastics. Creep and shrinkage are different for every (bio)plastic, and should always be taken into account when designing a mould. This is especially important for precise connecting parts.

Alignment of the fibres
The Vibers bioplastics are filled with elephant grass fibres. When the material is machined, it is expected that this will cause alignment of the fibres in the flow direction. By comparing an aligned and a randomised composition structure in CES Edupack (Granta Design Limited, 2019), it is concluded that alignment of fibres will cause extra strength in the material in the flow direction. For extruded products the strength increases in the length of the profile. For injection moulded products it depends on the flow direction of the material.

HOW TO DESIGN WITH VIBERS PLASTIC
The basic plastic design rules for extrusion and injection moulding can be applied designing with Vibers material.

Extra strength is created in the flow direction due to alignment of the elephant grass fibres.

RECOMMENDATIONS FOR VIBERS
Do research on how big the difference in strength is for aligned vs. non-aligned fibres.

8.5 Are there problems that can be caused by fatigue while designing with this material?

When designing this bench, it is important to take fatigue into account. Fatigue is the phenomenon of weakening of a material caused by cyclic dynamic load. This dynamic load can be someone sitting down and standing up from the bench. Also fastening the modular parts from the bench in situation 2 can cause a dynamic load.

Fatigue of a material can be compared using the endurance limit. The endurance limit is related to the tensile strength. The book 'Materials' by Ashby, Shercliff and Cebon (2014) explains that for polymers the data clusters around the line: endurance limit=0,33*tensile strength. Figure 34 shows a plot of different plastics and their fatigue strength vs. tensile strength. The vertical orange line indicates the tensile strength of granulate 1. The diagonal orange line indicates the relationship between the two factors. The orange striped box indicates where granulate 1 would fit in the figure. The fatigue strength at 10^7 cycles would be about 11 MPa. This is the highest stress the material can withstand for 10^7 cycles without breaking.

The maximum stress in the seating area is 21MPa calculated with the formula:

$$\sigma = \frac{M \cdot Z}{I}$$

The fatigue strength is too low to be able to withstand 10^7 cycles. This is however a rather large amount of dynamic cycles, that would not be reached with this bench. It is therefore concluded that the fatigue strength is rather low compared to other plastics, and should therefore be taken very serious while designing. However there are chairs made from PP, which has about the same fatigue strength as Vibers plastic, so for now it is assumed that it will not be an issue.

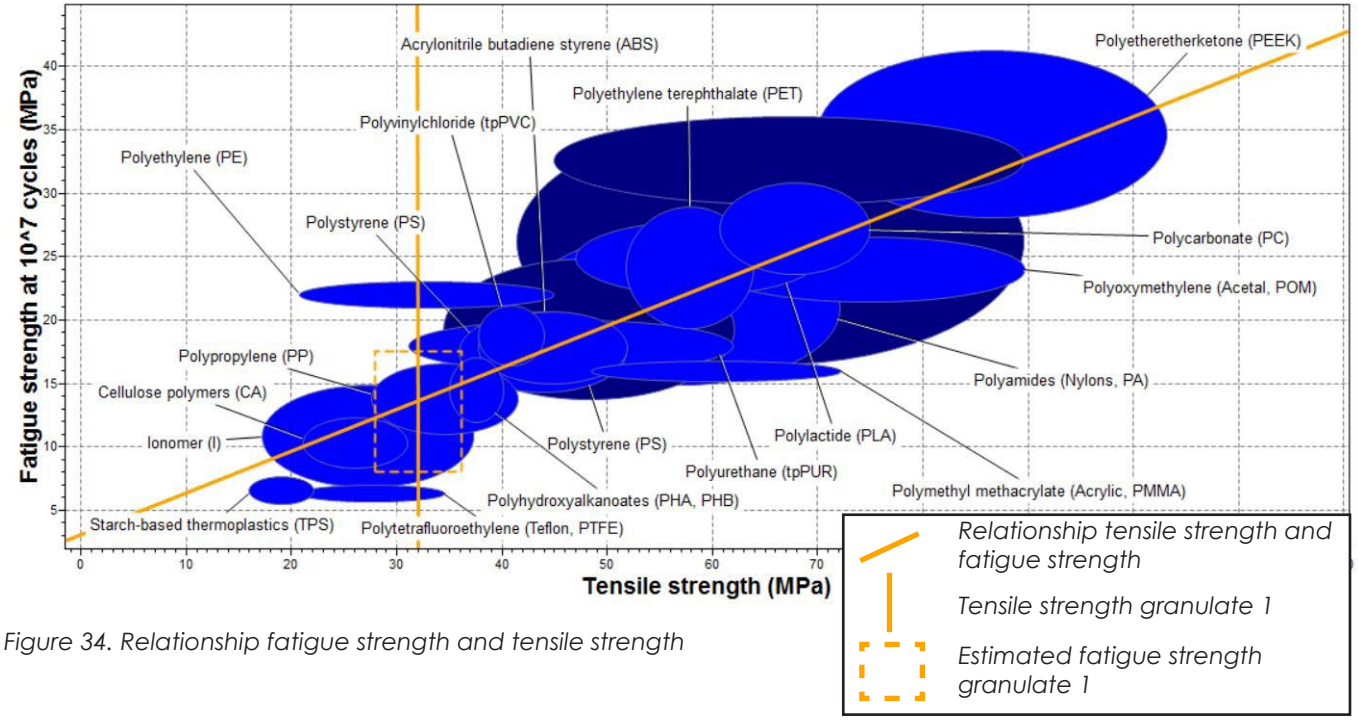


Figure 34. Relationship fatigue strength and tensile strength

HOW TO DESIGN WITH VIBERS PLASTIC

The fatigue strength of Vibers granulate 1 is about 11 MPa which is rather low. This should be taken seriously while designing

8.6 Is it possible to use different percentages of elephant grass in an application?

Using different percentages of elephant grass in an application could be interesting when different material properties are needed within an application. For the bench it could be useful when the backrest and seating are flexible so that it creates comfort, while the frame and the legs need more stiffness (figure 35).

For the current Vibers granulates it is not known how the mechanical properties change as a result to a varying percentage of elephant grass. In section 1.2 is predicted that a higher percentage of elephant grass would probably result in a lower tensile strength, a higher Young's modulus, a higher impact strength and equal thermal properties. If the predictions are correct, the material gains stiffness by adding elephant grass. It can be an option to have a higher amount of elephant grass in the frame to provide stiffness, and a lower amount of elephant grass in the backrest to provide comfort. In this situation the elephant grass differs per injection moulded part. Whether or not it is possible to inject two different granulates into one part, depends on the difference in preferred processing guidelines of both granulates. It is expected that the processing temperature differs for both granulates. This is something to research when the granulate is made.

Figure 35. Examples of frame-seat combinations in which the percentage of elephant grass of the frame could be different from the seating elements.

HOW TO DESIGN WITH VIBERS PLASTIC

Varying percentages of elephant grass within an application can be interesting since a higher percentage causes: lower tensile strength, higher Young's modulus, higher impact strength and equal thermal properties.

Varying percentages of elephant grass are possible in different parts. Whether this is possible within one part needs to be explored.

RECOMMENDATIONS FOR VIBERS

To confirm the conclusions, research on material properties need to be done for granulates with 10% to 40% of elephant grass.

In order to know if it is possible to inject two different granulates into one part, the processing guidelines for both granulates need to be known.

8.7 Can the material be recycled, and how can be made sure the material is returned?

As explained in section 4, the material can be recycled. However, there are some limitations, to this process. Firstly, the material can only be recycled into the same bioplastic, and not into the different materials this bioplastics exist of. Secondly, the material will not be recycled when it is thrown in the plastic recycling stream. The material needs to be collected and brought back to the manufacturing factory. Appendix 7 shows an exploration of several circular business models in which a bench is returned to the company. The business model for the bench in situation 1 is explained here (figure 36 and 37).

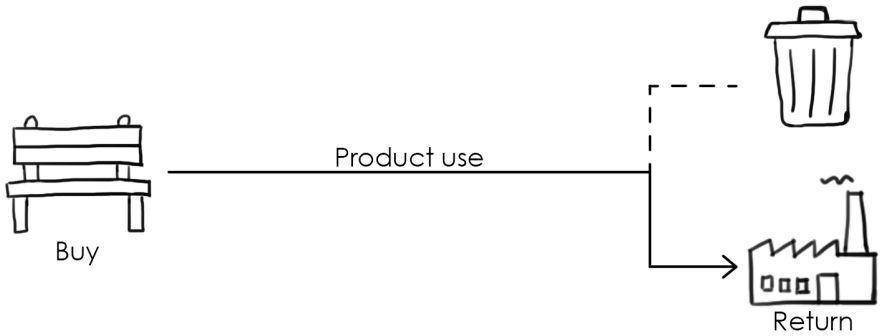


Figure 36. Business model of situation 1

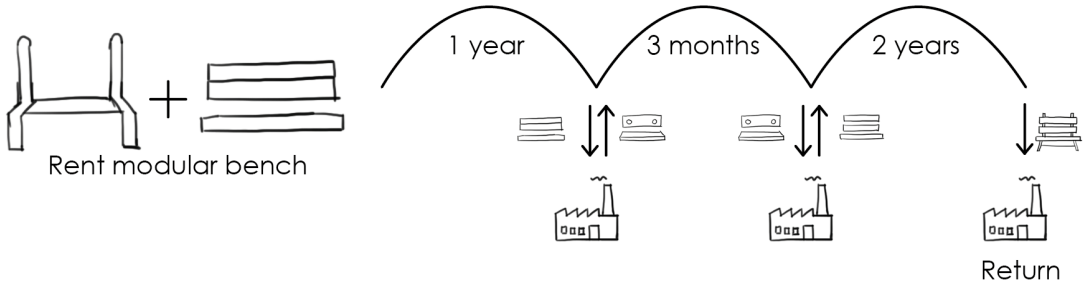


Figure 37. Business model of situation 2

In situation 1 the bench is designed to be as durable as possible, as the bench should last at least 20 years. After this long usage time, the bench should still be returned to the manufacturer, because the material can be recycled. In this situation the user needs to know the necessity of disposing the bench the right way, and he needs to feel the urge to actually do it. A quick brainstorm session is held on how to achieve this. The best option is to create a pick-up service in which the least effort of the user is needed. With just one phone call the pick-up service will come over to take back the bench. This take back service is communicated in a flyer when the bench is bought, and is explained shortly at the back of the bench.

At the manufacturing factory, a recycling stream needs to be added. In this stream the material is first cleaned and checked for unwanted additions. The checked material goes through a shredder after which the pieces are melted into new granulate. An interesting question is if partly degraded material can be recycled. For normal plastics this is not a big issue, so it is expected that this is also possible for bioplastics. When connections out of other materials are used in this product, those need to be removed from the shredded material. Screws and bolts can be removed with a magnet. Glue or coatings are not possible to remove, and the use of those should therefore be prevented.

HOW TO DESIGN WITH VIBERS PLASTIC
The material can be recycled. It is necessary that the material returns to the manufacturing factory. Examples of circular business models can be found in appendix 7.

RECOMMENDATIONS FOR VIBERS
Find out whether or not a partly degraded material can be recycled.

8.8 How can the bench be repaired, and can this be done by the user?

As explained in section 4, it is best for the environment when the material stays close to the user. The closest loop from the butterfly diagram is maintenance and repair. It is therefore explored whether a bench from Vibers plastic could be repaired.

In situation 2 it seems rather easy, since the bench is designed to be modular. A broken part can easily be replaced by ordering a new one. The replacement can be done by the user since reusable connections are used.

However, the bench in situation 1 is designed out of one injection moulded piece and the separate legs. In general, plastic is not repaired very often. There is the possibility to repair a tear by heating to the melting temperature in order to restore the connection between the molecules (figure 38). However this tear will continue to be a weak spot, and has a big chance of tearing again.

It is concluded that, besides replacing parts, the bench can not be repaired by the user. The bench should be designed well, so that it won't break at all.

Figure 38. Example of 'plastic welding'

HOW TO DESIGN WITH VIBERS PLASTIC
The material can not be repaired by the user.

The product should be designed not to break.

8.9 How can Vibers material be used in a timeless design?

For judging the material on timeless design, the 10 design rules for good (timeless) design from Dieter Rams are reviewed (Domingo, 2020). Most rules apply to the shape and function of the product. Just a few rules can be applied to the material.

The following design rules are discussed:

Good design is innovative
Even when the product would be just a bench, the Vibers plastic makes this bench an innovative product. With this rather new bio-based material it is safe to say that Vibers plastic is an innovative material that anticipates to the environmental impact of products.

Good design is honest
Although most information about this material is available to the users and therefore seems honest, the used terms like bio-based and biodegradable have many different understandings. The fact that the material looks sustainable, results in assumptions by users that might be wrong. It is therefore doubtful if this material contributes to a honest design.

Good design is long-lasting
This rule is focussed on not following trends or being a trendsetter. It is discussable if using bioplastics is a current trend to make just a small step towards a sustainable future, or if it is an innovative material that will replace regular plastics.

Good design is environmentally friendly
The material is environmentally friendly, and the design rules of designing with this material, will also be focussed on sustainability. Therefore this rule is achieved.

From those rules is concluded that the material is fit for making a timeless design. A weakness of this material is the assumption people make about sustainable materials. It is therefore important that terms like bio-based and biodegradable are better explained to users.

Figure 39. Timeless design furniture

HOW TO DESIGN WITH VIBERS PLASTIC
Vibers plastic is fit for timeless design. Take into account that people don't know what the right meaning of bio-based and biodegradable is. For a timeless design, honesty and clarity about those terms is needed.

RECOMMENDATIONS FOR VIBERS
Keep up with the innovations around bioplastic, in order to design a timeless material.

8.10 How can the bench be refurbished?

When the bench is returned to the manufacturer, it is decided whether the material is refurbished or recycled. In this section is described how the material can be refurbished.

Cleaning
When cleaning the bench, the water needs to be below 70°C so that the material won't deform. All purpose cleaner can be used to wash off dirt.

Testing
During the testing phase is evaluated if the bench is as strong as before. When it is, the bench can be refurbished. Otherwise it goes into the recycling stream. It is tested whether there are broken parts to the bench and how the material looks. A repairing plan is set up for during the next phase.

Repairing
The sun causes the material to fade colour. When repairing this by spray coating, the material cannot be recycled properly anymore. Therefore it is needed to add a new layer that can easily be removed. An option for this can be a fabric cover. It is therefore not possible to keep the Vibers look after refurbishing. When parts are broken, there is the possibility of melting the material back together using heat or friction. This leaves a significant scar which must be hidden. Besides the scar, the place of the crack will become a weak spot. If this spot is a critical load point, it will probably break again, and it would be best to recycle the bench.

Replacing
When the bench consists of multiple parts, it is possible to replace a broken part with a new or refurbished one.

Check
Another round of testing is done in order to check if the refurbishment is completed and successful.

It can be a difficult choice to decide whether you buy a new or a refurbished bench, since the concept of refurbishing is rather new. There are design strategies that change the experience of refurbished products and increase the acceptance of them (Mugge, 2017). For all strategies is discussed how those are applied in the design.

- Highlight the environmental benefit
This is something applicable to a bench design. The designer needs to be thoughtful of how and where to highlight this benefit. This can be done on the product itself, or in advertising.

- Make this environmental benefit more clear in the design
With the look and feel of the Vibers material, the bench already gives a sustainable look. It is important to embrace this property and to explain the user about the environmental benefits of refurbishing.

- Use packaging design as a cue for the environmental benefits
The packaging of the bench should have as less environmental impact as possible. Not just to give a cue to the user, but also to embrace the values of Vibers. The packaging could be left out, or Vibers paper or cardboard can be used as a sustainable solution.

- **Give information about product age, possible damages, how the product was used, and use intensity**
Some information about the bench is given to the user with a small info-graphic for every bench, which says what is done to refurbish the bench and a little background information is shown about how old the bench currently is.

HOW TO DESIGN WITH VIBERS PLASTIC
The colour faded material will be difficult to refurbish. Only a removable coating can be used so that it can be recycled afterwards (for example fabric).

Cuts could be repaired with heat or friction. However strength is lost and a scar will appear after repairing.

Use the design strategies of Mugge (2017) to increase acceptance for refurbished products.

8.11 How can a bench frame be designed with Vibers plastic?

Load situation

Rental use: the maximum load on the bench is 3000N. A load of 800N can be applied to the armrest. The load on the backrest is about 720N. The maximum deflection can be 25mm.

Static load calculation

The effect of static forces on the bench are calculated in order to decide the thickness of the material globally. A simple bench frame is drawn in figure 40. The needed moment of inertia is calculated to prevent (1) buckling in the legs and to prevent the (2) seating, (3) backrest and (4) armrest from deflecting more than 25mm (figure 41). The moment of inertia's are respectively 104,617mm^4, 1,440,000mm^4 and 346,083mm^4 and 24,576mm^4. Translating this to a bench structure, the legs could be hollow beams of 42x42mm with thickness of 4mm. The seating could be made out of beams of 70x70mm with a thickness of 10mm. The backrest can be made out of beams with 50x50mm with thickness of 7mm. The armrests can be made of beams with 30x30mm with thickness 3mm. A SolidWorks model is made to visualise those measurements (figure 42). The weight of the model is 15kg.

$$Pcr = \frac{\pi^2 \cdot E \cdot I}{(K \cdot L)^2}$$

Formula for (1)

$$\varepsilon = \frac{P \cdot L^3}{48 \cdot E \cdot I}$$

Formula for (2) and (4)

$$\varepsilon = \frac{-P \cdot L^3}{3 \cdot E \cdot I}$$

Formula for (3)

Dynamic load calculation

The deflection for the dynamic situation in which a person sits down on a bench is calculated. This is done in the same manner as in section 8.2. This thicker bench will deflect 15mm in the situation that someone sits down on the bench.

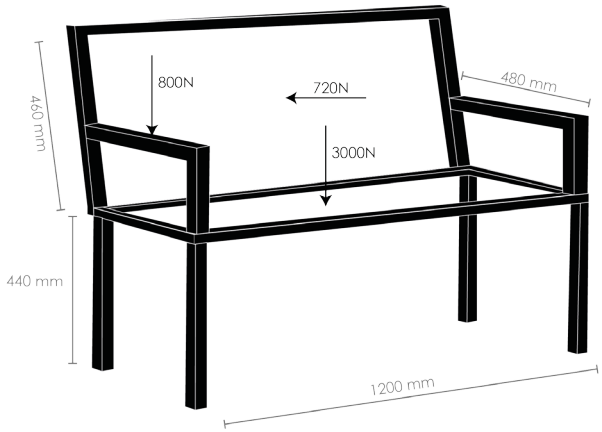


Figure 40. Simplified frame with forces and measurements

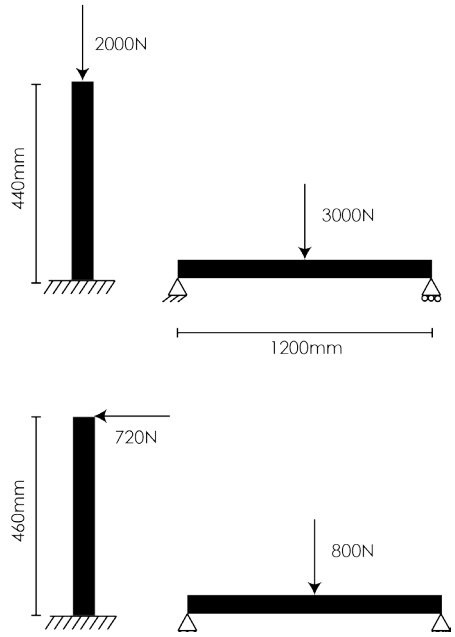


Figure 41. Visualisation of (1) buckling in the legs, (2) deflection in the seating (3) deflection in the backrest and (4) deflection in the armrest.

Figure 42. Construction of simplified frame in SolidWorks

HOW TO DESIGN WITH VIBERS PLASTIC

A reasonable bench frame, designed for rental conditions, could be made out of Vibers plastic, based on the static and dynamic analysis. The frame would weight about 15kg.

RECOMMENDATIONS FOR VIBERS

The yield strength needs to be determined, in order to determine whether the material deforms plastically.

8.12 What would a bench frame from Vibers plastic look like?

After determining that a frame could be made from Vibers plastic, the shape of this frame is designed. The measurements of section 8.11 are used to design a frame made out of extrusion profiles. The beams can be connected via connection parts as shown in figure 43.

An overview of the design process of the frame is shown on this page. There has been looked at ways to distribute the forces by splitting the legs in to two connection points to make the construction stiffer. SolidWorks simulations helped to review the strength of the model (figure 45). It appeared that it is necessary to attach the armrest to the backrest, to make sure the backrest is less flexible. The final shape of the frame and its measurements can be seen in figure 46.

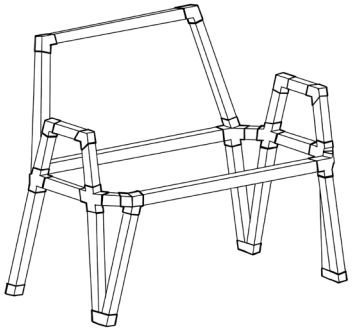


Figure 43. Frame with connection parts

Figure 44. Evolution in frame design

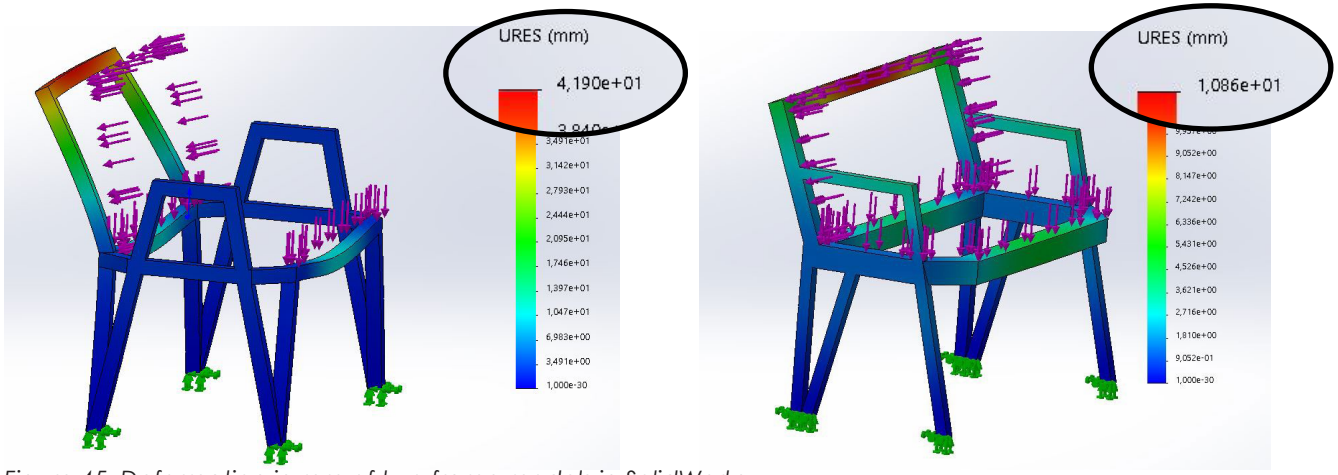


Figure 45. Deformation in mm of two frame models in SolidWorks

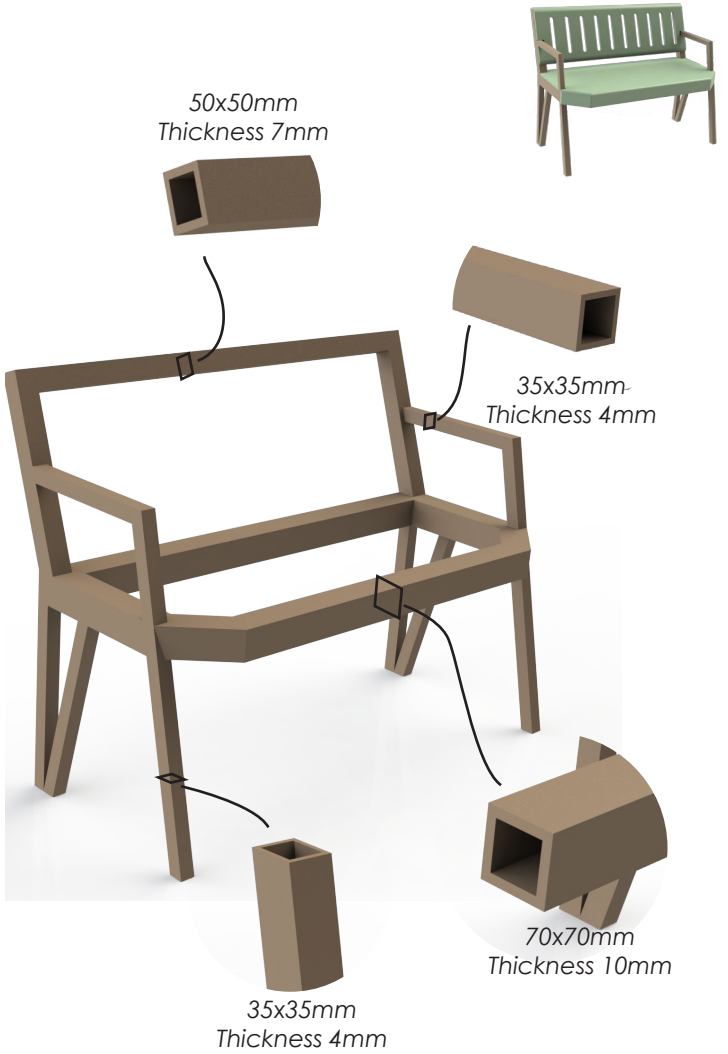


Figure 46. Shape of the frame and measurements of the beams

HOW TO DESIGN WITH VIBERS PLASTIC

The rather low Young's modulus of the material, compared to other plastics, causes the frame to be rather thick.

When designing a bench frame, attaching the armrest to the backrest causes more support which results in a less deformation in the backrest.

8.13 How can the bench be made modular?

The bench can be made modular by creating backrest and seating parts that are replaceable. In this section the parts are designed. In section 8.14 is shown how the parts are connected to the frame.

First, a simplified model of the backrest and the seating with a thickness of 5mm are made in SolidWorks in order to do a static analysis (figure 47). This analysis shows a maximum deformation of 18 mm for the backrest and 5 mm for the seating when it is loaded with respectively 720N and 3000N. From this analysis is concluded that a thickness of 5mm is sufficient for both parts.

Knowing the thickness of the material, the parts can be designed. An overview of the design process is shown on this page.

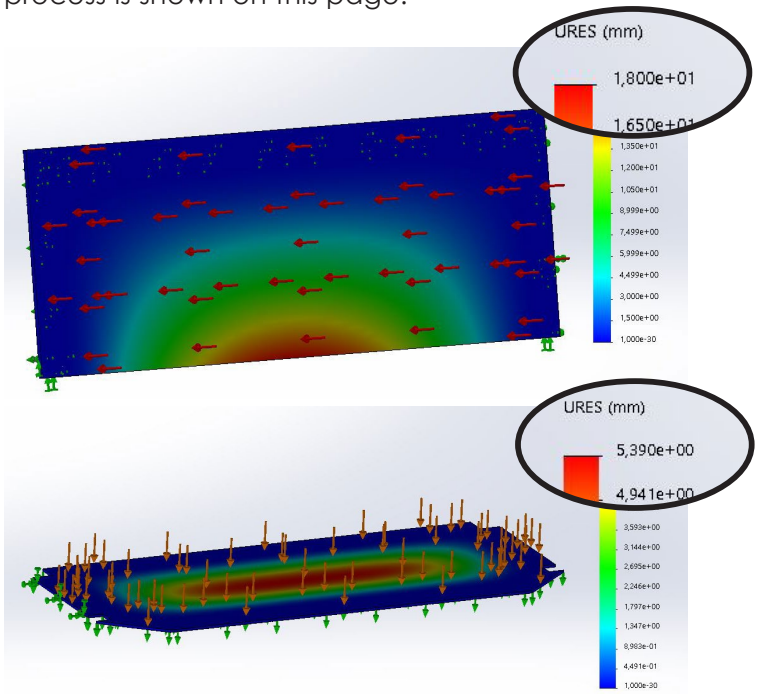


Figure 47. Deformation in mm of the backrest and seating in SolidWorks.

Figure 48. Overview of the design process

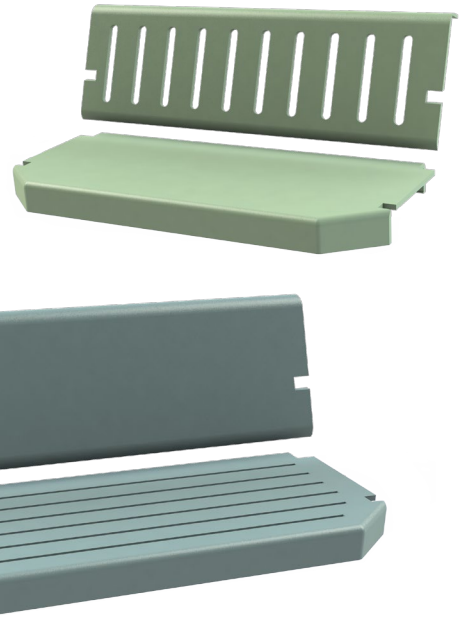


Figure 49. Final design of the modular parts

HOW TO DESIGN WITH VIBERS PLASTIC
The frame collects most of the forces. Therefore the modular parts can be rather thin.

8.14 What kind of connections can be made of Vibers plastic, and can the user assemble those?

The user needs to be able to change parts of the bench. Therefore the parts need to be designed for disassembly. Two basic design rules for design for disassembly are: To use as few parts as possible, and to use connectors that are easily unfastened (Güngör, 2006). The second rule is interesting to investigate, since the material properties can have influence on whether or not a connection type could work for this product. For the design of the backrest and seating, the snap fit connection is chosen to be investigated, because the brittleness of the material could give complications here.

A snap fit connection has a quick assembly time and is easy to disassemble since no special tools are needed. However, it is seen that the Vibers material is rather brittle, while the snap fit would need some flexibility to be opened. In the book 'The First Snap-Fit Handbook' (Bonenberger, 2016), a brittle material gets the so called 'red flag label'. This means that it is not impossible to design a snap fit, but extra attention is needed because failure risks are high. Snap fits from brittle materials should be protected against excessive deflection (Erhard, 2006). This could be done to create a barrier as seen in figure 50. Another possibility is to make the snap fit ribs very small which also makes sure excessive deflection is not possible. Lastly there is the possibility to add less elephant grass to the granulate which results in more flexibility (section 8.6).

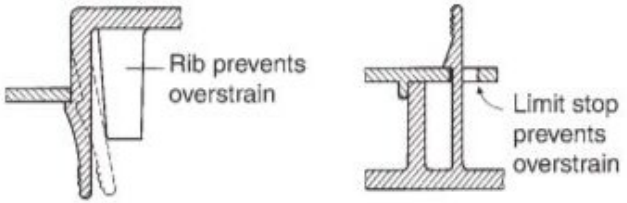


Figure 50. A barrier to protect the snap fit form excessive deflection (Erhard, 2006)

For the design of the backrest and seating, small ribs are added (figure 51) that keep the part in place. Those parts consist less elephant grass in order to keep the material more flexible. Tests need to be done to see how those ribs react during assembly. This visual is just a first estimation of how the snap fits could look like.

The modular parts can easily be assembled by the user, without the use of specific tools.

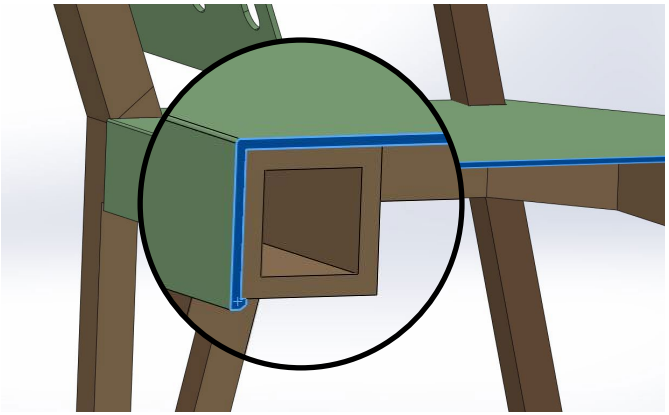


Figure 51. Snap fit connecting the seating to the frame

HOW TO DESIGN WITH VIBERS PLASTIC
Snap fits from Vibers plastic should be protected against excessive deflection by: (1) creating a barrier, (2) make the ribs small or (3) add less elephant grass to the granulate.

CONCLUSIONS

The conclusion of this research is split into two parts. Firstly, design guidelines, to be used by designers that want to use this material for their design. Secondly, recommendations for Vibers, which can help Vibers to improve their material and guide them to several application areas to invest in.

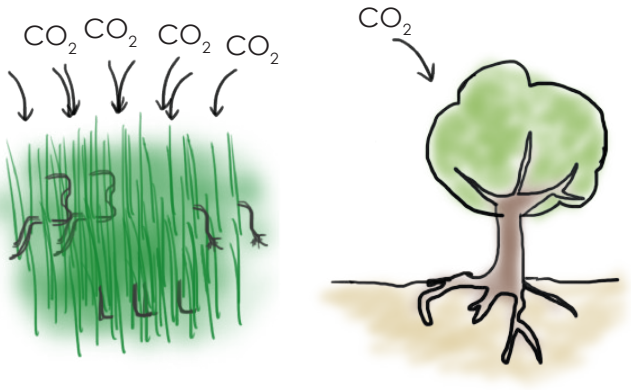
DESIGN GUIDELINES

Answering the design questions gives valuable information to designers who want to design with Vibers plastic. The possibilities and restrictions for this material are captured in the following design guidelines:

1. ADD VALUE TO THE PRODUCT

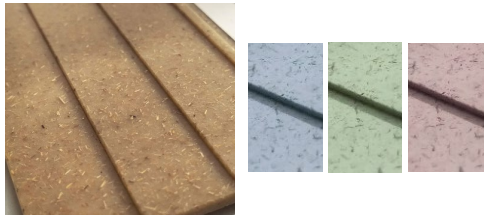
The material can add significant value to a product. The environmental benefits of the material in combination with its sustainable look and feel are the qualities that add value to the application. **Make sure to use those qualities.**

2. ENVIRONMENTAL BENEFITS



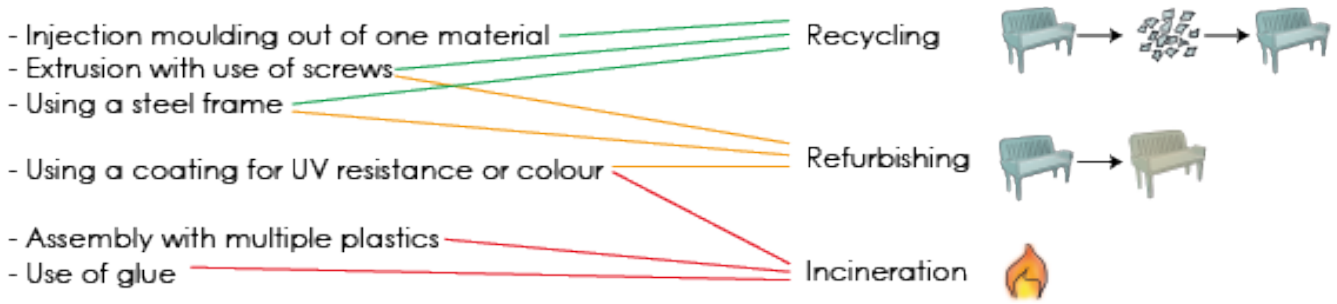
Elephant grass absorbs four times as much CO_2 per hectares as regular trees.

3. SUSTAINABLE LOOK AND FEEL



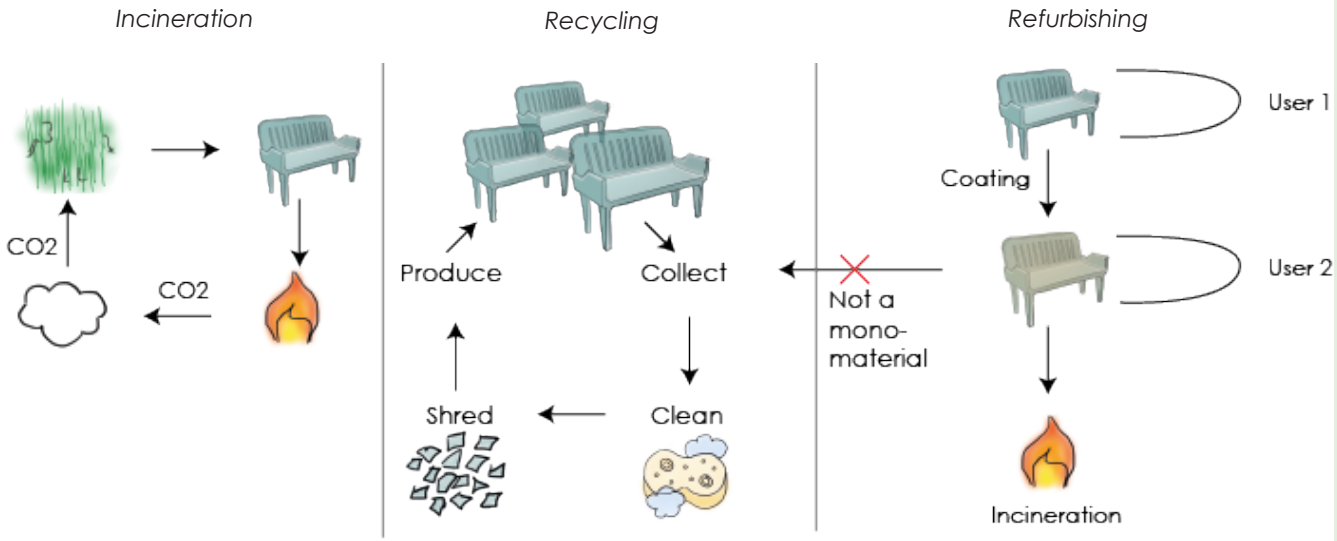
The user perceives the material as sustainable.

4. PRODUCTION DEPENDS ON DESIRED END-OF-LIFE



5. COMPARABLE TO

6. END OF LIFE POSSIBILITIES

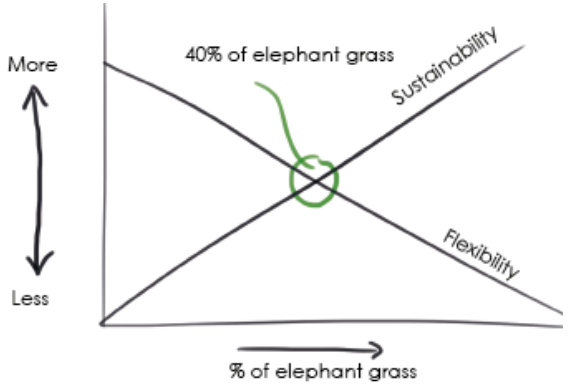


Since the bench is big and already rather clean, the recycling process is cheap. Only collecting the material will be an big investment.

7. UV RESISTANCE

Material colour does not seem to fade after being under UV lamp for 1200 hours. Test is performed with granulate 1.

8. ELEPHANT GRASS PERCENTAGE



A higher percentage of elephant grass makes the material more sustainable, but lowers the structural flexibility of the material. Per part can be decided how much flexibility is needed.

9. TIMELESS DESIGN

The material is suitable for designing a durable and timeless product.

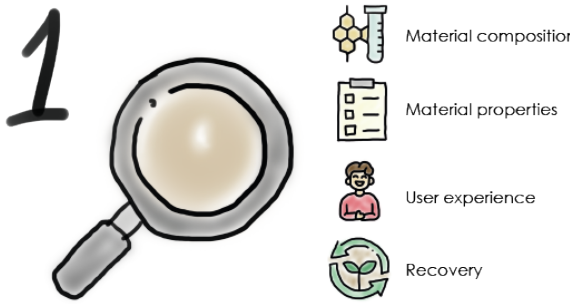
10. MODULAR DESIGN

The material is suitable for designing a modular product.

RECOMMENDATIONS FOR VIBERS

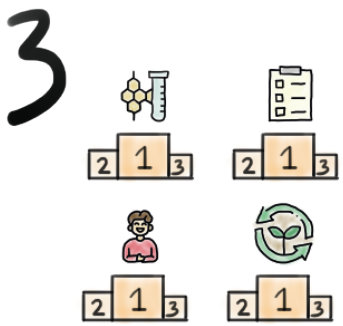
1. HOW TO EXPLORE A NEW MATERIAL

In the first phase of this research, a method is designed for exploring the unique quality of a new material. This unique quality is needed for choosing a fitting application area for this material.



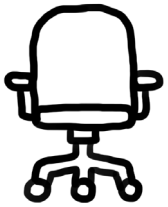
Analysis

Wishful thinking

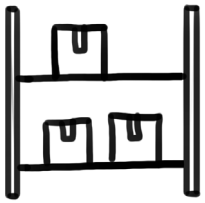


Quality of each section

Material's unique quality



Office furniture



Shop furniture

2. WHAT TO INVEST IN

The unique quality of your material is the combination between its environmentally friendliness and the sustainable look and feel. It is important that both aspects bring value to the product. The following application areas seem to fit well:

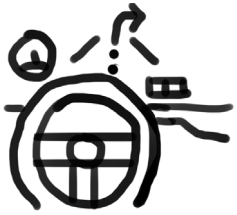
Accessories

Street furniture

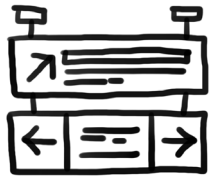
Garden furniture

House decoration

Household products



Car interior



Signage boards

3. TO DO LIST:

While designing the veranda bench, several design questions came up. Those questions are answered as far as time gave the opportunity. Questions that are still unanswered and require follow up research are discussed here:

- [ ] Find out whether or not a partly degraded material can be recycled, in order to know if an older product can be recycled as well.
- [ ] The yield strength needs to be determined, in order to determine whether the material deforms plastically.
- [ ] Do a weathering test with Vibers plastic and examine how quick the material properties change. You need to know this before investing in the garden furniture application area. Recommended properties to examine after weathering: tensile strength, yield strength, Young's modulus, material looks, and material feel.
- [ ] Research on material properties need to be done for granulates with consist of 10 to 40% of elephant grass. After this research is done, it might be possible to design a product with different percentages of elephant grass, depending on the required flexibility per part.
- [ ] Do research on how big the difference in strength is for aligned and non-aligned fibres. If this differs significantly, it should be communicated to the buyer.
- [ ] As far as we know now, it looks like the current material can be used in timeless design. However, time will tell whether or not this expectation is true. If you want a timeless material, you should keep up with the innovations around bioplastics.
- [ ] In order to know if it is possible to inject two different granulates into one part, the processing guidelines for granulates with different percentages of elephant grass need to be explored.

4. WRITER'S ADVICE

My opinion is that **transparency** is a key to a more sustainable world. Nowadays, sustainability has become a branding strategy. To make a packaging more attractive, advertisements are made that say a product is recyclable, biodegradable or even reusable. People interpret those words with a positive effect on the environment. Sadly, most plastic packagings end up to be incinerated, biodegradable doesn't mean it suddenly disappears when ending up in nature, and the packaging will not at all be actually reused.

It has become rather difficult for people to 'do the right thing' for the environment, since there are many misleading terms that are used in different contexts. I think it is important to, as a company, take the responsibility for the effects of your product, and explain to the user where the product truly comes from and where it ends up after they use it. I was happy to find out that Vibers is careful not to throw the recyclability and biodegradability aspect at their buyers carelessly. Instead, they explain how this could be an advantage, but also how this leads to confusion for users. However, advertising with 'a product made from elephant grass' makes the user think the product is completely made with this material, which it is not... yet.

When you reach this 40%, please celebrate this, and advertise it everywhere you can, because that is something to be very proud of. Until then, stick to advertising with a elephant grass + PLA combination, and explain how buying this material leads to future sustainability.

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Appendix 1. Presentation poster

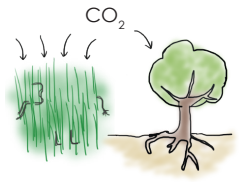
designing with vibers bioplastic

Design guidelines for designing with the elephant grass based bioplastic from Vibers

1. ADD VALUE TO THE PRODUCT

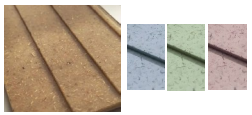
The material can add significant value to a product. The environmental benefits of the material in combination with its sustainable look and feel are the qualities that add value to the application. **Make sure to use those qualities in your design.**

Sustainable



Elephant grass absorbs four times as much CO_2 per hectares as regular trees.

Look & feel

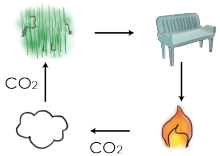


The user perceives the material as sustainable.

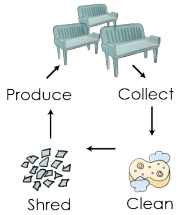
2. DESIGN THE END-OF-LIFE SCENARIO

Do not forget to design the end-of-life scenario for your product. Vibers bioplastic can be incinerated, recycled or refurbished. **Be aware that for recycling or refurbishing, a collection system needs to be established**. Since the bench is big and already rather clean, the recycling process is cheap. Only collecting the material will be a big investment.

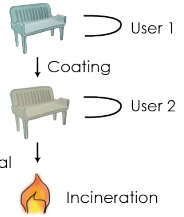
Incineration



Recycling



Refurbishing

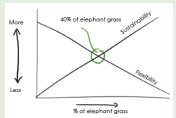


Durable bench

Modular bench

3. FIT FOR DURABLE AND MODULAR DESIGN

The material is fit for designing durable and modular products. The material does not fade colour when exposed to UV light. **Different percentages of elephant grass** can be used to change the structural flexibility of the material.



Romy Zwetsloot
Designing with elephant grass based bioplastic
09-07-2020
Integrated Product Design

Committee Ruud Balkenende
Martien Bakker

Company Vibers

TU Delft

Faculty of Industrial Design Engineering

Delft University of Technology

Appendix 2. Results and notes of user test

Participant	1	2	3	4	5	6	7	8	9	Average	Range
Hard(1)/soft(5)	3	2	3	2	2	3	2	1	2	2,2	1 to 3
Smooth(1)/rough(5)	2	1	1	1	1	1	2	1	1	1,2	1 to 2
Mat(1)/shiny(5)	4	1	1	1	1	2	1	2	4	1,9	1 to 4
Reflective(1)/non reflective(5)	4	3	5	4	5	5	5	4	2	4,1	2 to 5
Cold(1)/warm(5)	4	4	3	3	3	4	4	4	4	3,7	3 to 4
Elastic(1)/non elastic(5)	4	5	5	4	4	3	5	5	4	4,3	3 to 5
Transparent(1)/ intransparent(5)	5	4	5	4	5	5	5	5	5	4,8	4 to 5
Tough(1)/flexible(5)	4	2	4	2	4	2	2	2	4	2,9	2 to 4
Strong(1)/weak(5)	2	2	2	2	3	4	3	2	1	2,3	1 to 4
Light(1)/heavy(5)	1	2	2	2	2	2	1	1	2	1,7	1 to 2

User Study

1) Ik wil dat je rustig het materiaal bestudeerd en vertelt wat je eerste indruk is. Observaties:

Sustainable. Normaal materiaal. Light op normale potjes

2) Wat vind je van dit materiaal in vergelijking tot deze andere materialen? Vind je het materiaal ergens op lijken?

esthetisch beter uit. Andere plastics reputatie slecht milieu

3) Hoe zou je het materiaal omschrijven?

Bros. flexiebel. Goed te vervormen. Wel stevig. Glad. Niet transparant

4) Is er iets dat je fijn vind aan dit materiaal? Is er iets dat je vervelend vind aan dit materiaal?

Oogt wel goed. Light op een ander materiaal waardoor je het niet direct plaatst bij plastics. Zoals bestaande Planten potten

5) Hoe vind je het ruiken? Hoe vind je het klinken?

Geen geur / Wel een beetje / Ruikt wel geur. Kan het niet plaatsen

Ruikt niet zo fris. Alleen aan de binnenhant pot.

Vind je het materiaal:

Hard	o ◎ ● o o	Zacht
Glad	◎ ● o o o	Ruw
Mat	◎ o o o o	Glimmend
1Reflectief	o o ◎ o o	Niet reflectief
Koud	o o o ◎ o	Warm
Elastisch	o o o ● ◎	Niet elastisch
Transparant	o o ● ◎ o	Ondoorzichtig
Taai	o ◎ o ● o	Buigzaam
Sterk	o ◎ o o o	Zwak
Licht	o ◎ o o o	Zwaar

User Study

1) Ik wil dat je rustig het materiaal bestudeerd en vertelt wat je eerste indruk is. Observaties:

tikt er op benieuwd waarvan het gemaakt is gecompreste Papier + coating
geeft mee, niet super buigzaam solid waterdicht

2) Wat vind je van dit materiaal in vergelijking tot deze andere materialen? Vind je het materiaal ergens op lijken?

kleur geeft indruk van sustainable. gerecycled. Positieuwe indruk daar
iets minder sterk dan ABS. Maar sterker dan de deksels. kort gebruik door.

3) Hoe zou je het materiaal omschrijven?

licht bruin. gespikkeld. Glad. licht glanzend
licht gebold gevormd. Er zitten kleine stukjes in maar die voel je niet
voelt prettig.

4) Is er iets dat je fijn vind aan dit materiaal? Is er iets dat je vervelend vind aan dit materiaal?

Schuur stoort → breekbaar.
Structuur voelt prettig. Niet te glad.

5) Hoe vind je het ruiken? Hoe vind je het klinken?

↳ ruikt niks
verkouden.
zoetig

↳ chill
tikt lekker

Vind je het materiaal:

Hard	o o ◎ o o	Zacht
Glad	o ◎ o o o	Ruw
Mat	o ◎ o o o	Glimmend
1Reflectief	o o o ◎ o	Niet reflectief
Koud	o o o ◎ o	Warm
Elastisch	o o o ◎ o	Niet elastisch
Transparant	o o o o ◎	Ondoorzichtig
Taai	o o o ◎ o	Buigzaam
Sterk	o ◎ o o o	Zwak
Licht	◎ o o o o	Zwaar

User Study

1) Ik wil dat je rustig het materiaal bestudeerd en vertelt wat je eerste indruk is. Observaties:

Lijkt op karton. Maar steviger. Glad. Stevige versie van karton.

2) Wat vind je van dit materiaal in vergelijking tot deze andere materialen? Vind je het materiaal ergens op lijken?

Beter voor het milieu. nice dat het geen plastic is. niet waterresistent

Moor, voelt nice, maar licht er aan waar voor het gebruikt wordt. ↓ in de regen wordt hij slap

3) Hoe zou je het materiaal omschrijven?

Karton achtig. stevig maar wel buigbaar/veerbaar

Glad. Echt glad.

4) Is er iets dat je fijn vind aan dit materiaal? Is er iets dat je vervelend vind aan dit materiaal?

↳ licht

stevig maar zacht

minder pijn dan plastic.

5) Hoe vind je het ruiken? Hoe vind je het klinken?

muf.

niet vies

↳ hard maar iets dofter dan plastic

Vind je het materiaal:

Hard	o o ● o o	Zacht
Glad	● o o o o	Ruw
Mat	◐ o o o o	Glimmend
1Reflectief	o o o o ◐	Niet reflectief
Koud	o o ● o o	Warm
Elastisch	o o o o ◐	Niet elastisch
Transparant	o o o o ◐	Ondoorzichtig
Taai	o o o ● o	Buigzaam
Sterk	o ● o o o	Zwak
Licht	o ◐ o o o	Zwaar

User Study

1) Ik wil dat je rustig het materiaal bestudeerd en vertelt wat je eerste indruk is. Observaties:

hard. dacht dat het karton was. Sustainable mok ☺ stuk je.

2) Wat vind je van dit materiaal in vergelijking tot deze andere materialen? Vind je het materiaal ergens op lijken?

Als je het niet aanraakt, karton

mooier dan plastic.

3) Hoe zou je het materiaal omschrijven?

bruin. Vezel samengesteld. karton achtig. Plantaardig

Glad.

4) Is er iets dat je fijn vind aan dit materiaal? Is er iets dat je vervelend vind aan dit materiaal?

Fijn dat het niet egaal is. Ziet er niet cheap uit.

Ga je niet na 1 keer weg gooien.

5) Hoe vind je het ruiken? Hoe vind je het klinken?

↳ beetje vreemd ↳ voelt goed

↳ wel ohe. Maar minder snel uit drinken

Vind je het materiaal:

Hard	o ◐ o o o	Zacht
Glad	◐ o o o o	Ruw
Mat	◐ o o o o	Glimmend
Reflectief	o o o o ◐	Niet reflectief
Koud	o o ◐ o o	Warm
Elastisch	o o o ◐ o	Niet elastisch
Transparant	o o o ◐ o	Ondoorzichtig
Taai	o ◐ o o o	Buigzaam
Sterk	o ◐ o o o	Zwak
Licht	o ◐ o o o	Zwaar

User Study

1) Ik wil dat je rustig het materiaal bestudeerd en vertelt wat je eerste indruk is. Observaties:
niet zo goed weet wat het is. afgebroken van iets. afgeschaafd miss.
Bruin. niet heel hard maar ook niet zacht.

2) Wat vind je van dit materiaal in vergelijking tot deze andere materialen? Vind je het materiaal ergens op lijken?
~~lijkt meest op~~
beetje zelfde sterkte

3) Hoe zou je het materiaal omschrijven?
hard maar niet metaal hard. Kan het scheuren. Bruin beige kleur
Voor speelgoed bv.

4) Is er iets dat je fijn vind aan dit materiaal? Is er iets dat je vervelend vind aan dit materiaal?
mwa. ligt aan context

5) Hoe vind je het ruiken? Hoe vind je het klinken?
↳ beetje muffig ↳ hol achtig
↳ niet, vies
↳ licht geur, daarom muffig

Vind je het materiaal:

Hard	o ● o o o	Zacht
Glad	● o o o o	Ruw
Mat	● o o o o	Glimmend
Reflectief	o o o o ●	Niet reflectief
Koud	o o ● o o	Warm
Elastisch	o o o ● o	Niet elastisch
Transparant	o o o o ●	Ondoorzichtig
Taai	o o o ● o	Buigzaam
Sterk	o o ● o o	Zwak
Licht	o ● o o o	Zwaar

User Study

1) Ik wil dat je rustig het materiaal bestudeerd en vertelt wat je eerste indruk is. Observaties:
heel glad beetje scherp. light op karton light op papier
feel van plastic ↳ door vezels

2) Wat vind je van dit materiaal in vergelijking tot deze andere materialen? Vind je het materiaal ergens op lijken?
voelt luxer. Kan wel buigen maar het voelt sterk.
geleid anders. andere plastics hebben meer weerstand

3) Hoe zou je het materiaal omschrijven?
kleur is onderwets. medium sterk. Voelt heel lekker.

4) Is er iets dat je fijn vind aan dit materiaal? Is er iets dat je vervelend vind aan dit materiaal?
↳ heel egaal. je voelt stipjes niet ↳ scherp aan randen

5) Hoe vind je het ruiken? Hoe vind je het klinken?
↳ koffie ↳ schell
cappuccino met suiker

'Ik zou er een gebruiksvoorwerp van maken want ik wil het voelen'

Vind je het materiaal:

Hard	o o ● o o	Zacht
Glad	● o o o o	Ruw
Mat	o ● o o o	Glimmend
1Reflectief	o o o o ●	Niet reflectief
Koud	o o o ● o	Warm
Elastisch	o o ● o o	Niet elastisch
Transparant	o o o o ●	Ondoorzichtig
Taai	o ● o ● o	Buigzaam
Sterk	o o ● o o	Zwak
Licht	o ● o o o	Zwaar

User Study

1) Ik wil dat je rustig het materiaal bestudeerd en vertelt wat je eerste indruk is. Observaties:

scheur. tikt er op stijf en sterk beetje kartonig
↳ breekbaar buigt wel een beetje bijzonder scherp

2) Wat vind je van dit materiaal in vergelijking tot deze andere materialen? Vind je het materiaal ergens op lijken?

meer kwaliteit. duurzamer uiterlijk karton
↳ gerecycled

3) Hoe zou je het materiaal omschrijven?

bruin dik flexibel kan veel aan

4) Is er iets dat je fijn vind aan dit materiaal? Is er iets dat je vervelend vind aan dit materiaal?

Wikkel glad → fijn voelt zacht zit een soort coating op aan 1 kant.

5) Hoe vind je het ruiken? Hoe vind je het klinken?

↳ kranten ↳ tikt anders
prima niet chemisch milieuvriendelijk
je ruikt wel iets

Vind je het materiaal:

Hard	o ● o o o	Zacht
Glad	● o o o o	Ruw
Mat	o o o ● o	Glimmend
1Reflectief	o ● o o o	Niet reflectief
Koud	o o o ● o	Warm
Elastisch	o o o ● o	Niet elastisch
Transparant	o o o o ●	Ondoorzichtig
Taai	o o o ● o	Buigzaam
Sterk	● o o o o	Zwak
Licht	o ● o o o	Zwaar

User Study

1) Ik wil dat je rustig het materiaal bestudeerd en vertelt wat je eerste indruk is. Observaties:

glad matt licht sterk beetje buigen → bross

2) Wat vind je van dit materiaal in vergelijking tot deze andere materialen? Vind je het materiaal ergens op lijken?

moeilijk. plantenpot = meer toepassing dan de plastics die er voor liggen
past er wel tussen door verschillen. Dik.

3) Hoe zou je het materiaal omschrijven?

plastic. vezeltjes. zou er een beker van maken
bruin

4) Is er iets dat je fijn vind aan dit materiaal? Is er iets dat je vervelend vind aan dit materiaal?

fijn gevoel glad, maar ook ruw. alsof het met fijn schuurpapier is opgesch.
Plakt niet.

5) Hoe vind je het ruiken? Hoe vind je het klinken?

↳ koffie koekjes ↳ gewoon als plastic
↳ mss iets lager

Vind je het materiaal:

Hard	o ● o o o	Zacht
Glad	● ● o o o	Ruw
Mat	● o o o o	Glimmend
1Reflectief	o o o o ●	Niet reflectief
Koud	o o o ● o	Warm
Elastisch	o o o o ●	Niet elastisch
Transparant	o o o o ●	Ondoorzichtig
Taai	o ● o o o	Buigzaam
Sterk	o o ● o o	Zwak
Licht	● o o o o	Zwaar

User Study

1) Ik wil dat je rustig het materiaal bestudeerd en vertelt wat je eerste indruk is. Observaties:

Plastic icm kurk/hout : Sws iets van plastic

licht glad

2) Wat vind je van dit materiaal in vergelijking tot deze andere materialen? Vind je het materiaal ergens op lijken?

Sjc sjögue natuurlijk. Lijkt op mdf

3) Hoe zou je het materiaal omschrijven?

aardkleurig. niet goedkoop

4) Is er iets dat je fijn vind aan dit materiaal? Is er iets dat je vervelend vind aan dit materiaal?

heel glad niet fijn

fijn dat het mat is.

5) Hoe vind je het ruiken? Hoe vind je het klinken?

biologisch

naar afval?

niet vies

plastic

Vind je het materiaal:

Hard	● o o o o	Zacht
Glad	● o o o o	Ruw
Mat	o ● o o o	Glimmend
1Reflectief	o o o ● o	Niet reflectief
Koud	o o o ● o	Warm
Elastisch	o o o o ●	Niet elastisch
Transparant	o o o o ●	Ondoorzichtig
Taai	o ● o o o	Buigzaam
Sterk	o ● o o o	Zwak
Licht	● o o o o	Zwaar

Appendix 3. Ideas from creative sessions

CES comparison: individual brainstorm sessions

Make up packaging
Parfum
Soap dispenser
Mirror
Hair brush
Tape dispenser
Pencil shaprner
Pencilcase
Scissors
Promotional gifts webshop
Postboxes on desk
A4 ordner boxes
Ruler
Handles
Toothbrush
Keys
Tools
Glasses
Sunglasses
Spectical frames
Glasses case
Headphones casing
3D glasses for cinema
Cardridges casings
Sustainable inkt company
Deposit money
Signage boards
In hospital
In theme park
Storage boxes
Photo frames
Garbage bin
Scale
Your own picture on Vibers plastic
Curtain drag stick
Wall outlet
Power strip
Licht switches with structure
Pet toys
Chair
Storage closet system
Side table on wheels
Low side table
Lamp fitting or lamp shade
Rolling lamp
Garden chair and table
Seating in lecture halls (business-to-business)

Furniture sector: creative session with 2 people

The session plan was as follows: to get into the context, a flower association was done. Afterwards we did a quick energiser to start the ideas flowing. Then we did a brainstorm on sticky notes to generate as many ideas as possible. Halfway the brainstorm session was showed how the material reacted to temperature changes.

Standing table (catering furniture, chairs)
Dixie toilets (sustainable look)
Garbage bin outside
Storage boxes
Garbage bin inside
Salt bin outside
Sandbox children (shell) (with luxury looks that fits in with the garden) (Learn children stustainability)
Fruit bowl
It is possible to cut it with scissors. So something do it yourself.
Sheet material with structure, not smooth.
Lampshade
Coat hooks + towel hooks (make it yourself)
Roof tiles
Indication poles for gas pipes
Roadblock poles
Bench in public spaces. Combined with metal.
Bike rack
Lounge set (pitriet/wicker)
Garden chair
Plastic armchair
Wallpaper plastic (easy cleanable)
3D wallpaper (structures)
Garden fencing
Photo frame/painting frame/mirror frame
Room divider office
Floor tiles (mosaic)
Attachment acoustic panels
Fences in shops
Window shutters
Folding chair
Instead of plasterboard to make walls (trespa platen)
Electricity pipes (PVC)
Curtains/rolcurtains (letting through light/not)
Open closets
School chairs for children. Recycle
Roof covering
Office desk
Ironing it makes it flat again
Housing of an fire extinguisher or AED
Bulletin board
Playhouse for children in garden.

Deformability with hot temperatures: creative session with 4 people

Quickly mould making of an existing product
Foldable storage container. You can make it exactly the right fit for your food.
Flexible coaster. Customised for all glasses. Design your own.
Quick prototype material
Decoration (for in house)
Dating: at festival. You get a piece, deform it into your shape. Find a person with the same.
Teaching about materials
Support for sprained wrist
Brushes attachment to distinguish them from eachother
Scissor holder for in schools etc
For every brush a brush holder
Brushes

Pens/Pencils
Crafting (class) (for children)
Paper/Plastic plane Do it yourself
Way of expressing your feelings
Calendar (sort of like a tear-off-calendar) (fold the days after warming)
Coins for festivals
Candle holder. When the material gets hot, it gives a specific smell -> smell candle
Model building (airplanes, trains etc)
Miniature 3D maps for in building industry/museum
Painting with 3D elements
Racetrack for toy cars
Marble track: build your own (knikkerbaan)
Window frames
Occupational therapy
Make up holder for people with rheumatism
Thermometer (when deforming -> hotter than 40 degrees)
Make your own Christmas tree. Fold them in each other
Pattern for spray painting. Make a new pattern every time
The backside of a cap
Reinforcement in shoes
Pipe to put drawings in
Wallet
Hooks
Lego/duplo/play mobil
Sunshade (curls up when it is hot)
Make costumes
Board games
Use in escape room -> deform a go through
Self made box for a present
Cardboard boxes
Boxes
Build houses
Pencil case
Lid for special pots (every pot fits a lid)
Business cards
In a hospital
Serving tray
Make your own toys
Taylor made flower pot
Pizza box
Packaging
Jewellery box
Personalised computer mouse
Magic show
Hot air bubbles making, changing shape
Art
Bookstorage/closet
Easel for painting
Toy Crown
Head band
Dough roll
Measurement stick
Selfiestick
Watch
Watch gadget
Menu card
Book cover
Knife
Cover for keys
Alarm clock
Sewing set
Shoehorn
Tooth paste tube
Jewellery
Headphones
Noise cancelling
Water gun
Music record
Desk
Phone case
Painters palette
Lamps
Teabag holder
Steering wheel game controller
Cookie cutters
Clutch
Inside out

How to find new products: creative session with 7 people

Make feel good product ranges
Products for pets/for under water, to prevent pollution by micro plastics
Getting carbon points for the products that use bioplastics.
Entering new market niches
Explore new territories
Create products that keep people safe
Build a tree house with bioplastic
KLM has bioplastic plates and cutlery
International contest
Temporary small scale usage
Hangars (products that use less material by weight) (not solid)
Create new value for companies
Luxury products
Who might be interested in telling the world that they're using this kind of material
Create social platform where people can show their social network how they're being good for the environment
Create art to generate awareness
Testing in extreme environments
Games that need plastic pieces (board/toys)
Container
Expensive products that are used within the house
By designing production processes that are replaceable (the existing)
The product range should appear as innocent
Make toys for fun and to learn
Understanding users perception and willingness
Container for art products
Crete leverages/touch points during the bio-plastic life cycle
Product for Christmas
Spectacle frames
Limited edition products
Toys/games

Use for infrastructure
Awareness in schools about sustainable materials/ study environment
Make the impact visible
Jewellery
Allow users to experience production
Be transparent about the property/future of the product or material (no greenwashing)
Bio-based hydraulic structure (sluice gate for example)
Make it a go-to alternative for model making/ prototyping
A product that drops water
Shelters for homeless
Learnable products
Kinetic sculptures
Pop up labs/stores to experience the material
Make a dynamic/shape shifting material (motion)
Custom production system
Cover people/plants/animals from winter
Apply in something you are passionate about
Make it transformable into a different product
Winter sport products
Make it 3d-printable
Easy recycling process
Small products with high margin
Disney world made of bioplastics
Surface applications for plastics
Make something that can change state
Make it recognisable by using three colours
Use it on another planet
Board games
Wave breaking elements or dissipation
Dike revetment blocks
Light weight furniture

Temperature behaviour: brainstorm with 4 people dical appliences

Brace
Ipv gips
Hearing aid
Children helmet for children with flat head
Do it yourself
Jewellry
Iron beads
Prototyping material
Own lamp design
Tailor made
Watches
Headphones
Soles in ski shoes
Chair sitting
Face mask
Icehockey mask
Head protection for sports
Your own grip
Tools
Kitesurfboard
Crutches
Bike
Long ruler
Toys for grown ups
Flat transportation
Sealing
Piggy bank
Repair
Make something small when you don't use it

A walk through the plastic world: individual brainstorm session

Downspout
Plastic poles
Trafic light
Mannequin
Fake plant
Shopping basket
Fruit bowl
Signs in cinema
Dustpan
Watering can
Combine the different granulate
Picture frame
Laundry basket
Slow down sign
Umbrella
Pens or markers
Bicycle seat for children
Headphones

Medical sector: creative session with 3 people

Important is the sterilisation of products in hospitals
Formable indicator for teeth positions
Tool for position holding in scans (Fixation)
Splint
Instead of plaster cast
Tongue stick (plastic is better cleanable than wood)
Stick to moisten lips
Toothpick
Badge holder
Name tags during conferences
Hospital card for patients
Dressing screen
Human prototype (teaching)
Skeleton
Furniture in waiting room (tables, chairs)
Cart with metal sliding doors (for medication, epd, instruments etc)
Table on bed
Medical glasses
Doctors light with Vibers housing
Head of the echo machine
OR lamps
Housing infusion pump
Hula hoop
Glasses
Physiotherapy exercises tool like stairs or steps
Whiteboard
Clipboard
Serving tray
Cup

Lid of blood tubes
Boxes/containers for food/storage
Homecare food packaging
Cosmetic prosthesis (breast)
Wood (not cleanable)
Verneveling kapje (engels?)
Test material for students (doesn't need to be sterile)
Stretcher
Speculum
Measuring stick
Ordners

Automotive sector: creative session with 2 people

Architecture scale model
Licence plates
Sunglasses for in the car
Festival: create cool stuff with plastic
Plastic cups and cutlery in food trucks
Public transport interior
Cup holder in car
Clock in the car
Dashboard interior (big panels)
DIY mechano toys
Garden fencing
Liquid lids
Inside of the door
inside of the roof
Drinking bottles
Scale model of racing circuit (DIY)
Toilet seats
Mirrors in the car
Gear stick
Handbrake
Holder for keys in the car
Toy racing circuit
Sign board/promo board/billboard food truck
Name tags
Phone holder in car
Keycord card/keychain
Handles in car factory
Lid of valve
Wiper housing
Handles of the car door
Pens
Plastic in drill appliances
Roller coaster
Theme park decoration
Bus stops
Lining in the car
Bumper
Bridges from plastic (pedestrian)
Foldable table
Details on the dashboard
Charging station
Engine hood
Waterbottle lids
Anti-slip in bathroom
Traffic lights
Housing of robots
Housing phone
Playground
Billboards on racing circuit
Lid/valve for tank
Dog house
Clothes hook in car
Housing lamp
Sponsor boards at circuit
Anti slip in factory
Garbage bin
Paint sprayer
Helmets
Breaks
Asphalt
Traffic signs
Crashtest dummy
Hectometre post
Plastic in the electronics of the car
Merchandise
Bench
Gas pump handle
Seat belt
Rims
Engine cover
Flag staff
Buttons in cars and robots
Birdhouse
Assembly line
Hotwheels toys
Noice reduction (highway)
Movable toilet
Cover of instruction manual car
Helmet pitcrew

Appendix 4. Clustering in application areas

Beauty products
Hair combs
Baby nappies
Cosmetic packaging
Parfum
Soap dispenser
Mirror
Hair brush
Make up holder for people with rheumatism

Jewellery
Jewellery box

Glasses
Sunglasses
Spectical frames
Glasses case
3D glasses for cinema

Handles
Toothbrush
Keys
Cover for keys
Tools
Kitesurfboard
Crutches
Bike
Scissors

Desktop products
Tape dispenser
Pencil shaprner
Pencilcase
Scissors
Postboxes on desk
Ruler
Pens/pencils/markers
Scissor holder for schools etc
Measurement stick
Sealing

Office supplies
A4 ordner boxes
Cartridges B2B
Promotional gifts webshop
Ordners
Whiteboard
Clipboard
Keycord card/keychain

Electronic devices/gadgets
Personalised computer mouse
Alarm clock
Noise cancelling headphones
Steering wheel game controller
Headphones
Business machine housing
Electrical equipment housing

Crafting
Pipe to put drawings in
Drawing stencils
Iron beads
Quick prototype material
Crafting (class) (for children)

Paint supplies
Painting with 3D elements
For every brush a brush holder
Brushes
Pattern for spray painting. Make a new pattern every time
Easel for painting
Painters palette
Brush attachment to distinguish them from each other

Kitchen products
Dough roll
Knife
Teabag holder
Cookie cutters
Kitchenware and tableware
Beakers
Scale
Serving tray
Fruit bowl
Flexible coaster. Customised for all glasses. Design your own.
Cup
Serving tray

Storage products
Foldable storage container. You can make it exactly the right fit for your food.
Boxes/containers for food/storage
Storage boxes
Laundry basket
Lid for special pots (every pot fits a lid)

House products
Household appliances
Curtain drag stick
Your own picture on Vibers plastic
Piggy bank

Decoration in house
Watering can
Coat hooks + towel hooks (make it yourself)
Attachment acoustic panels
Bulletin board
Calendar (sort of like a tear-off-calendar) (fold the days after warming)
Fake plant
Photo frame/painting frame/mirror frame
Plant pots (Taylor made flower pot)
Make your own Christmas tree. Fold them in each other
Toilet seats

Building material
Build houses
Instead of plasterboard to make walls (trespa

platen)
Wallpaper plastic (easy cleanable) (3D wallpaper (structures)
Wall outlet
Licht switches with structure
Downspout
Floor tiles (mosaic)
Window frames
Sunshade (curls up when it is hot)
Window shutters
Roof tiles
Roof covering
Electricity pipes (PVC)

Furniture products

Lamp fitting or lamp shade
DIY Own lamp design
Furniture casters (wieltjes)
Chair + tailor made chair sitting
Storage closet system
Side table on wheels
Low side table
Rolling lamp
Garbage bin
Power strip
Shelving
Standing table (Sta-tafels) (catering furniture, chairs)
Plastic armchair
Folding chair
Curtains/rolcurtains (letting through light/not)
Open closets

Garden furniture

Garden chair and table
Garbage bin outside
Sandbox children (shell) (with luxury looks that fits in with the garden) (Learn children stustainability)
Lounge set (pitriet/wicker)
Garden fencing
Playhouse for children in garden.
Swing set

Street furniture

Plastic poles
Traffic light
Dixie toilets (sustainable look)
Salt bin outside
Indication poles for gas pipes
Roadblock poles
Bench in public spaces. Combined with metal.
Bike rack
Bus stops
Bridges from plastic (pedestrian)
Playground
Traffic signs
Hectometre post
Noice reduction (highway)

Shop furniture

Mannequin
Shopping basket
Fences in shops
Merchandise

Other furniture

Room divider office
School chairs for children. Recycle
Office desk
Housing of a fire extinguisher or AED
Seating: lecture halls, tribune etc (B2B)
Furniture in waiting room (tables, chairs)

Signage boards

In hospital
In theme park
In cinema
Laminated structures
Panels for illuminated signs
Slow down sign
Badge holder
Name tags during conferences
Sign board/promo board/billboard food truck

Sports products

Spatbord fiets
Icehockey mask
Golf balls
Head protection for sports
Hula hoop
Physiotherapy exercises tool like stairs or steps

Toys

Toys for pets
Toys for grown ups
Racetrack for toy cars
Marble track: build your own (knikkerbaan)
Lego/duplo/play mobil
Board games
Use in escape room -> deform a go through
DIY mechano toys
Toy racing circuit
Hotwheels toys

Medical: position holding tailor-made

Brace
Tool for position holding in scans (Fixation)
Support for sprained wrist
Splint
Instead of plaster cast

Medical appliences

Hearing aid
Children helmet for children with flat head
Shoehorn
Face mask
Formable indicator for teeth positions
Tongue stick (plastic is better cleanable than wood)
Stick to moisten lips
Toothpick
Hospital card for patients
Dressing screen

Cart with metal sliding doors (for medication, epd, instruments etc)
Table on bed
Medical glasses
Doctors light with Vibers housing
Head of the echo machine
OR lamps
Housing infusion pump
Glasses
Lid of blood tubes
Homecare food packaging
Cosmetic prosthesis (breast)
Wood (not cleanable)
Verneveling kapje (engels?)
Test material for students (doesn't need to be sterile)
Stretcher
Speculum
Measuring stick

Fashion
The backside of a cap
Reinforcement in shoes
Wallet
Watch
Clutch

Car interior
Licence plates
Public transport interior
Clock in the car
Cup holder in car
Dashboard interior (big panels)
Inside of the door
inside of the roof
Mirrors in the car
Gear stick
Handbrake
Holder for keys in the car
Phone holder in car
Lid of valve
Wiper housing
Handles of the car door
Lining in the car
Bumper
Details on the dashboard
Charging station
Engine hood
Lid/valve for tank
Clothes hook in car
Housing lamp
Crash test dummy
Gas pump handle
Seat belt
Rims
Engine cover
Buttons in cars and robots

Shoe soles tailor-made
Soles in ski shoes tailormade

Do it yourself
Make costumes
Self made box for a present
Make your own toys
DIY from old records
Scale model of racing circuit (DIY)

Model making
Paper/Plastic plane
Model building (airplanes, trains etc)
Architecture scale model

Cleaning
Dustpan

Normally paper
Menu card
Book cover
Business cards

Gadgets
Selfiestick
Watch gadget
Phone case
Headphones casing
Housing of robots
Housing phone

Repair products
Plastic in drill appliances

Changeable size products
Make something small when you don't use it

Prototyping material
It is possible to cut it with scissors. So something do it yourself.
Ironing it makes it flat again
Quickly mould making of an existing product

Random ideas
Umbrella
Bicycle seat for children
Suitcases (te bros?)
Dating: at festival. You get a piece, deform it into your shape. Find a person with the same.
Way of expressing your feelings
Occupational therapy
Coins for festivals
Candle holder. When the material gets hot, it gives a specific smell -> smell candle
Thermometer (when deforming -> hotter than 40 degrees)
Miniature 3D maps for in building industry/museum
Festival: create cool stuff with plastic
Roller coaster
Theme park decoration

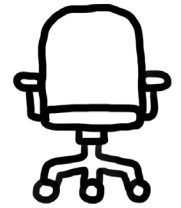
The many ideas found are clustered in application areas in order to get a better overview. The areas are:

- Beauty products
- Jewellery
- Glasses
- Handles
- Desktop products
- Office supplies
- Electronic devices/gadgets
- Crafting
- Paint supplies
- Kitchen products
- Storage products
- House products
- Decoration in house
- Building material
- Furniture products
- Garden furniture
- Street furniture
- Shop furniture
- Other furniture
- Signage boards
- Sports products
- Toys
- Medical: position holding tailor-made
- Medical appliences
- Fashion
- Car interior
- Shoe soles tailor-made
- Do it yourself
- Model making
- Cleaning
- Normally paper
- Gadgets
- Repair products
- Changeable size products
- Prototyping material
- Random ideas

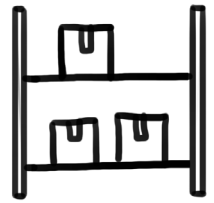
The application areas are judged on one requirement: does the material add value to the application? This requirement can be divided into the four categories in which it could add value: composition of the material, the material properties, the user experience and the recovery phase. The conclusions are the qualities of the Vibers material: it is made from bio-based materials, it has a sustainable look and feel, it is biodegradable and it fit for a business-to-business strategy. Judging the application areas is be done by asking the following question:

'Does this application area benefit from the combination between the bio-based material, the sustainable look and feel and the biodegradable or business-to-business end-of-life?'.

For the following application areas, the question can be answered with 'yes'. Therefore they are the right fit for this material.



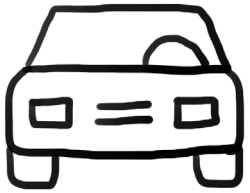
Office furniture



Shop furniture

Garden furniture

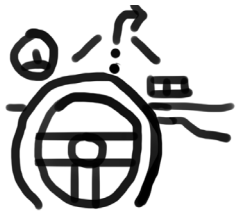
House decoration



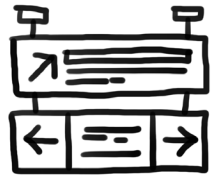
Car interior

Street furniture

Household products



Car interior



Signage boards

Fashion

Appendix 5. Clustering in requirements

Products that need to withstand a specific load

Hair brush
Scissors
Tools
Curtain drag stick
Chair
Side table
Standing table (Sta-tafels) (catering furniture, chairs)
Dixie toilets (sustainable look)
Salt bin outside
Roof tiles
Bench in public spaces. Combined with metal.
Bike rack
Lounge set (pitriet/wicker)
Garden chair
Plastic armchair
Garden fencing
Floor tiles (mosaic)
Fences in shops
Folding chair
Electricity pipes (PVC)
Open closets
School chairs for children. Recycle
Roof covering
Office desk
Playhouse for children in garden.
Support for sprained wrist
Reinforcement in shoes
Dough roll
Selfiestick
Shoehorn
Desk
Steering wheel game controller
Chair sitting
Kitesurfboard
Crutches
Traffic light
Shopping basket
Watering can
Laundry basket
Umbrella
Bicycle seat for children
Splint
Furniture in waiting room (tables, chairs)
Housing infusion pump
Physiotherapy exercises tool like stairs or steps
Stretcher
Public transport interior
Cup holder in car
Wiper housing
Bridges from plastic (pedestrian)
Foldable table
Noice reduction (highway)

Products that need to withstand impact load (laten vallen)

Toothbrush
Tools
Glasses
Sunglasses
Glasses case
Headphones casing
Standing table (Sta-tafels) (catering furniture, chairs)
Dixie toilets (sustainable look)
Salt bin outside
Roadblock poles
Garden fencing
Room divider office
Electricity pipes (PVC)
School chairs for children. Recycle
Housing of a fire extinguisher or AED
Playhouse for children in garden.
Scissor holder for in schools etc
Racetrack for toy cars
Pipe to put drawings in
Lego/duplo/play mobil
Board games
Serving tray
Dough roll
Selfiestick
Water gun
Phone case
Steering wheel game controller
Face mask
Head protection for sports
Kitesurfboard
Crutches
Shopping basket
Laundry basket
Hula hoop
Phone holder in car
Noice reduction (highway)

Products that need to be opened and closed of in elkaar gezet, bewegen, bros afbreken

Pencilcase
Glasses
Sunglasses
Glasses case
Headphones casing
3D glasses for cinema
Storage boxes
Garbage bin inside
Garbage bin outside
Standing table (Sta-tafels) (catering furniture, chairs)
Dixie toilets (sustainable look)
Salt bin outside
Storage boxes
Fences in shops
Folding chair
Housing of a fire extinguisher or AED
Pipe to put drawings in
Selfiestick
Watch
Steering wheel game controller
Bicycle seat for children
Clipboard
Stretcher
Mirrors in the car

Foldable table

Products that need to withstand heat above 50 degrees

Flexible coaster. Customised for all glasses. Design your own.
Teabag holder
Cookie cutters
Cup
Public transport interior
Dashboard interior (big panels)
Inside of the door (car)
inside of the roof (car)
Mirrors in the car
Gear stick
Handbrake
Details on the dashboard
Engine hood
Clothes hook in car

Products that are disposable after use

Make up packaging
Parfum
Soap dispenser
Pens/Pencils
Packaging
Tooth paste tube

One-use products

3D glasses for cinema
Coins for festivals
Packaging

Products that need to last in changing weather conditions

Signage boards
Garbage bin outside
Garden chair and table
Dixie toilets (sustainable look)
Salt bin outside
Sandbox children (shell)
Roof tiles
Indication poles for gas pipes
Roadblock poles
Bench in public spaces. Combined with metal.
Bike rack
Lounge set (pitriet/wicker)
Garden chair
Garden fencing
Roof covering
Housing of a fire extinguisher or AED
Playhouse for children in garden.
Window frames
Downspout
Plastic poles
Traffic light
Umbrella
Theme park decoration
Bridges from plastic (pedestrian)
Traffic signs
Hectometre post
Noice reduction (highway)

Products that need to be cheap

Promotional gifts webshop
3D glasses for cinema
Quick prototype material
Coins for festivals
Pipe to put drawings in
Packaging
Water gun
Teabag holder
Dustpan
Name tags during conferences
Merchandise

Products that need to last for more than 10 years

Garden chair and table
Salt bin outside
Sandbox children (shell)
Roof tiles
Bench in public spaces. Combined with metal.
Lounge set (pitriet/wicker)
Wallpaper plastic (easy cleanable)
3D wallpaper (structures)
Open closets
School chairs for children. Recycle
Office desk
Housing of a fire extinguisher or AED
Scissor holder for in schools etc
Downspout
Furniture in waiting room (tables, chairs)
Public transport interior
Traffic signs

Products that need to give comfort

Chair
Garden chair and table
Seating in lecture halls
Bench in public spaces. Combined with metal.
Lounge set (pitriet/wicker)
Steering wheel game controller
Garden chair
Plastic armchair
School chairs for children. Recycle
Pens/Pencils
Watch
Headphones
Hearing aid
Chair sitting
Face mask
Crutches
Bicycle seat for children
Splint
Furniture in waiting room (tables, chairs)
Stretcher

Products in which Vibers replaces other plastics. Need to be more sustainable.

Electricity pipes (PVC)

Products in which Vibers replaces other materials.

Need to be more sustainable.
Keys
Bike rack
Wallpaper plastic (easy cleanable)
3D wallpaper (structures)
Garden fencing
Floor tiles (mosaic)
Instead of plasterboard to make walls (trespa platen)
School chairs for children. Recycle
Roof covering
Office desk
Bulletin board
Support for sprained wrist
Scissor holder for in schools etc
Calendar (sort of like a tear-off-calendar) (fold the days after warming)
Window frames
Wallet
Hooks
Cardboard boxes
Business cards
Easel for painting
Dough roll
Menu card
Book cover
Painters palette
Cart with metal sliding doors (for medication, epd, instruments etc)
Licence plates
Traffic signs
Birdhouse

Products from which it is difficult to return the material to Vibers.
Hair brush
Make up packaging
Parfum
Soap dispenser
Tape dispenser
Pencil shaprner
Pencilcase
Promotional gifts webshop
Ruler
Toothbrush
Sunglasses
Glasses case
Headphones casing
Storage boxes
Curtain drag stick
Storage closet system
Side table
Garbage bin inside
Sandbox children (shell)
Plastic armchair
Lounge set (pitriet/wicker)
Garden chair
Folding chair
Open closets
Roof covering
Bulletin board
Playhouse for children in garden.
Flexible coaster. Customised for all glasses. Design your own.
Quick prototype material
Decoration (for in house)
Pens/Pencils
Miniature 3D maps for in building industry/museum
Reinforcement in shoes
Wallet
Pipe to put drawings in
Hooks
Lego/duplo/play mobil
Board games
Business cards
Packaging
Jewellery box
Serving tray
Taylor made flower pot
Personalised computer mouse
Easel for painting
Toy Crown
Dough roll
Selfiestick
Watch
Book cover
Alarm clock
Shoehorn
Tooth paste tube
Phone case
Painters palette
Teabag holder
Steering wheel game controller
Cookie cutters
Toys for grown ups
Downspout
Fake plant
Dustpan
Watering can
Laundry basket
Bicycle seat for children
Name tags during conferences
Hula hoop
Physiotherapy exercises tool like stairs or steps
Clipboard
Architecture scale model
Public transport interior
Cup holder in car
Clock in the car
Dashboard interior (big panels)
DIY mechano toys
Scale model of racing circuit (DIY)
Toy racing circuit
Details on the dashboard
Clothes hook in car
Merchandise

Make it yourself is too hot
Coat hooks + towel hooks (make it yourself)
Quickly mould making of an existing product
Flexible coaster. Customised for all glasses. Design your own.
Quick prototype material

Dating: at festival. You get a piece, deform it into your shape. Find a person with the same.
Support for sprained wrist
Pens/Pencils
Crafting (class) (for children)
Paper/Plastic plane Do it yourself
Way of expressing your feelings
Calendar (sort of like a tear-off-calendar) (fold the days after warming)
Model building (airplanes, trains etc)
Marble track: build your own (knikkerbaan)
Occupational therapy
Make your own Christmas tree. Fold them in each other
Pattern for spray painting. Make a new pattern every time
Self made box for a present
Make your own toys
Taylor made flower pot
Personalised computer mouse
Jewellery
Own lamp design
Tailor made
Your own grip
Formable indicator for teeth positions
Splint

Products that need to be easy to clean

Garbage bin inside
Standing table (Sta-tafels) (catering furniture, chairs)
Dixie toilets (sustainable look)
Wallpaper plastic (easy cleanable)
Serving tray
Painters palette
Cookie cutters
Toothpick
Tongue stick (plastic is better cleanable than wood)
Table on bed
Medical glasses
Head of the echo machine
OR lamps
Housing infusion pump
Cup
Public transport interior
Toilet seats

Products existing of multiple parts. All need to be sustainable.

Handles
Cardridges casings
Scale
Window shutters
Watch
Alarm clock
Headphones
Steering wheel game controller
Hearing aid
Umbrella
Doctors light with Vibers housing
Head of the echo machine
OR lamps

Products that need to be fire proof

Wall outlet
Power strip
Licht switches with structure
Lamp fitting or lamp shade
Electricity pipes (PVC)
Housing of an fire extinguisher or AED

Products that need to withstand UV radiation

Window shutters
Window frames

Products in which it is difficult to see that it is a sustainable material

Signage boards
Your own picture on Vibers plastic
Floor tiles (mosaic)
Instead of plasterboard to make walls (trespa platen)
Hearing aid
Children helmet for children with flat head
Formable indicator for teeth positions
Hospital card for patients
Tool for position holding in scans (Fixation)
Human prototype (teaching)
Skeleton
Table on bed
Medical glasses
Doctors light with Vibers housing
Head of the echo machine
OR lamps
Housing infusion pump
Hula hoop
Physiotherapy exercises tool like stairs or steps
Clipboard
Stretcher
Licence plates
Mirrors in the car
Gear stick
Handbrake
Phone holder in car
Wiper housing
Theme park decoration
Engine hood
Clothes hook in car
Hotwheels toys

Product that need to be child safe (toxicity)

Toothbrush
Pet toys
Sandbox children (shell)
Fruit bowl
Playhouse for children in garden.
Crafting (class) (for children)
Racetrack for toy cars
Lego/duplo/play mobil
Make your own toys
Toy Crown
Water gun

Children helmet for children with flat head
Bicycle seat for children
Formable indicator for teeth positions
Toothpick
Tongue stick (plastic is better cleanable than wood)
Cup
Cosmetic prosthesis (breast)
DIY mechano toys
Toy racing circuit
Hotwheels toys

Photo frame/painting frame/mirror frame
Iron beads

Products that lose quality by using Vibers

Reinforcement in shoes
Make costumes
Music record
Cookie cutters
Kitesurfboard
Bumper
Crashtest dummy

Different manufacturing method needed

Mannequin

Not as beautiful as original product

Jewellery box
Jewellery
Clutch
Fake plant
Human prototype (teaching)
Cosmetic prosthesis (breast)
Inside of the door (car)
inside of the roof (car)

Products that have no restrictions

Mirror housing
Postboxes on desk
A4 ordner boxes
Photo frames

The ideas are also clustered on their weak spots. For every idea is asked: why is this a bad idea/ why wouldn't it be a success? The outcome of this question are requirements that applications have, that might not be fulfilled. The requirements are:

- Products that need to withstand a specific load
- Products that need to withstand impact load.
- Products that need to be opened and closed.
- Products that need to withstand heat above 50 degrees
- Products that are disposable after use
- One-use products
- Products that need to last in changing weather conditions
- Products that need to be cheap
- Products that need to last for more than 10 years
- Products that need to give comfort
- Products in which Vibers replaces other plastics. Need to be more sustainable.
- Products in which Vibers replaces other materials. Need to be more sustainable.
- Products from which it is difficult to return the material to Vibers.
- Make it yourself is too hot
- Coat hooks + towel hooks (make it yourself)
- Products that need to be easy to clean
- Products existing of multiple parts. All need to be sustainable.
- Products that need to be fire proof
- Products that need to withstand UV radiation
- Products in which it is difficult to see that it is a sustainable material
- Product that need to be child safe (toxicity)
- Products that lose quality by using Vibers
- Different manufacturing method needed
- Not as beautiful as original product

Within those requirements, there is searched for requirements that are interrupting with each other in order to find interesting obstacles for this material

- It needs to be a consumer product **VS.** The material needs to be returned to Vibers for recycling
Example product: beauty products, office supplies, kitchen products

- The product should be durable **VS.** The product should withstand loads
Example product: furniture, building material, sports products

- The product should be durable **VS.** The product should withstand all weather conditions
Example product: garden furniture, signage boards, street furniture

- The product should be durable **VS.** The product needs to be cheap.
Example product: building material, fashion, gadgets

- The product need to be aesthetically pleasing **VS.** The product should withstand loads.
Example: furniture, car interior, glasses

- The product needs to be comfortable **VS.** The product should withstand loads.
Example product: furniture

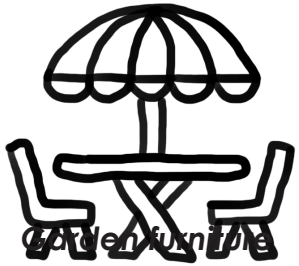
- The product should be durable **VS**. Product needs to be easy to clean.
Example product: medical appliances, kitchen products

- The product should have a natural look **VS.** The product should be made out of plastic.
Example product: garden furniture, decoration in house

- The product needs to be durable **VS.** The product needs to be used a lot.
Example product: glasses, furniture, toys

- The sustainability of the material should be visible **VS.** The product needs to be printed on.
Example product: signage boards

For the rest of the project, one application area is chosen to be used in the 'explore through design' method. The area 'garden furniture' runs against many of the obstacles, and is therefore an interesting area to design and explore a product in.



Appendix 6. Results of the UV test

The results of the weight differences in the UV test are shown in table 1. The weight is measured weekly. At the start of the test, 10 samples (1 to 10) are put under the UV lamp. Sample 11 has never been under the lamp. Every week, one sample is removed and stored in a dark spot. The blue marked values indicate the time they were underneath the lamp. The values are plotted in a graph in figure 2, in which the development in weight of each sample is shown underneath each other. Sample 11 shows little changes in weight. This sample has never been underneath the UV lamp. Samples 1, 2, 3, 4 and 5 show a pattern in which the weight increases in the week after removing it from the lamp. The weeks after that are comparable to sample 11. The weights of sample 7 to 10, which have been under the UV lamp during the whole test, clearly show a comparable development in weight. They have all been under the UV lamp during the whole test. Only sample 6 is an outlier. It is expected that the measurement in the sixth week went wrong.

The conclusion that can be drawn from figure 2, is that the weight of the material decreases when it is exposed to UV light. However, when the exposure to UV light is stopped, the weight increases again to about its original value.

Figure 1. Test setup

Table 1. Weights over time of the 11 samples

Sample	29-4-2020 (start weight)	6-5-2020 (after 1 week)	13-5-2020 (after 2 weeks)	20-5-2021 (after 3 weeks)	27-5-2020 (after 4 weeks)	4-6-2020 (after 5 weeks)	10-6-2020 (after 6 weeks)	17-6-2020 (after 7 weeks)
1	2,628	2,593	2,618	2,620	2,624	2,620	2,623	2,631
2	2,706	2,673	2,670	2,701	2,705	2,702	2,704	2,712
3	2,645	2,621	2,618	2,632	2,653	2,649	2,655	2,659
4	2,640	2,615	2,613	2,626	2,621	2,642	2,644	2,652
5	2,737	2,705	2,702	2,716	2,711	2,717	2,735	2,743
6	2,672	2,649	2,647	2,661	2,656	2,661	2,608	2,689
7	2,657	2,634	2,631	2,644	2,639	2,644	2,634	2,661
8	2,723	2,693	2,690	2,704	2,699	2,704	2,694	2,720
9	2,647	2,607	2,604	2,618	2,613	2,618	2,608	2,634
10	2,634	2,601	2,598	2,612	2,607	2,612	2,602	2,628
11	2,669	2,663	2,662	2,665	2,668	2,665	2,667	2,676

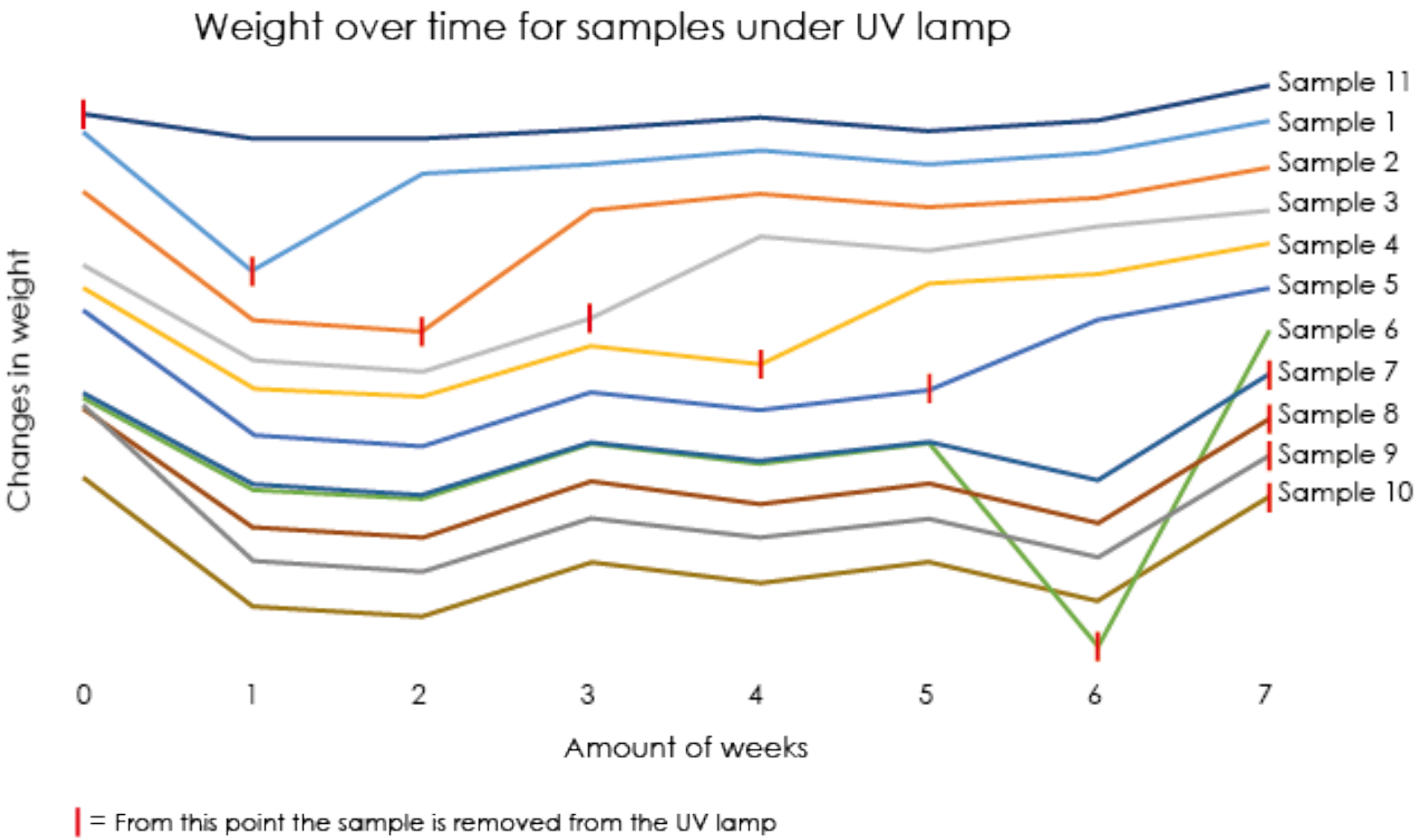


Figure 2. Graph of the results of the weight over time of the 11 samples

Figure 3 show the samples 1 to 7, and 11 after the UV test. There is analysed weather or not the samples had a change in colour. No clear differences were seen on the samples. Therefore is concluded that the material does not fade colour when exposed to sunlight.

Figure 3. No visual collour difference in the samples 1 to 7, and 11.

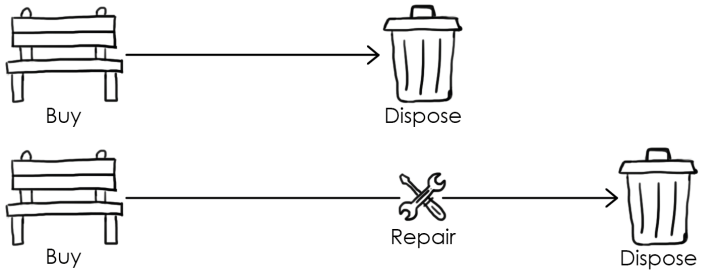
Appendix 7. Circular business model exploration

As seen in section 4, the end-of-life scenario of the bench should be postponed as long as possible. This chapter discusses the possibilities in the technical cycle of the butterfly diagram, by applying different business models. A guideline to setup those models are the eight types of product-service systems from (Tukker, 2004). The product-oriented services and use-oriented services are most applicable for this application. Those services are oriented on respectively adding a service to sale products and changing the ownership of the product to the provider instead of the customer.

Business model 1

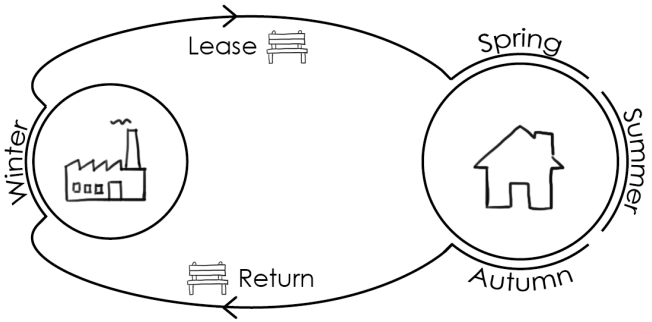
The first business model has a 'product-related service'(Tukker 2004). A maintenance service is applied In order to keep bench as close to the user as possible. In this product-oriented service system the users themselves can ask up information about how to repair their bench. They get a tutorial with simple visuals or videos on how to repair your product yourself.

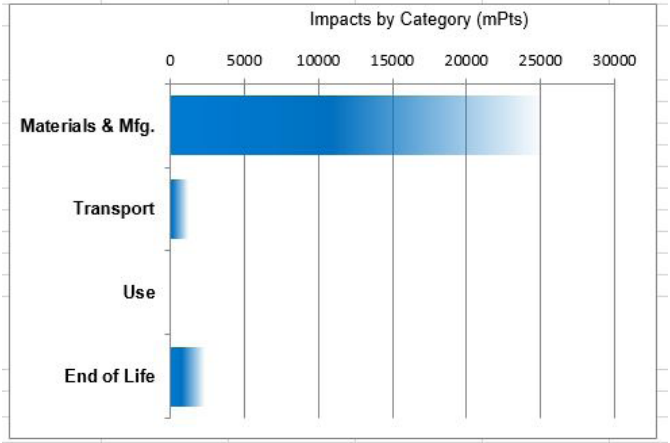
The effect of this model is that people can use their bench for a longer period, and therefore postpone the purchase of a new bench. However it should first be researched with what reason the bench would normally be thrown away. If that is because of boredness with the bench, this is no the right model. Another con is that the Vibers material is not necessary returned to the manufacturer.

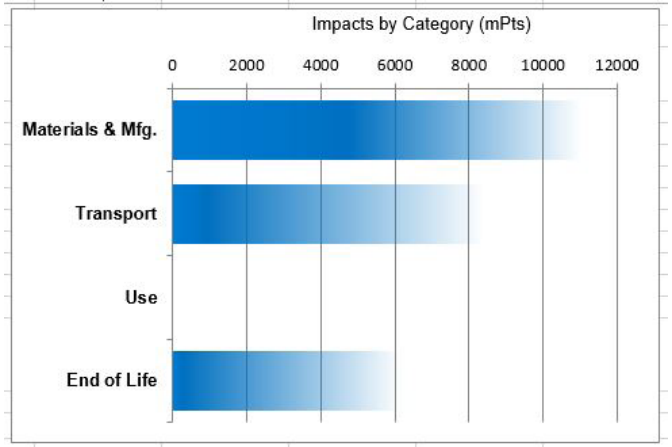


Business model 2

In this second model the bench is leased per season. It is delivered in spring, and in autumn the bench is returned to the shop so that it stays inside for the winter. This use-oriented service makes sure that the bench isn't exposed to the bad winter weather and therefore the bench will live longer. However every season the bench has transport from and to the shop. Figure graphs shows the consideration of the environmental impact of the situation in which a new bench is bought every four years, and the situation in which the bench lives for 6 years, returning to the shop every winter.



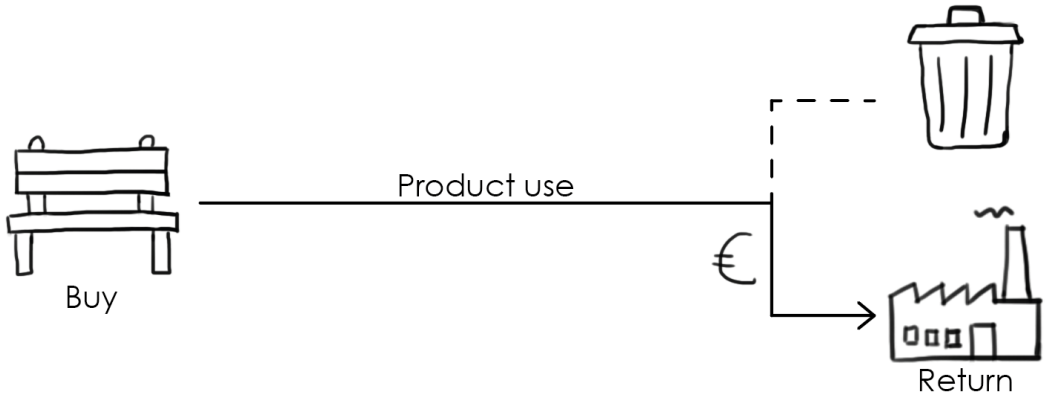




Business model 3

The third business model is also a product-related service (Tukker, 2004), but is based on a take-back agreement at the end-of-life of the bench. A refund is given after handing in the old bench. It is rather easy to implement and it has the benefit that the material will be returned to the manufacturer after use.

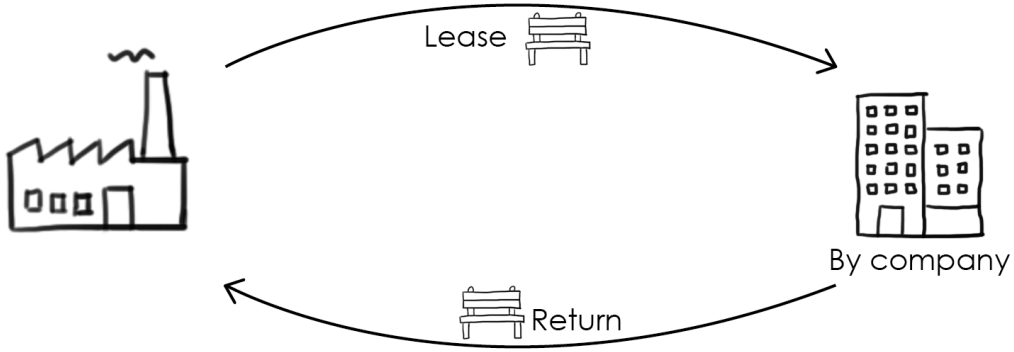
The uncertainty of this model is that the refund might not be attractive enough for people to bring back the couch. This should be researched before implementing this model.



Business model 4

In the fourth business model the product will be part of a business-to-business plan in which a company leasing benches and other furniture. The furniture is still property of the manufacturer and therefore the material can easily be returned by collecting the furniture from the companies.

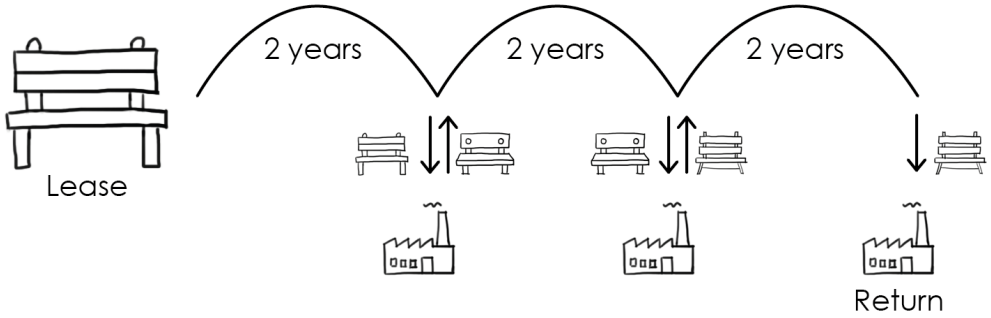
Pro's: certainty that bench is returned.
Con's: bench can not be bought by consumers



Business model 5

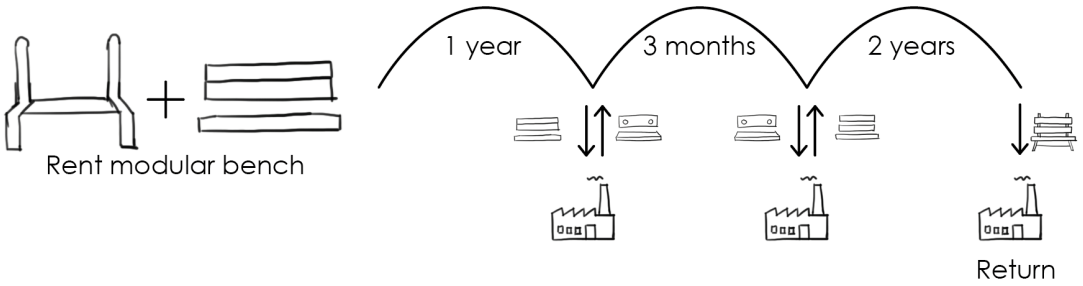
This business model looks like model 2. The bench can be leased per year by consumers. Every year they have the option to return the bench or to keep renting it. The rent gets less every year, encouraging people to use the product longer and to store it during the winter. When the user gets bored of their bench, another bench can be rented.

Pro's: handy for people that change taste quickly.



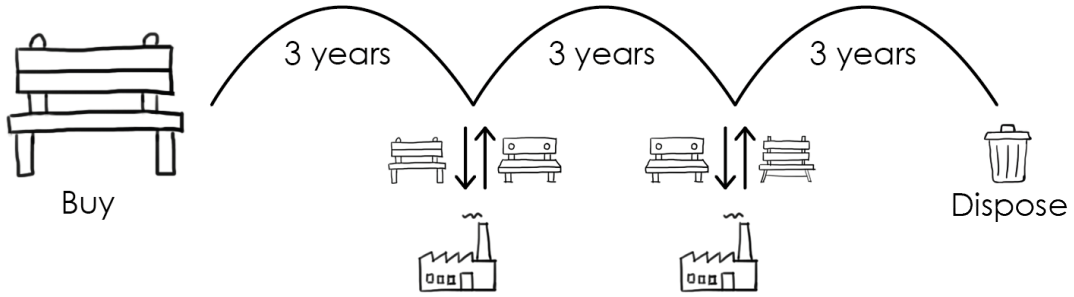
Business model 6: relining service

With this business model the frame and the cover of the bench is bought separately. It is a product-related service where every two years the user has the possibility to change the cover for a small amount of money when the old cover is returned. This way consumers won't become bored of their bench, and the material is returned to the manufacturer.



Business model 7: swap service

With this product-related service business model the bench is bought by the user and there is the possibility to swap the bench every three years for a small amount of money. The bench could be swapped for a new bench or a refurbished one. This way the consumers will not become bored of their bench.



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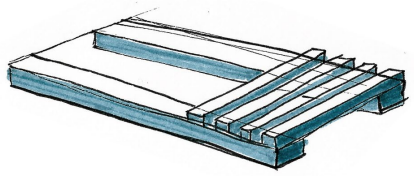
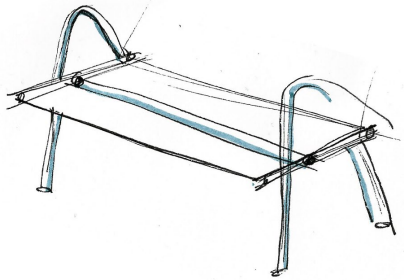
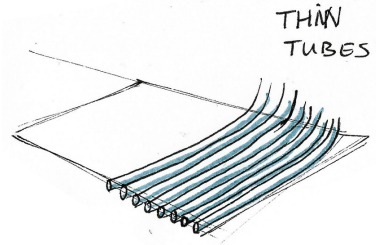
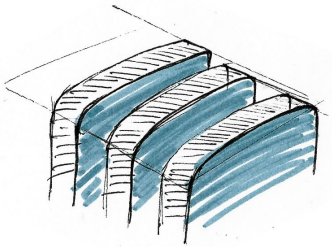
Tukker, A. (2004). Eight types of product–service system: eight ways to sustainability? Experiences from SusProNet. *Business Strategy and the Environment, 13*(4), 246–260. https://doi.org/10.1002/bse.414

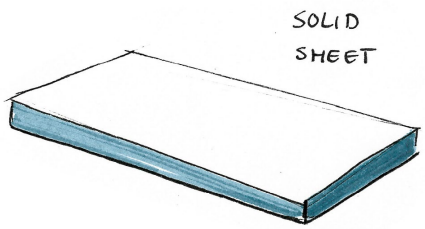
Appendix 8. Shape exploration

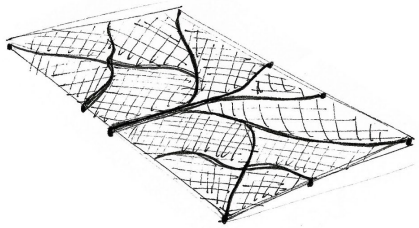


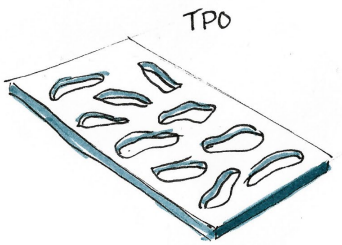


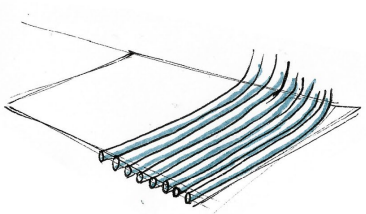


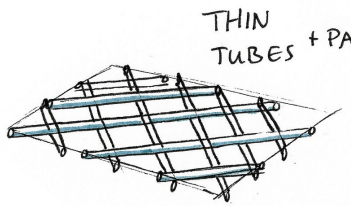


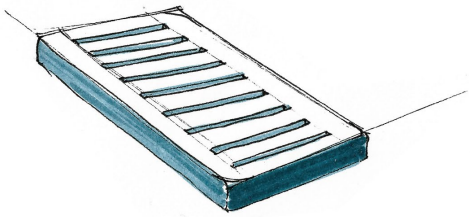


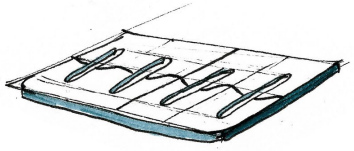


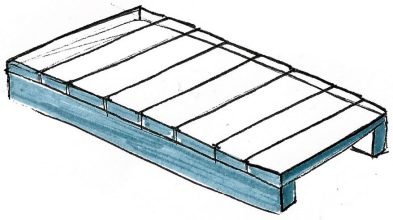


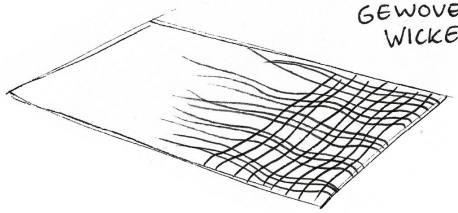


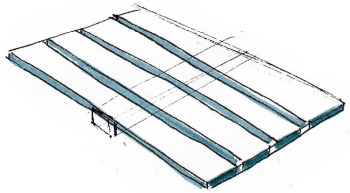


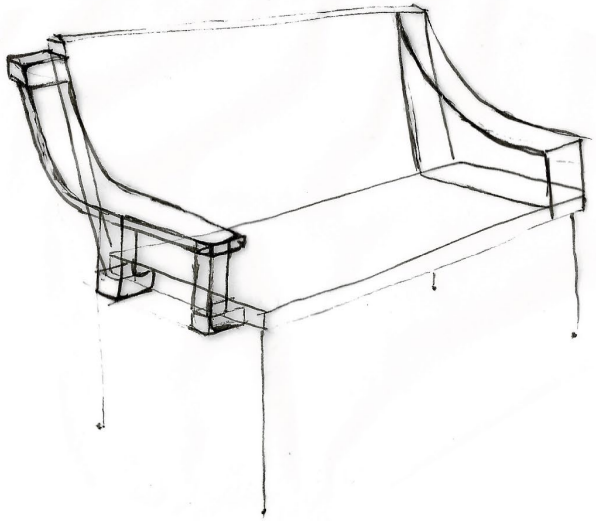


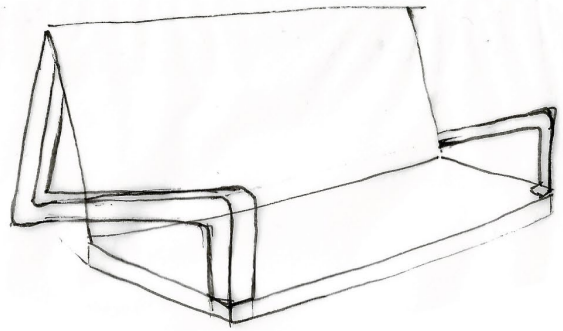


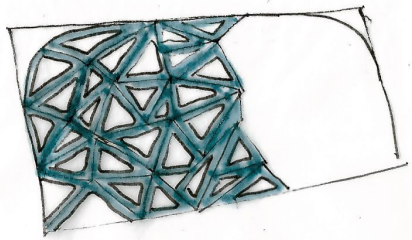


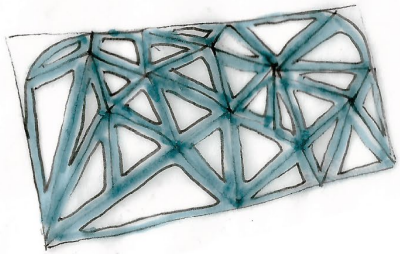


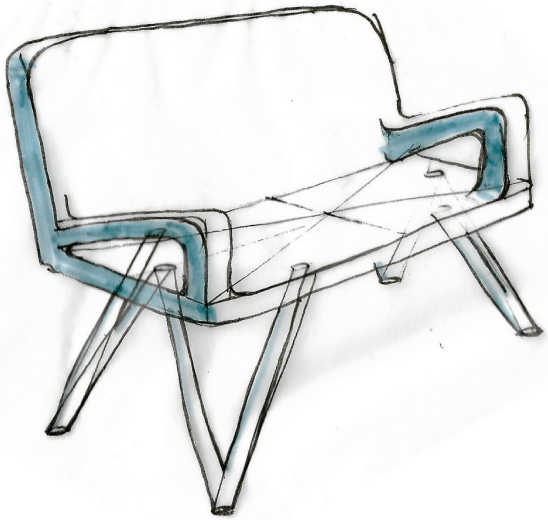


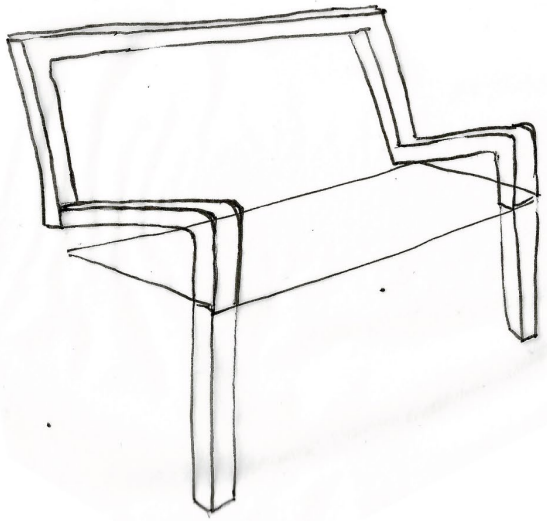


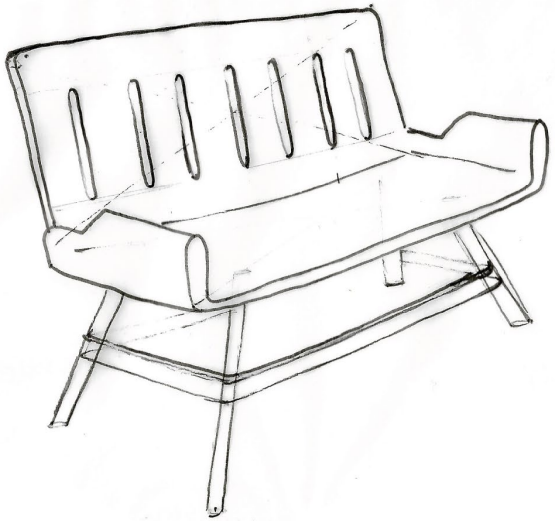


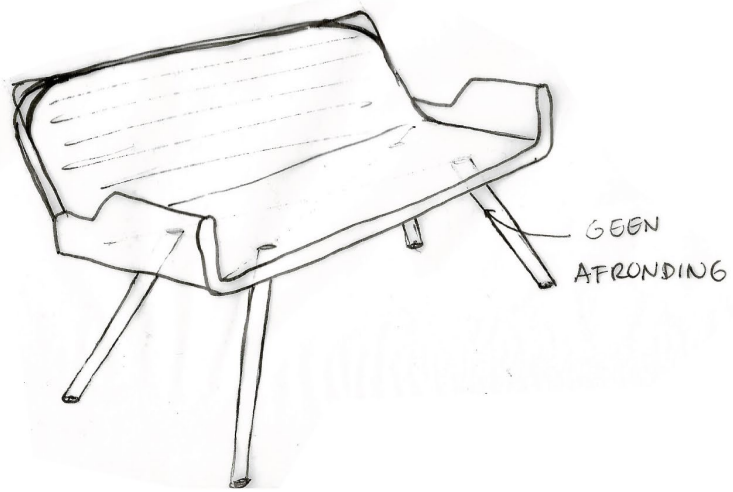








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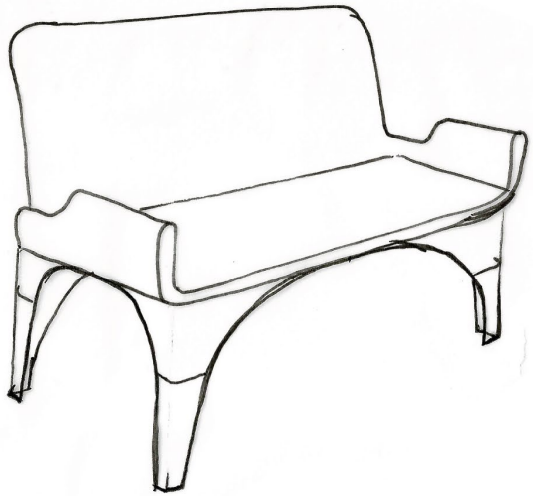

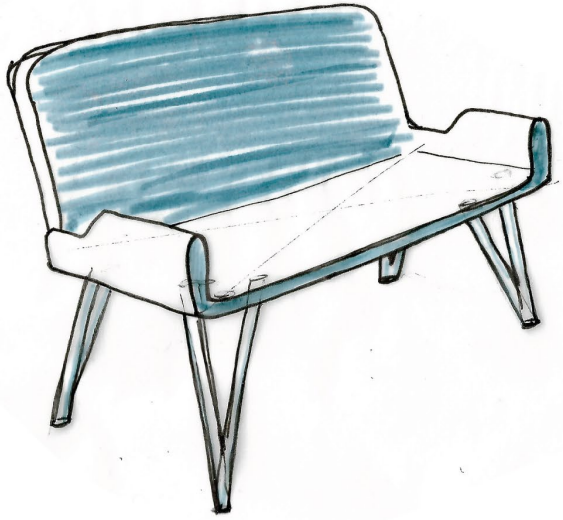

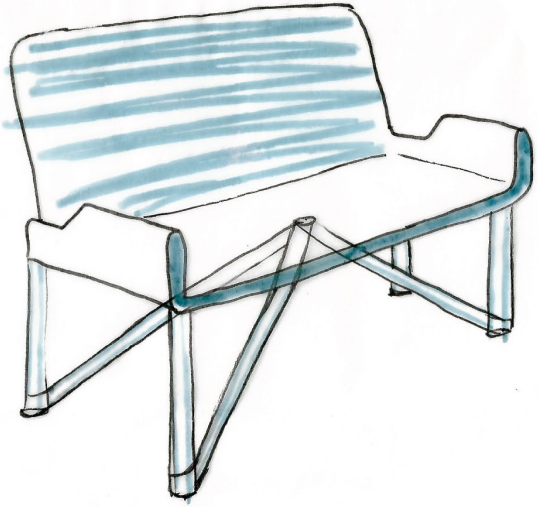

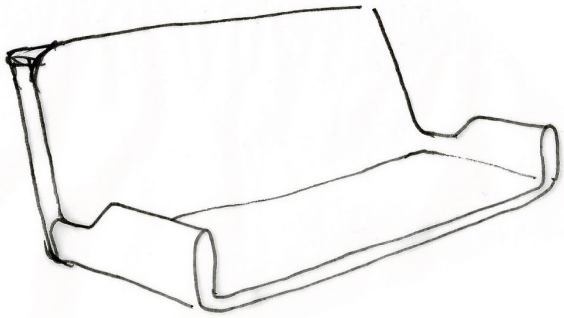

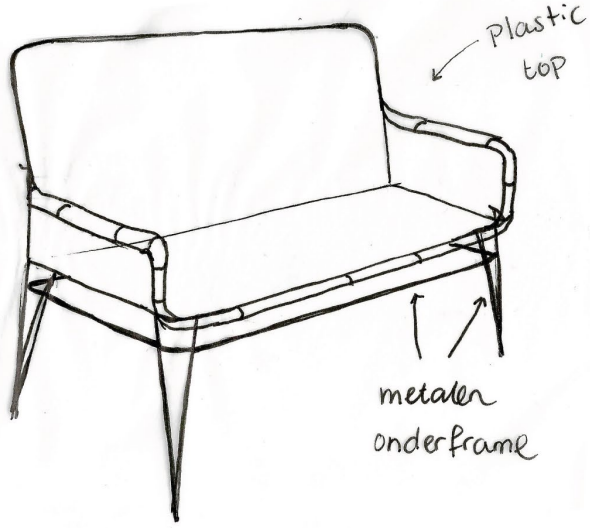
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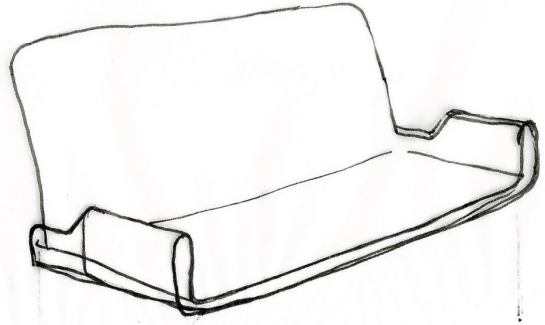
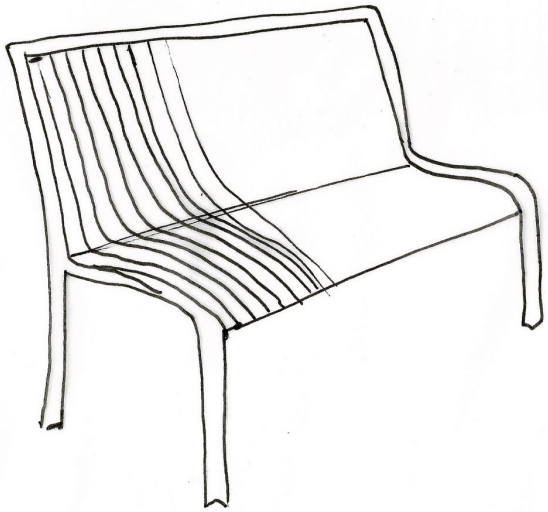
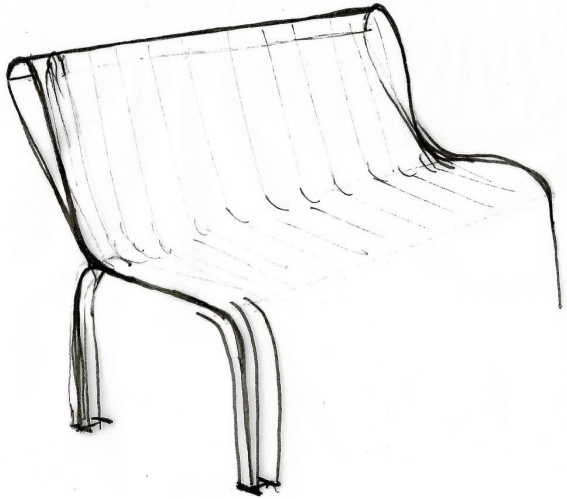
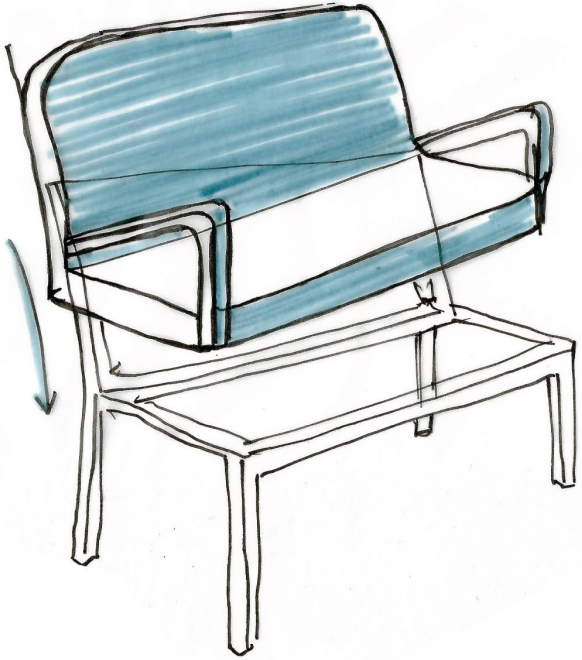
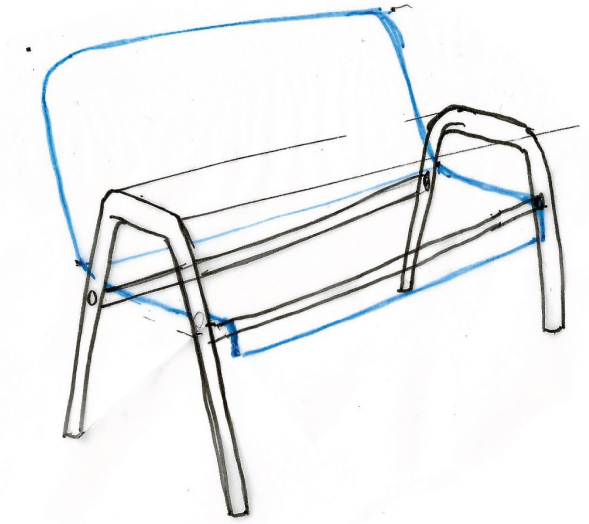
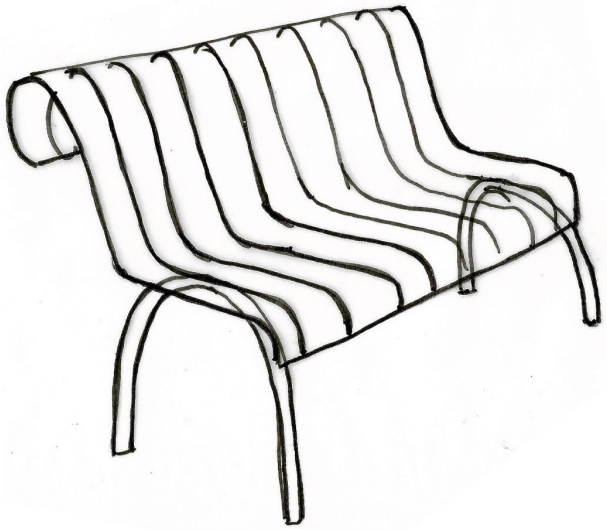


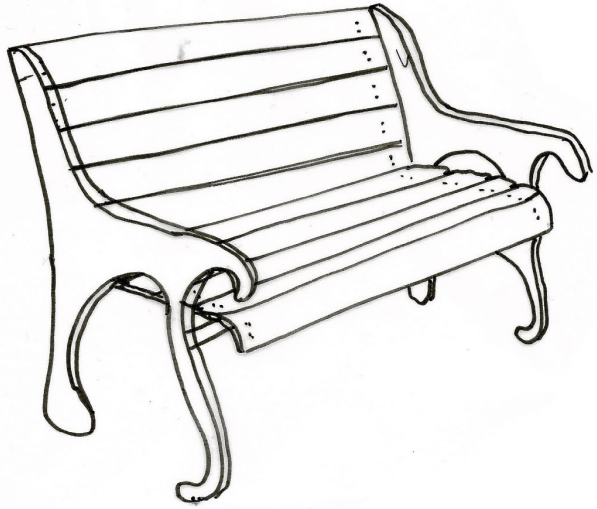


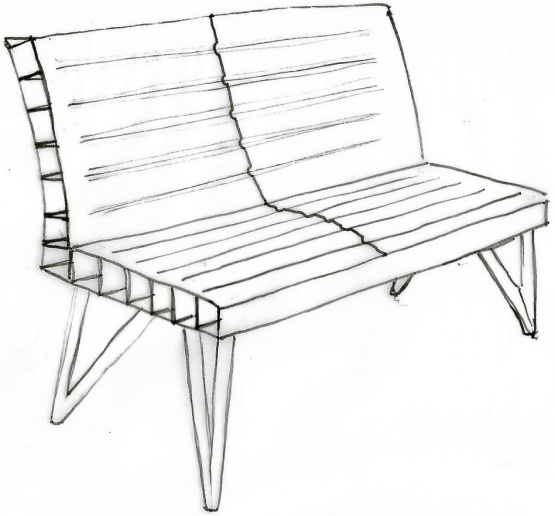


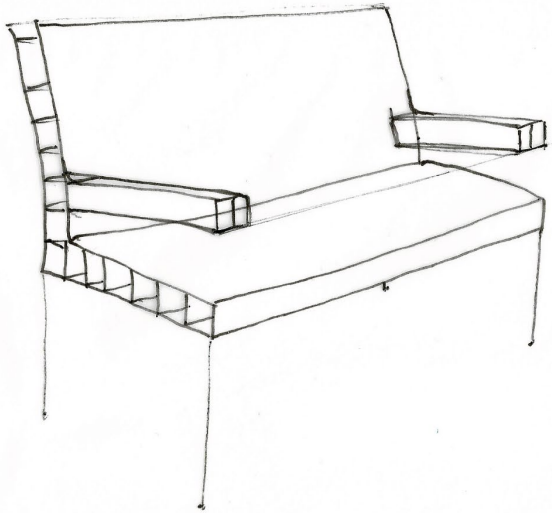


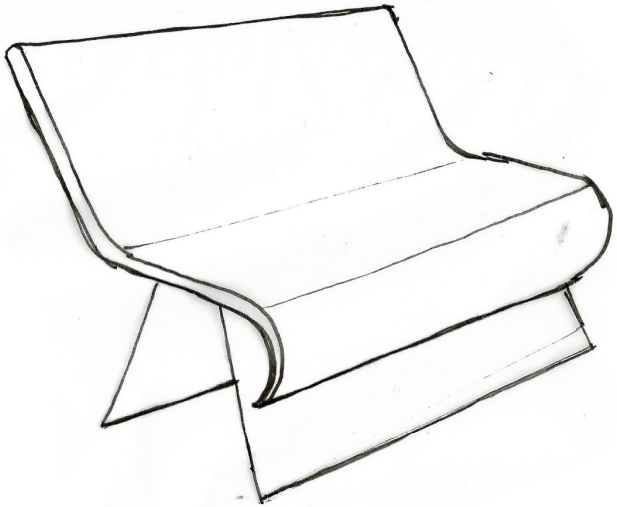


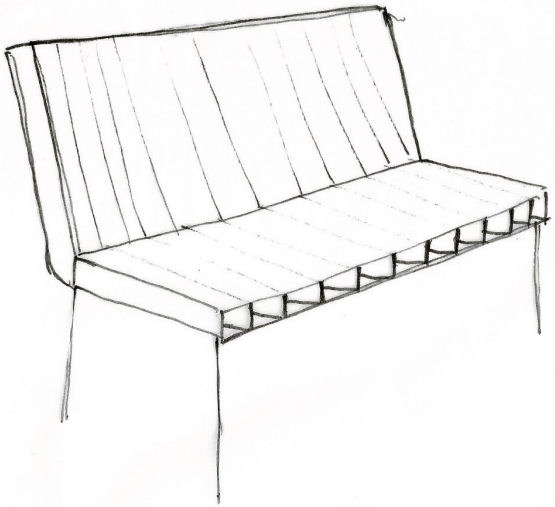


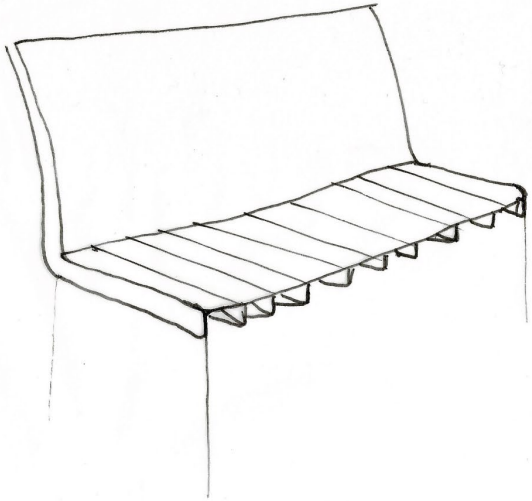


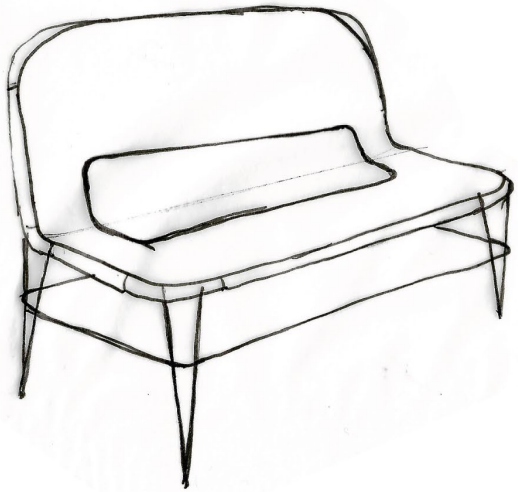




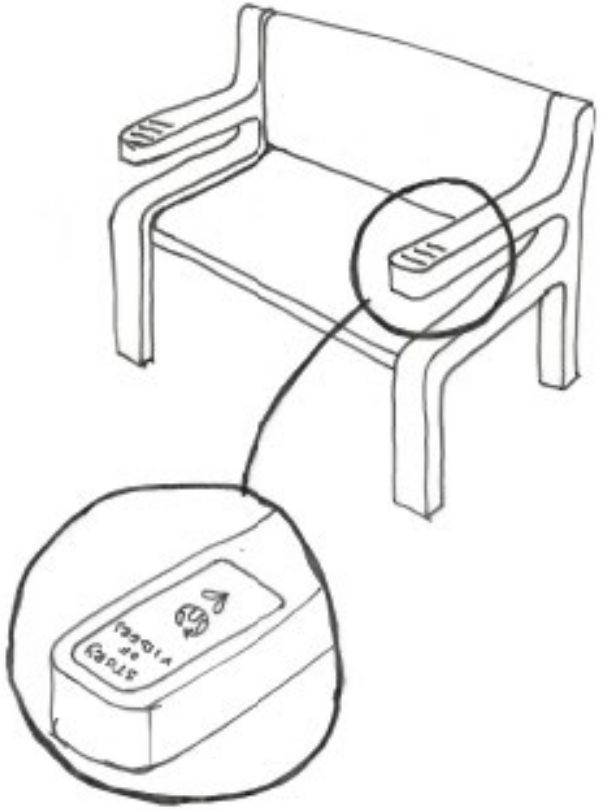








EVERY 2 YEARS A 'NEW' BENCH WITH THE REDESIGN SERVICE

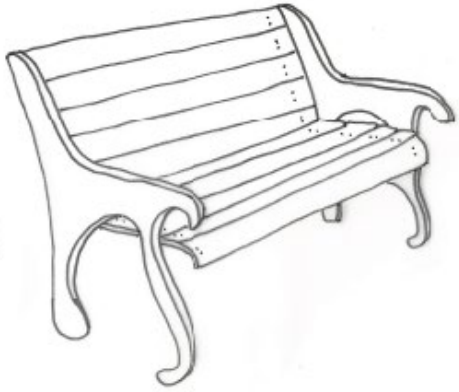


FRAME

MODULAR PARTS ADDED

DIFFERENT PARTS ADDED

RENT EVERY YEAR A NEW DESIGN



Appendix 9. Design brief

DESIGN FOR our future

TU Delft

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IDE Master Graduation

Project team, Procedural checks and personal Project brief

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

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

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

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

STUDENT DATA & MASTER PROGRAMME

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

family name: Zwetsloot
initials: R.D. given name: Romy
student number: 4371674
street & no.: Van Hasseltlaan 668
zipcode & city: 2625JR Delft
country: The Netherlands
phone: 0630659274
email: romyzwetsloot@gmail.com

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

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

SUPERVISORY TEAM **

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

** chair: Ruud Balkenende dept. / section: DfS
** mentor: Martien Bakker dept. / section: PAD
2nd mentor: Fredric Petit
organisation: Vibers
city: Honselersdijk country: The Netherlands

comments (optional)

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

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

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

TU Delft

Procedural Checks - IDE Master Graduation

APPROVAL PROJECT BRIEF

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

chair Ruud Balkenende date 5/3/'20 signature

CHECK STUDY PROGRESS

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

Master electives no. of EC accumulated in total: 30 EC
Of which, taking the conditional requirements into account, can be part of the exam programme 30 EC
List of electives obtained before the third semester without approval of the BoE

(X) YES all 1st year master courses passed
( ) NO missing 1st year master courses are:

name date 10-3-2020 signature

FORMAL APPROVAL GRADUATION PROJECT

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

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

Content: (V) APPROVED ( ) NOT APPROVED
Procedure: (V) APPROVED ( ) NOT APPROVED

comments

name Manon Borgstijn date 02-04-2020 signature MB

Initials & Name R.D. Zwetsloot Student number 4371674
Title of Project To design a suitable application for elephant grass bio-based-plastic

To design a suitable application for elephant grass bio-based-plastic — project title

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

start date 10 - 02 - 2020 — 09 - 07 - 2020 end date

INTRODUCTION **

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

It is big in the news; plastic is everywhere. It is threatening the environment and the animals living in it. CO_2 emissions are high and the earth is warming up. It is clear that humans need to change their materialized behaviour, but how? Making a big change is hard, but what about multiple small changes? A small scale solution could be the use of bio-based-plastic made by Vibers.

About the material
The bio-based plastic from Vibers is made from elephant grass and is biodegradable. An additional benefit is that the elephant grass crops grow on marginal land that is not fit for food production. Furthermore, the crop absorbs about 30 tons of CO_2 per hectare per year, which is four times more than a European forest. The granulate is fit for existing injection molding, extrusion and thermoforming machines. Most of the material properties are tested and known by Vibers.

About the company
The company, Vibers, produces plastic granulate made from elephant grass, and sells the granulate to other companies that are eager to use it in their products (figure 1). All stakeholders and their interests for this project can be found in figure 2. Finding companies to buy the granulate is rather difficult since the material is unknown and it costs more than regular plastic. Right now, Vibers is working with manufacturers to make samples with existing moulds. Those samples are used to show companies what the Vibers material can be used for. However, Vibers is unsure of what products can be modified to use the material.

Uncertainties of the material
A problem with bio-based plastics is that it can be difficult to determine if it is a sustainable material. There are various methods to judge products on how sustainable they are, like the Cradle-to-Cradle method and the Life Cycle Analysis from the Eco-Design method, which could be used during this project. Another problem of bio-based plastic is that the end-of-life scenario is not very clear for the user. Sometimes it is said to be biodegradable, which could mean that it could be thrown in the GFT garbage. However, it is a plastic so maybe it needs to be recycled by throwing it in the PMD bin. In both situations the bio-based-plastic will pollute the garbage stream because it belongs in the regular bin to be incinerated.

To conclude, Vibers invented an interesting bio-based plastic made from elephant grass, that can substitute part of the conventional plastics. However, the material is not sufficiently explored yet. Most material properties are known but how to use its distinguishing properties in design and to identify the best suited applications for the granulate isn't well-known yet.

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introduction (continued): space for images

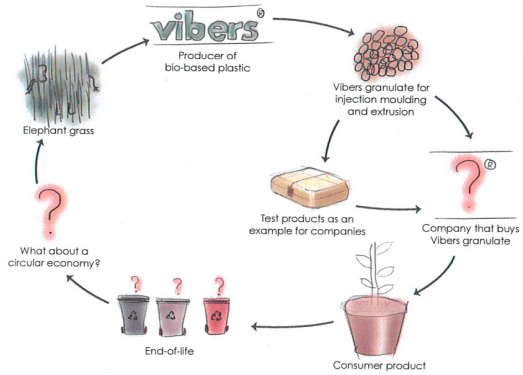


image / figure 1: Context of the current material

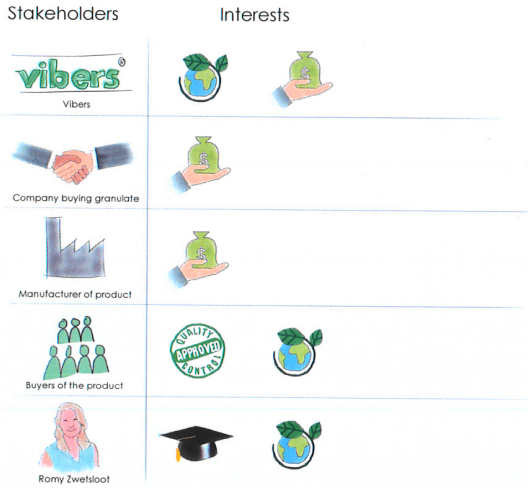


image / figure 2: Stakeholders of the project and their interests

PROBLEM DEFINITION **

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

The company Vibers wants to expand the range of companies that buy their bo-based plastic granulate. They are unsure of what products fit the material, and if there are products that could have a specific benefit by this material. Right now, they try out different applications by trial and error. A more structured way of opportunity finding to identify the right fit for their material is needed.

ASSIGNMENT **

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

Identify appropriate applications for the bio-based-plastic from Vibers and design a suitable concept product that fits the properties of this material and is illustrative for the application area.

The expected outcome of this research is a range of suitable applications for the Vibers plastic and a concept design of one relevant application. It depends on the complexness of the product how far the concept can be elaborated on. I will aim for the following results: a concept drawing, specifications of the product at concept level and a prototype of the design. The applications will be validated by approaching design companies that could be the buyer of the material to ask for their opinion. The concept design can help convincing a company as a proof of concept.

PLANNING AND APPROACH **

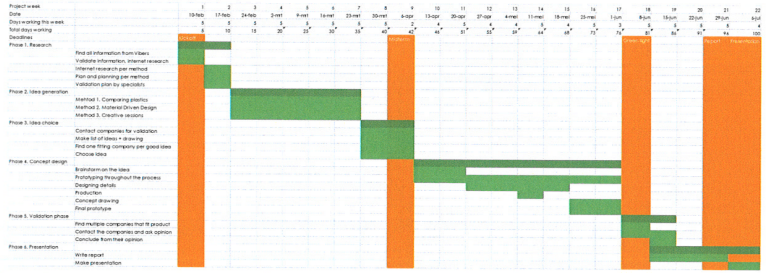
Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20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

start date 10 - 2 - 2020 9 - 7 - 2020 end date

Graduation plan

Phase 1. Research	Phase 2. Idea generation	Phase 3. Idea choice	Phase 4. Concept design	Phase 5. Validation
Get to know the material	Method 1. Comparing plastics	Contact companies for validation	Brainstorm on the idea	Find multiple companies that fit the concept
Find all information from Vibers	Method 2. Material Driven Design	Make list of ideas + drawing	Prototyping throughout the process	Contact the companies and ask opinion
Validate this information via internet research	Method 3. Creative sessions	Find one fitting company per good idea	Designing details	Conclude from their opinion
Internet research per method		Choose idea dependent on what companies think of it	Production	
Plan and planning per method			Concept drawing	
Validation plan by specialists			Final prototype	

Graduation planning



Note: The planning shows how many days I work per week in the third row of the table.

Kick-off meeting: 11 February 13:30 at Industrial Design Engineering
Midterm: 7 April 13:30 at faculty Industrial Design Engineering
Green light: 11 June 11:00 at faculty Industrial Design Engineering
Graduation: 9 July 10:45 at faculty Industrial Design Engineering
Chair and Mentor meetings: Every two or three weeks, and regularly a meeting with both.

During the ideation phase I want to use a structured approach with different opportunity finding methods to generate ideas. Examples of methods I want to use are:

Method 1: Comparison of regular plastics and bio-based-plastics and the applications they intrinsically fit best.
Most of the material properties of the Vibers granulate are known. It would be valuable to compare this material to regular plastics and other bio-based materials since materials with similar properties could have suitable examples of applications.

Method 2: Material Driven Design (MDD).
When using the MDD method, a material is the starting point of the design process. The goal is to design a product that fits the material well and provides a specific material experience. An interesting problem to tackle with this method could be creating awareness of how to dispose the product after usage.

Method 3: Creative sessions.
A creative session on opportunity finding can give a broad range of ideas for applications for the Vibers material. This method is interesting since it can be held with the employees of Vibers. When a good idea is introduced by one of the employees their selves, the willingness to implement this idea could be much higher than when I introduce an idea.

Personal Project Brief - IDE Master Graduation

TU Delft

MOTIVATION AND PERSONAL AMBITIONS

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

During my masters education I found a big interest in sustainability topics. This combined with the interests for material properties and manufacturing methods, makes this assignment a great fit. When I heard of Vibers, I was convinced that I had to do my graduation project at their company

The competences that I acquired during my masters:

- Facilitating creative sessions
During the course Creative Facilitation I learned how to use creative methods with people that are not used to the IDE approach of finding ideas. I would like to practice another session, with exercises on opportunity finding.

- Sustainable design methods
During the course sustainable design strategies I learned how to implement 'Eco-design', 'Biomimicry' and 'Cradle-to-Cradle' in a design project. I would like to use the knowledge about those methods during my graduation project.

- Graphic skills
I was never very good at visualising my ideas, but since I followed the course 'computer sketching', I feel much more confident about my graphic skills. During my graduation I want to show what I have learned.

Competences that I want to learn during my graduation project:

- Material Driven Design
Material Driven Design is an interesting design method that I learned about when preparing my graduation project. I would like to know more about it, therefore I want to use the method in my project.

- Personal: regulating energy.
In the last couple of years, stress levels went over de limit many times. The result of this was never a better project, but it resulted in insecurity and tiredness. Since a few months I am getting help for this and I am starting to change my behaviour and regulate my energy. The goal is to reflect on my mental health every once in a while during my graduation project.

FINAL COMMENTS

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

Initials & Name R.D. Zwetsloot Student number 4371674

Title of Project To design a suitable application for elephant grass bio-based-plastic