Product client
:
New Applications for Seagrass

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Saxion University of Applied Sciences
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Project introduction

Preface

This is the final report for the Smart Solutions Project ''New Applications for Seagrass.'' In this report, we will present you the research that we have done for the material seagrass. We investigated the technical specifications of seagrass, the possibilities to make a new application out of the seagrass and we made a communication plan to create more awareness towards sustainability. This was done by a project group of 8 students with all very different backgrounds.

This project group was part of a bigger project from ArtEZ University where three different project groups from ArtEZ University, Saxion University of Applied Sciences and Wageningen University worked together to find more information about the material seagrass under the guidance of Michelle Baggerman, Marijke Bruggink and Conny Groenewegen. The Smart Solutions Project from Saxion was guided by Ruben Sinkeldam and Taco van Loon.

We would like to thank Michelle Baggerman, Marijke Bruggink and Conny Groenewegen for the guidance of our project as client and Ruben Sinkeldam and Taco van Loon for the guidance from Saxion.

Enschede, January 21st, 2022
Fleur Abbink, Sieme van As, Bart ten Den, Elio Fissore, Niels Masselink, Mel Rolink, Anna Schäfer, Michel Tieberink

Introduction

The purpose of this introduction is to provide the context in which the research project "New Applications for Seagrass" is carried out. It contains a description of the Smart Solutions project, project stakeholders, and the project group. It describes the context and problem of the research. The sources used for the introduction are the meeting with the client, the company's website, and the annual reports.

Smart Solutions Project

As part of the Smart Solutions semester at Saxion University of Applied Sciences, the group will be working on the project "New Applications for Seagrass" from September 2021 till January 2022. Smart Solutions projects are created for students to cope with the working field of the future. In this research and development semester, students work in groups of 6 to 8 students from at least three different studies on a complex problem, provided by a company or a Saxion lectorate. Each group is accompanied by a tutor who will supervise and coach the students in the project. Ruben Sinkeldam and Taco van Loon will be our tutors during this project. In this project, the group will be researching whether it is possible to turn seagrass into a sustainable textile application and how to raise awareness for this new sustainable material application.

Project Stakeholders

This research project is a collaboration between three parties: the Smart Solutions semester research group from Saxion University of Applied Sciences, Wageningen University, and ArtEZ University. The stakeholders involved in this project are further explained in the next subchapters.

Wageningen University

Wageningen University is involved in this project by conducting literature research. The mission of Wageningen University is "to explore the potential of nature to improve the quality of life". The university works for various businesses, the Dutch government, and social-cultural causes. Since the Wageningen University research group has its deadline for the final deliverable in October, the results will be useful for the Smart Solutions project. In addition, the basis of this project is somewhat related to Wageningen University, as they have conducted a study on the state of the Netherlands in 2120.

ArtEZ University

ArtEZ University offers education in art in three cities: Arnhem, Enschede and Zwolle. In this project, ArtEZ University in Arnhem will be involved with the department "Future Makers". ArtEZ is a university that emerged from a fusion of several art, conservatory, and theatre programs. Nowadays, all locations have their own focus on some of the previously mentioned components. In Arnhem, the focus is on art and design, dance, drama, conservatory, and architecture. Besides being the client in this project, ArtEZ also provides research results for this project by students. Their research will mainly focus on the design and possible oil recovery of seagrass. Finally, Conny Groenewegen and Marijke Bruggink are involved in the project through ArtEZ, and as clients. Conny Groenewegen and Marijke Bruggink are both designers and strive to change the fashion industry. Both have done preliminary research on this topic and will be closely involved and regularly updated.

Project Group

In the following subchapter, the project group of Saxion University of Applied Sciences is presented in more detail. The expectations of the client and the group are named as well as the roles resulting from the expectations of the client and the group.

Roles in the Project

Since the client has asked us to research possible applications for seagrass as well as create awareness of this new, sustainable material, the research will be divided into two groups. The first group is the technical group, this group consists of Anna, Bart, Niels, and Sieme, who study Fashion and Textile Technologies and Biomedical Laboratory Research. The second group, Marketing and Communications, consists of Elio, Fleur, Mel, and Michel who study International Business, Commercial Economics, and Creative Business. Both groups will continue to work together as a team and discuss frequently. Meetings will be held together, and we will work in an interdisciplinary manner. Niels is the note taker during meetings. Fleur is the contact person for everyone involved through Saxion, while Michel is the contact person for the clients. Mel is responsible for any creative or artwork.

Problem Statement

Currently, torn loose seagrass is considered a waste product of the sea, it grows on the bottom of the sea and is washed up on the beaches. The beaches of the Baltic Sea and other European marine regions are filled with seagrass every night, which must be removed before sunrise so that beachgoers can enjoy their day. But what happens to all this seagrass? Some of it is used for insulation, fertilizer, or as a base for dunes. With the impending tightening of laws, this may not be possible in the future. Eventually, there will be no place for the seagrass and no money to dispose of it. Since it is a waste product directly from the sea, people do not associate it with a pleasant feeling. But seagrass could be used for various applications and encourage the use of more sustainable materials. Since our planet is in a bad state, the use of more sustainable materials and local production is a must. Seagrass seems to be a possible solution. This project will therefore investigate possible sustainable textile applications based on seagrass and propose a communication plan to create awareness about the use of more sustainable materials.

Research Objective

To investigate the possibilities for a sustainable textile application based on seagrass, along with a communication plan to create awareness for this new application to Conny Groenewegen and the ArtEZ Future Makers group, before 21 January 2022.

Lab research

Lab research

Preface

This report covers the technical specifications of seagrass, potential fibre production methods as well as potential applications for seagrass. For the Smart Solutions Semester at Saxion University of Applied Sciences, a research report has been written for the project "New applications for seagrass". For this project, we conducted a literature review, several expert interviews, laboratory research and prototyping. This report contains various topics that are determined, such as the introduction, the methods, the results, the conclusion, and the recommendations.

Main research question: What are the possibilities to produce a sustainable application made from seagrass in the Netherlands?

Sub-questions:

1. What are the technical specifications of seagrass?
2. What are possible fibre production methods for seagrass?
3. What are potential applications for seagrass?

Summary

Bio-based materials and applications that use bio-based resources are seen as a sustainable alternative to materials and applications currently in use. In response, new biological material sources are gaining attention. Seagrass is a material that is currently considered as an unpleasant waste product. However, if new applications are found for seagrass, the material can be transformed into a useful and valuable resource. The aim of the research is therefore to gather knowledge and information about seagrass as a material, to identify potential applications for seagrass and to raise awareness about the use of seagrass as a material resource. The research strategy implements six elements: 1. Literature review, 2. Preparation, Conduct and Analysis of Expert Interviews, 3. Laboratory Research, 4. Prototyping, 5. Derivation of conclusions and 6. Development of recommendations. In laboratory tests, the cellulose content of the seagrass plant was determined. The results show that the percentage of cellulose in the seagrass is between 24-32%. The antibacterial property of seagrass was also tested. The seagrass did not show any antibacterial activities. This means that seagrass itself has no antibacterial properties. It could be that the seagrass extract is antibacterial. However, this was not within the scope of this study. The research shows that there are many concept ideas that can be used for bio-based applications with seagrass: Seagrass packaging material, seagrass leather, dyeing etc. It is important to distinguish between existing concepts such as the use of seagrass as nature-based coastal protection, fertilizer, filler material, or environmentally friendly surface and novel unproven concepts such as seagrass packaging material, seagrass leather and pulp production. All novel applications need further validation, demonstration, and commercialisation. However, they do offer an idea of what is possible and could form the basis for further research. Regarding textiles made from aquatic plants such as seagrass, companies and material innovators should work together on more in-depth research, as current production processes could be used for bio-based materials from seagrass but have not yet been explored.

Methods

This chapter explains the qualitative and quantitative research methods used to answer the main research question and sub-questions. Qualitative methods of data collection included a literature review, expert interviews, and laboratory research. Quantitative methods included quality research.

Literature Review

A literature review was chosen as a qualitative research method to investigate the technical specification of seagrass and analyse existing methods for fibre production. Sub-questions 1, 2, and 3 were partially answered based on the literature review. Relevant studies were collected, reviewed, and the methods were analysed for relevance. Subsequently, they were compared, and a conclusion was drawn as to which method is best suited to produce textiles or textile applications from seagrass. These data allowed a better understanding of the possible production process of seagrass fibres and could also serve as a basis for interviews and laboratory research. In addition, the results of the laboratory tests could be compared with published data, for example, on technical specifications.

Expert Interviews

Expert interviews were chosen as the second method of data collection in order to gather expert knowledge in much greater detail to answer sub-question 2 and 3. In this way, complex questions could be better explained, and the interviewee could supply added insights into textile production and potential applications for seagrass. It also provided an opportunity to learn about the interviewee's perspectives and feelings, particularly when using open-end questions and engaging in discussion.
Table *1* below shows a list of the interviewees who had partaken the interview. A small description of the interviewees' profession and workplace is mentioned in the table.

Table 1 *Overview expert interviewees*

Interviewee	Professional position
Interviewee 1	Jens Oelerich - Associate Lecturer Sustainable Textiles at Saxion University of Applied Sciences
Interviewee 2	Felix Pöttinger – Master of Arts Product Designer
Interviewee 3	Manager for New Business Development of Smartfiber AG

Each interviewee is given a different number in order to identify each interviewee.

Face-to-face Interview

In order to obtain and conduct a video call interview with an expert in the field of pulp and fibre production processes, extensive research was first made on the available production processes and seagrass applications. Jens Oelerich, associate lecturer in sustainable textiles at Saxion University of Applied Sciences, was deemed relevant to the research and general project management and an email was sent to him. The interview was arranged and conducted in a personal call via Microsoft Teams. During the meeting, the interviewer asked the already selected questions about fibre extraction, pulp production, advantages and disadvantages, and project management. After the interview, the meeting was transcribed and coded based on the grounded theory (DelveTool, 2021) for better analysis of the research results. Open coding and axial coding were the two steps to analyse the qualitative data. In open coding, the transcript was broken down into individual parts, which were given codes. In the second step, axial coding, connections were drawn between the codes and categories were marked with codes. Lastly, an overview of all axial codes and the associated open codes and the person who said them was created.

Written Interviews

Secondly, extensive research was conducted on the technical specifications of seagrass, textile processing and potential applications. When a company was deemed relevant to the research and more information about their work was needed, an email was sent in the contact section of the website. As some of the experts did not feel comfortable or did not have time for a face-to-face interview, written interviews were conducted. The interviewed experts work for two different organizations: Felix Pöttinger Design and Smartfiber AG. The organisations and experts were contacted if they had any relation to using seagrass as a material, fibre production processes, and new material innovations. The first mail was a general mail asking if the experts would be willing to provide the researchers with more information about fibre production processes, especially aquatic plants and seagrass, innovations, and developments. The experts directly gave the researchers more information and answered the questions in detail. Different follow up questions related to the research topic were then emailed by the researchers. After the interviews, the mails were transcribed and coded for better analysis of the research results. This was done in the same manner as for the face-to-face interview.

Laboratory Research

Laboratory research includes material experiments to answer sub-questions 1, 2, and 3. The methods found in the literature research for producing fibres from seagrass are tested in a trial-and-error approach in the laboratory of Saxion. In the laboratory, the cellulose concentration was measured, the possible antibacterial property of seagrass was analysed, and pulp was produced made from seagrass.

Cellulose Determination

To answer sub-question 1 and learn more about the chemical composition of the seagrass, the cellulose content of the cell wall in the seagrass was determined. For this purpose, different methods for cellulose determination were investigated with the use of google scholar and PubMed. Several methods that were used to determine the cellulose content made use of infrared spectroscopy (Li, Sun, Zhou, & He, 2015). However, these materials were not available in the Saxion laboratory. Therefore, another method was used. This is the Nelson method. In this method, the cellulose is determined by breaking the cellulose molecule down into glucose molecules (Biocyclopedia, n.d.). The concentration of glucose was determined by the Nelson method. All the glucose was derived from the cellulose. This means that the concentration of glucose was the same as the concentration of cellulose.

For this determination, 33% sulphuric acid was made from concentrated sulphuric acid. 2 grams of seagrass was weighed and hydrolysed in 100 ml of 33% sulphuric acid in a shaking stove for 24 hours. 1 ml hydrolysed seagrass was taken and used as the sample. The samples were neutralised to a diluted to a concentration of 50 mg/ml hydrolysed seagrass. Nelson reagents were prepared by using the following protocol (Biocyclopedia, n.d.). A glucose standard line was made with concentrations from 0 mg/ml till 100 mg/ml. All the samples were cooked in a water bath for 20 minutes and were cooled on ice. 1 ml ammonium molybdate reagents was added to all the samples. This was incubated for 10 minutes at room temperature. The absorption of the samples was measured by 510 nm. Cotton was used as a referencing material because cotton is almost completely made from cellulose. This was used as a positive control for this method.

The Nelson method turned out to be inaccurately to only determine the cellulose in the seagrass. The lignin and the hemicellulose interfered with this method which made the results inaccurate. Then a next method was found, the Updegraff method (Kumar & Turner, 2015). In this method, the seagrass was cut in pieces with a length of 5 cm. These were washed with ethanol and then with acetone. This was incubated overnight. The seagrass was then incubated with acetic/nitric reagent to remove the lignin and hemicellulose from the seagrass. The cellulose is resistant against this reagent.

The cellulose from the samples was then hydrolysed into glucose molecules using 67% sulfuric acid for one hour in a shaking stove. The glucose was turned into furfural and that could be determined with anthrone. With the concentration of furfural, the concentration of cellulose could be calculated. A detailed step-by-step guide of the procedure can be found in Appendix A.

Antibacterial Properties

A possible characteristic of seagrass is that it might be antibacterial. In this part of the research, we wanted to investigate how antibacterial the seagrass is and how this characteristic could be used in different applications. The antibacterial properties of seagrass were determined with the use of the bacteria *E. Coli*. This is a very common bacterial specie that is relatively easy to grow. The first test was to add different concentrations of seagrass solution (the seagrass was diluted in sulfuric acid to break it down and get it in a solution) to *E. Coli* cultures. The second test was to mix the seagrass with the nutrient agar in different concentrations and add *E. Coli* cultures to it. This test was also done by grinding the seagrass with a mixer/mortar and add different concentrations of *E. Coli* suspension to it. The *E. Coli* suspension was made by adding *E. Coli* cultures that grew on a nutrient agar plate to sterilised 0.9% sodium chloride solution until a bacterial suspension of 0.5 McFarland is reached. Six plates were incubated with each a higher concentration of grounded seagrass. On every plate, 100 µl *E. Coli* suspension was added. These plates were incubated for 24 hours at 37°C. After the incubation, the colonies on the plates were counted.

Pulp Production

To make pulp from seagrass, the process of papermaking as described by Syed et al. (2016) and Dulmalik et al. (2019) was used. The seagrass fibres were soaked in demi-water and then boiled in a solution of sodium hydroxide to clean the fibres. After two hours of boiling, the seagrass was ready to be processed into pulp. Now the fibres could be separated from the seagrass by hand-beating with a wooden mallet. A detailed step-by-step guide of the procedure can be found in Appendix B.

Prototyping

Finally, small-scale prototyping was carried out to decide whether the production processes researched are suitable for further applications and to answer sub-question 3. The prototyping aimed to prove the concept ideas. Key quality standards and properties, such as sufficient strength in dry conditions, were also outlined and tested in initial out-of-the-box experiments.

Seagrass Packaging Material

The aim of this experimental research was to find out whether *Zostera marina* can be used to produce a seagrass packaging based on the process used by Felix Pöttinger for his POC material (seagrass packaging) and what the optimal processes and conditions are for the material. The ingredients used are dried seagrass, which is chopped into pieces, and wallpaper paste made from methyl cellulose. In the beginning, the protocol was developed as follows.

1. Drying of seagrass
2. Cutting the dried seagrass into pieces
3. Mixing binding agent (cellulose-based wallpaper paste)
4. Mixing binder and seagrass pieces
5. Apply the mixture onto backing paper
6. Drying for 24 hours
7. Removing material from backing paper

Adjustments were then made to achieve a better durable material. This included different mixing ratios of binder and seagrass pieces.

Seagrass Leather

Vegetable and fruit leathers are gaining more and more attention as a sustainable alternative to artificial leather based on plastics. For apple leather, for example, postproduction waste from apple cultivation (shells, core housing, stems) is used. To produce apple leather, 50% apple waste is mixed with 50% Poly Urethane (PU), and coated onto a cotton/polyester canvas (Oliver Co. London, n.d). Other production sites mix a solvent, a biodegradable plastic substitute made from milk protein and the apple waste in powder form to produce the coating for apple leather production (Galileo, 2016). The aim of the experimental research was to find out if seagrass can be used to make a seagrass leather based on the process commonly used for fruit leather and what the optimal processes and conditions are for the material.

The ingredients used are dried seagrass ground into a powder, casein (from milk) as an alternative to the plastic substitute and baking soda dissolved in water as a solvent. In the beginning, the protocol was developed as follows.

1. Drying of seagrass
2. Milling of dried seagrass to fine powder
3. Mixing vinegar with milk, filter the casein
4. Mixing seagrass powder and casein + baking soda + water
5. Applying the mixture onto a cotton base fabric
6. Ironing of material

Adjustments were then made during the research to achieve a better durable material. This included different mixing ratios of seagrass powder, casein, baking soda, and water. As well as, adding vegetable oil and washing the material.

Dyeing

A by-product of the pulp production process is black liquor. This is the liquid that remains when the seagrass is boiled for two hours. It has a strong dark colour, hence the name black liquor. This liquid was used in this experimental research to dye an untreated cotton cloth. The cotton cloth was boiled in water to open the fibres and the black liquor was heated again. Then the cloth was placed in the black liquor for 24 hours.

Results

Given the large amount of seagrass that washes up on European beaches every day, the Dutch designers Conny Groenewegen and Marijke Bruggink are looking for new applications for seagrass. One of their goals is to upcycle the seagrass by finding new applications to create a value stream.

Literature Review

Literature on the processing of seagrass was reviewed. In this chapter, the literature results are presented by thematic segments. Three segments have been identified: Technical Specifications, Textile Processing, and Potential Applications. These segments are presented below with the key findings. An overview of all relevant journal articles, books, and reports can be found in the literature review matrix in Appendix C.

Technical Specifications

In order to find possible applications for seagrass, a closer look must be taken at the plant itself such as microscopic image, chemical composition, and plant properties.

Distribution

The common seagrass (*Zoster marina*) is a plant species of the seagrass family. It grows underwater on the seacoasts of the northern hemisphere, where it forms submarine seagrass beds together with other marine species, which are important habitats for spawning fish and other marine animals. *Z. marina* is one of the most widely distributed and abundant seagrasses on the North Sea coast, see Figure 1. A detailed map of the distribution of *Z. marina* and other seagrass species in Europe can be found in Appendix D. The plant breaks loose from the submerged wetland soil and drifts with the sea current and waves to the coast as sea wrack (INNOVA, 2018).

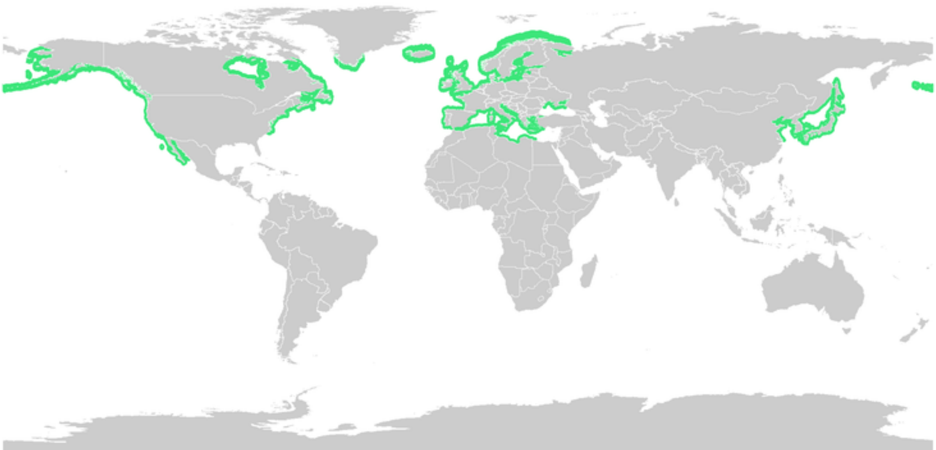

Figure 1 Global distribution of *Zostera marina (IUCN, 2010)*

Microscopic Image

For clarity and to avoid misunderstandings, this research report when referring to seagrass talks about the species *Zostera marina*. Figure 2 shows a microscopic image of the *Z. marina* seagrass, where fibres at the broken end are clearly visible.

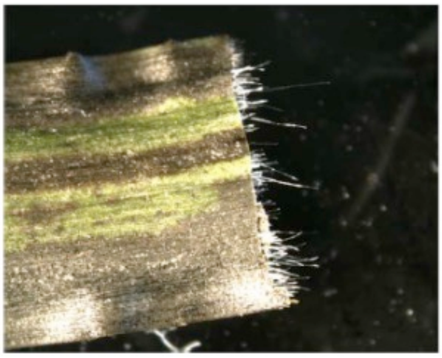

Figure 2 Broken *Zostera marina* seagrass (Davies, et al., 2007)

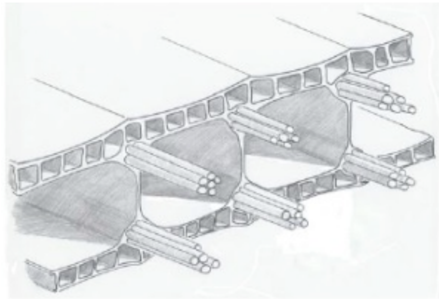

Figure 3 Sketch of seagrass showing fibre position (Davies, et al., 2007)

The seagrass consists of a closed-cell structure and can be considered a composite in which the fibres reinforce a matrix. The fibres are in bundles of 6-12 fibres, mainly near the outer surfaces of the blade (see Figure 3).

Chemical Composition

The chemical composition of a material is very important. According to Cabello-Pasini (2004) the seagrass *Z. marina* consists of <15% carbohydrates, <15% proteins, <40% ash and <60% fibres. Every fibre is composed of certain elements. These elements determine the properties of the fibre as well as suitable extraction processes. Plant fibres, in general, consist of molecular chains of cellulose (Eberle, et al., 2014). Common examples include cotton, jute, flax, sisal, and hemp. These fibres are extracted from the fruits, seeds, leaves, stems, and skin of plants (Chand & Fahim, 2008). Seagrass, like any other plant, consists mainly of cellulose, lignin, and hemicellulose. Davies (2007) determined the chemical composition of cellulose, lignin, and hemicellulose in *Z. marina*. In Table 2, the values of the seagrass are compared with those of common plant fibres. It can be seen that the cellulose content is relatively high, similar to jute and sisal.

Table 2 *Chemical composition of Zostera marina (Z. marina) fibres compared with those of other natural fibres*

Fibres	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Pectin (%)	References
Z. marina	54-60	23-33	4-6	8-12	(Davies, Morvan, Sire, & Baley, 2007)
Banana	60-65	6-19	5-12	3-5	(Ansell & Mwaikambo, 2009)
Cotton	82-96	2-6.4	0-5	<1-7	(Ansell & Mwaikambo, 2009)
Flax	60-81	14-20.6	2.2-5	2.3	(Ansell & Mwaikambo, 2009)
Hemp	70-92	18-22	3-5	1	(Ansell & Mwaikambo, 2009)
Jute	51-84	12-20	5-13	0.2	(Ansell & Mwaikambo, 2009)
Pineapple	70-82	16-19	5-12	2-3	(Ansell & Mwaikambo, 2009)
Sisal	43-78	10-24	4-12	0.8-2	(Ansell & Mwaikambo, 2009)

Technical Properties

To learn more about what kind of application the seagrass plant is suitable for, the fibre characteristics of seagrass were studied. The diameter of the fibre is about 5 µm. From Table 3 it can be seen that this is much smaller than other natural fibres.

Table 3 *Mechanical properties of Zostera marina fibres compared with those of other natural fibres*

Fibres	Diameter (μm)	Tensile strength (MPa)	Modulus (GPa)	Elongation (%)	References
Z. marina	4.3-4.9	453-693	13-26.6	3.1-3.7	(Davies, Morvan, Sire, & Baley, 2007)
Bamboo	10-40	575	27	-	(Ansell & Mwaikambo, 2009)
Banana	-	529-914	27-32	1-3	(Ansell & Mwaikambo, 2009)
Cotton	11.5-17	300-700	6-10	6-8	(Ansell & Mwaikambo, 2009)
Flax	17.8-21.6	500-900	50-70	1.3-3.3	(Ansell & Mwaikambo, 2009)
Hemp	17-23	310-750	30-60	2-4	(Ansell & Mwaikambo, 2009)
Jute	25.9-20.7	200-450	20-55	2-3	(Ansell & Mwaikambo, 2009)
Pineapple	20-80	413-1627	60-82	0-1.6	(Ansell & Mwaikambo, 2009)
Sisal	18.3-23.7	80-840	9-22	2-14	(Ansell & Mwaikambo, 2009)

The mechanical properties of seagrass fibres are very promising. Tensile modulus values up to 27 GPa and tensile strengths up to nearly 700 MPa have been measured by Davies (2007). These values are comparable to those of the other natural fibres. It is a tough material, but stiff.

Textile Processing

The proliferation of seagrass washed ashore on beaches requires costly removal and disposal. If fibres can be extracted from seagrass, this could provide an economic outlet for what is currently a costly nuisance (Davies, Morvan, Sire, & Baley, 2007). Therefore, the present work was initiated to evaluate whether fibres found in these materials can be processed into environmentally friendly bio-based textile materials.

Textile manufacturing usually includes fibre production, yarn spinning, fabric production, and finishing. This study aims to understand the fibre production phase in the case of seagrass and comparisons are made with other natural fibres.

Fibre Processing

The fibre extraction process is the process of separating fibres from plant parts. It depends on the shape and position of the fibre bundles (Ansell & Mwaikambo, 2009). There are three major fibre extraction methods: mechanical extraction, chemical extraction, and retting process (Hulle, Kadole, & Katkar, 2015).

Mechanical decortication	Crushing, steaming, pressurising, grinding, or beating the plant so that only fibres remain
Chemical extraction	Use of acids, alkali and enzymes that affect the microstructure of the fibres to produce cellulose, which is spun into fibres
Retting process	Soaking the plant in water for a period of time so that the fibres are released; Enzymes can be used to speed up the process

The company Enkev has already conducted trials with the aim to produce textiles from seagrass (van Delden, et al., 2020). These trials were not successful because the fibres were not stable enough for the mechanical process that the company uses. In the case of seagrass, the fibres are pulverized. This may be due to the high stiffness of the material. Therefore, a mechanical process is assessed as not suitable to produce textiles from seagrass.

Instead, a chemical process must be carried out. Another seagrass species, *Posidonia oceanica*, also called Neptune grass or Mediterranean tape weed can be treated by delignification and alkali treatment followed by acid hydrolysis to obtain pure microcrystalline cellulose (Tarchoun, Trache, & Klapötke, 2019). The microcrystalline cellulose has a high degree of crystallinity, indicating increased hardness and density. Its physicochemical properties are comparable to those of cotton. This method has already been used on a larger scale for cotton and wood. Therefore, it is assumed that no new machinery must be developed to process seagrass using this method (van Delden, et al., 2020). Further research is needed to determine whether this method can be used economically and whether it is suitable for extracting microcrystalline cellulose from *Z. marina* (van Delden, et al., 2020).

No study could be identified that extracts cellulose from *Z. marina*. If this were the case, the cellulose extracted from the seagrass could be used as a raw material to produce cellulosic man-made fibres, as it is common with man-made fibres from wood or other plants. Man-made fibre production comprises three basic steps: conversion of the fibre-forming substance into a liquid by solution or melting, extrusion of the fluid through spinnerets, solidification of the extruded filaments (Eberle, et al., 2014).

In order for cellulose to be spun, it must be dissolved. There are many ways to do this, but in practice, only four of them are used (Eberle, et al., 2014).

Viscose process	Treatment of cellulose with caustic soda and with carbon disulphide to form cellulose xanthate, which is then dissolved in a weak caustic solution to form a viscous solution, which is then extruded
Cuprammonium process	Dissolving of cellulose in a solution of ammoniacal copper oxide has been discontinued in some countries for cost and environmental reasons
Acetate process	Acetylation of cellulose with acetic acid or acetic anhydride and sulfuric acid catalyst
Lyocell process	Regenerating cellulose in an organic solvent which is non-toxic and biodegradable, the cellulose undergoes no significant chemical change

The basic techniques of extraction and spinning of cellulose fibres are briefly discussed below using selected plant fibres as examples.

Bamboo

A plant that has great potential for sustainability. The process begins with the cultivation of the plant. The leaves and inner pitch are extracted and chopped into pieces. These pieces are crushed and then soaked to create a solution. This solution is filtered to release the chemical used to break it down, then it is dried. Now sodium hydroxide is added to produce more cellulose. The cellulose solution is forced through a spinneret into an acid bath to create hardened fibre threads. This acidic bath also neutralises any residual chemicals. Finally, the fibres can be spun into yarn (Wordpress, 2013).

Sisal

A fibre product of the agave plant, which grows in South America, China, and East Africa. Commonly, mechanical decortication is used to extract the fibres from the plant. The large leaves of the plant are laid out on a conveyer belt and in the machine separated from the leaves. After separation, the fibres are washed to separate them from the plant's slimy inside (Textileblog, 2020).

SeaCell™

A patented technology of the Smart fibre AG Group. SeaCell™ is a product made from two natural resources: Wood and seaweed. The seaweed is cultivated in Iceland, washed, dried, crushed into a powder-like substance, and then incorporated into a cellulose fibre made from wood by means of the lyocell or viscose process (Smartfiber, 2020). The wood is cut and processed into chips. The chips are dissolved into a pulp with the help of some chemicals. The pulp is rinsed with water and optionally bleached. The pulp is then dried in from of large sheets of cellulose. The sheets are cut into smaller pieces, which are processed into a liquid with the help of heat, pressure, and a chemical solution. After are a short soaking time, the seaweed powder is added, and the solution is pumped through a spinneret (Woodward, sd). Further research should be conducted to determine whether a similar process is suitable for seagrass.

Pinatex

A leather-like material made from the leaves of pineapples. After the pineapple harvest is finished, the long fibre bundles are extracted from the leaves. The fibres are dried and purified, resulting in a really fluffy material. The fibres are then mixed with corn-based polylactic acid (PLA). The PLA is made from fermented plant starch. A mechanical process makes this into a non-woven mesh (Pinatex, 2021).

Requirements

In summary, there are many different natural fibres and processing methods. The most important cellulosic fibre classes include seed fibres (e.g., cotton), leaf fibres (e.g., sisal, pineapple), bast fibres (e.g., hemp), and stem fibres (e.g., jute) (Chand & Fahim, 2008). For textile production, seed fibres do not necessarily have to be very long. Cotton fibres, for example, have a twisted structure and can therefore adhere to each other, which makes it easy to make them into a yarn during spinning. With stem fibres, on the other hand, it is important to have long fibres. These fibres should have as small a diameter as possible, and the diameter should be the same along the entire length of the fibre. If the fibres are in fibre bundles, attention should be paid to the diameter in the bundle. The length of the fibre should be a thousand times the diameter of the fibre. Also, the number of consecutive glucose units within the cellulose is important. There must be at least 15.000 glucose units in a row. Note that in a chemical process the glucose rows are constantly shortened, which is not desirable (van Delden, et al., 2020).

Potential Applications

The most prominent and established player in the innovation of textile technologies for cellulosic man-made fibres is the company Lenzing, which is described briefly below, as well as other suppliers and innovators. There are not many research projects on producing bio-based materials from seagrass, one is shortly described below.

Algaeing	Founded in 2016, the Israeli company produces dyes and fibres from algae (Algaeing, n.d). The algae are blended with virgin wood pulp to produce fibres. It is a drop-in solution for spinning mills, meaning that only minimal machine adjustments should be required in the downstream supply chain. A 100% algae feedstock is under research and development.
Enkev	A Polish natural fibre manufacturer with roots in the Netherlands (ENKEV, n.d). They produce filling and covering materials for the mattress and furniture industry, but the natural products are also excellent for packaging purposes, car seats, and filter products.
Fieldwork Company	A Dutch research company that collects ecological data in the broadest sense of the word (Fieldwork Company, 2020). Since 2011 they have been involved in the restoration of *Z. marina* in the Dutch Wadden Sea.
INNOVA	A European research project dedicated to the development of climate services at various innovation centres. One of these innovation centres, located in the Bay of Kiel in Germany, was led by Ecologic Institute. The core topics of the innovation centre were: How the problem of beach wrack affects coastal management; and how climate change might affect beach wrack (INNOVA, 2018).
Lenzing	One of the world's largest viscose producers has developed Refibra, the first lyocell fibre made from recycled materials to be available on a commercial scale (Lenzing, n.d). Lenzing also produces the SeaCell™ fibre.
Smartfiber AG	A German innovator in the field of nature-based lyocell fibres for the textile market (Smartfiber, 2020). It has patented a process to permanently incorporate natural additives such as zinc and seaweed into cellulosic fibres, with positive effects on the skin and body. These fibres are sold on the market under the trademarks SeaCell™ LT, SeaCell™ MT, and smartcel™ sensitives
SaltyCo	A materials science company with a manufacturing facility located in Scotland. It manufactures BioPuff®, a down filling made from natural fibres grown in saline wetlands (Saltyco, n.d).

Previous studies have identified several possible applications for seagrasses. For example, seagrass has been studied as a possible source of raw material for the textile industry. But there are also applications in other industries. Successful innovations, products, and research projects are briefly described below.

Material Applications

Bio-composite

A bio-composite is a material that consists of two or more distinct constituent materials (one being naturally derived) combined to form a new material. The constituent materials are the matrix and reinforcing components (Rudin & Choi, 2013). There are few publications on bio-composites from marine sources. Sánchez-Safont et al. (2018) investigated the properties of a composite made from *P. oceanica* collected from the beaches of Valencia, Spain. The seagrass was suitable for the development of fully compostable bio-composites for packaging purposes (see Figure 4).

Figure 4 Seagrass bio-composite

Stool seats

German designer Carolin Pertsch has used bundles of seagrass (*Z. marina*) to create an eco-material that is used to make the seats of a collection of stools (Tucker, 2015). Pertsch combined shreds of the seagrass with a bio-based resin made from vegetable oil, creating a reinforced bioplastic that she then moulded into stool seats (see Figure 5). The result is a lightweight yet very strong material, that Pertsch says feels like a cork. By sorting the seaweed into light and dark tones, three colour variations are created (Pertsch, n.d).


Figure 5 Seagrass stools

Biodegradable food packaging

German designer Felix Pöttinger has developed a sustainable alternative to plastic food packaging using seagrass (*P. oceanica*) washed up on Mediterranean beaches (Tucker, 2017). It is a joint project between the Royal College of Art in London, Tesco Labs, and Microsoft Research Cambridge (Pöttinger, n.d). The material is completely biodegradable as well as antibacterial. To produce the packaging material, a binder is extracted from the seagrass fibres and mixed with the intact fibres. The mass is then pressed into a metal mould and baked at 180°C until it has completely dry (see Figure 6). The product is still in the development stage and needs to be tested to see if it meets all EU regulations for food packaging (Tucker, 2017). Further research should be conducted to determine whether the same process is suitable for *Z. marina*.


Figure 6 POC material by Felix Pöttinger

Homeware

In 2015, Swedish furniture giant IKEA launched a collection of cork and natural-fibre products by London designer Ilse Crawford (Howarth, 2015). Dried seagrass is used for a variety of products including baskets and carpets (see Figure 7) (Humphrys, 2021).


Figure 7 Seagrass homeware by IKEA

Surface

Metis Seagrass eco-friendly surfaces are made from *P. oceanica* and bonded with organic and natural raw materials (Metis , 2020). The eco-surface can be used as wall coverings and veneers and can be applied in exterior and interior spaces (see Figure 8).

Figure 8 Seagrass surface by Metis

Insulation

"Using Seagrass as Insulation Material" by Nico Stelljes (2021) was published in the "Baltic Stories Magazine" which is dedicated to promoting cooperation around the Baltic Sea. The project was embedded in the INNOVA project. The short paper gives an example of how seagrass (*Z. marina)* can be used sustainably. Stelljes used seagrass from the Baltic Sea to insulate his roof (see Figure 9). Also, the German research institute Fraunhofer (Fraunhofer, 2013) has developed a process to produce insulation material from *P. oceanica* without chemical additives (see Figure 10). Flame retardant, mould resistant, and free of pollutants: Thanks to these properties, Neptune balls are particularly suitable for insulation.

Figure 9 Seagrass roof insulation

Figure 10 P. Oceanica insulation material

Pillow filling

Speltex® sells seagrass (*Z. marina*) from the Baltic Sea as fillings for pillows (Speltex, n.d). As long-fibre filling material, seagrass offers a very special feel, comparable to horsehair, good climatic properties, and a particularly low weight (Avocadostore, 2019). The seagrass is impregnated with natural rubber milk, dried, and then heated. Because of its natural robustness, seagrass has been used as cushioning material for centuries. With the rubber impregnation, it meets today's standards. The fillings as can be seen in Figure 11, are thus dust-free, and the crimped structure of the seagrass is stabilised.

Figure 11 Seagrass pillow filling

Papermaking

Syed et al. (2016) investigated fibre properties and paper production from seagrass using hand-beaten and mixed pulp. Seagrass species native to the tropical Indian and Western Pacific Oceans were studied. Due to their physical and chemical composition properties, the seagrass species studied have the potential to serve as a source of fibre material to produce handmade paper. The paper is made by firstly removing the lignin from the plant, this leaves a black liquor and a weakened plant. The plant is then hand-beaten with a wooden mallet to remove the fibres from it. When the fibres are removed a cellulose plate can be made which is eventually turned into paper.

None-material Applications

Microcrystalline cellulose

The process for extracting microcrystalline cellulose from seagrass has already been described earlier. The extracted microcrystalline cellulose can be used in many fields, e.g., in the pharmaceutical industry (as binders, absorbents), in the food industry (as stabilizers, fat substitutes), in the beverage, cosmetic and other industries (as binders) (Trache, et al., 2016).

In terms of materials, microcrystalline cellulose can be used in bio-composites and packaging, but this use is still limited (Trache, et al., 2016).

Dyestuff
The company Algaeing has developed the revolutionary Algadye 3.0 (Algaeing, n.d). It is an algae-based dye formulation that is 100% biodegradable and can be applied to all types of fabrics: synthetic, natural, and protein-based. Further research should be done to see if the same process is suitable for seagrass.

Nature-based coastal protection
The use of beach wrack to create and stabilise dunes has already been demonstrated by the municipality of Eckerförde, Germany (INNOVA, 2018). This approach for the beneficial use of beach wrack, which includes seagrass and algae appears promising given the various scenarios for rising sea level and increasing coastal erosion. As well as it is locally used and a relatively inexpensive form of disposal. Such beach wrack dunes can be planted with typical dune plants and serve as an inexpensive 'nature-based' coastal defence structure.

Fertiliser
Seagrass can be used as fertiliser in agriculture and gardening (INNOVA, 2018). In the past, farmers used to pick up the beach wrack from the beach and use it as fertiliser for their fields. This is no longer done on a large scale, as industrial fertilisers are more efficient and new laws in the agricultural sector impose detailed regulations on fertilisation. In Germany, it is still under debate how much beach wrack farmers are allowed to use depending on the nutrient content. This also varies from municipality to municipality. Beach wrack is known to improve the quality of clay soils; it can also be used very well for gardening purposes.

Food source
Seagrass (*Z. marina*) grains have been consumed as food by the Sen Indians of Sonora, Mexico for centuries. In folk medicine, seagrasses are used for a variety of healing purposes, e.g., to treat fever and skin diseases, muscle aches, wounds, stomach problems, as a remedy for stings of various ray species and as a sedative for infants (de la Torre-Castro & Rönnbäck, 2004). Rengasamy et al. (2013) studied the nutrient composition of six seagrass species from the Indian Ocean. The seagrasses studied were rich in protein, fibre, and lipids, and were attributed beneficial effects on diseases such as obesity and diabetes. The high content of chlorophylls and carotenoids in these seagrasses is beneficial as they can act like vitamins and antioxidants. Literature on the species *Z. marina* was also reviewed and the nutritious composition was reported as follows: Carbohydrates 65,3%; Proteins 10-11,3%; Lipids 0,8-1,4%; Fibre 7,4%; Ash 7,1%.

Antifouling agent
Other studies have investigated the use of seagrass as an anti-fouling agent. An anti-fouling agent is a substance that prevents or retards fouling or marine underwater growth on plants, rocks, ship bottoms, etc. Zosteric acid is a natural product produced by the seagrass *Z. marina* that prevents the attachment of some bacteria, algae, tubeworms, and barnacles. The results of Newby et al. (2006) suggest that it may also be effective in reducing the early stages of biofouling, i.e., the fouling of, for example, underwater pipes and other surfaces by organisms such as barnacles and algae. It could also prevent the formation of bacteria into a thin film of

slime called biofilm. In summary, Zosteric acid could be used in a much less toxic but effective antifouling agent.

Beauty extract

The Japanese company Three Cosmetics (n.d) has developed a *Zostera marina* extract. The extract is derived from *Zostera marina*, which grows wild in the sandy and muddy substrates along the Japanese coast up to several meters underwater and plays an important role in the coastal ecosystem. The extract keeps the skin firm and radiant by boosting the moisture-retaining function of the horny cell layer, according to Three Cosmetics' website.

Expert Interviews

The project group contacted 16 experts to conduct an interview. As a result, there were three responses with helpful information, two of which wanted to conduct an interview by mail, and one expert in a personal meeting.

Face-to-face Interviews

Interviewee 1: Jens Oelerich – Associate Lecturer Sustainable Textiles at Saxion University of Applied Sciences

During the interview with Jens Oelerich, the group member took notes and translated the relevant points into a transcript (see

Appendix E) for better analysis and completion of the research report. Based on the transcript, axial and open coding was done and included in Appendix F of this report. After all the necessary recording methods had been carried out, the transcript was analysed to clarify the findings and results of the interview.

The questions asked during the interview focused on fibre processing and general project management. Mr. Oelerich gave a general overview of how plants are processed into fibres. Generally, fibres are made only from the cellulose, possibly also from the hemicellulose, of a plant. The cellulose is extracted, regenerated, and then purified. The process of obtaining the fibres is called pulping. It is used for wood or cotton, for example. Conventional wood has a cellulose content of about 50%, so he advised determining the cellulose content of the seagrass. From this, conclusions can be drawn as to whether it is a useful source of cellulose. A disadvantage for fibre processing is a high mineral content. "Pollutants" such as pigments, on the other hand, can be extracted.

Written Interviews

After the interviews had been conducted, the mails were transcribed and coded (see Appendix F). All information given was assessed to ensure that it is useful and relevant for the development of a new application for seagrass. The quality of the research was ensured by making sure the interviewees were experts in the specific field the group was researching. In addition, all given concepts were evaluated and/or tested with prototypes. The results are now described based on the individual interviews.

<u>Interviewee 2: Felix Pöttinger - a German designer who has developed a sustainable alternative to plastic food packaging using seagrass (*P. oceanica*) washed up on Mediterranean beaches</u>

The answers from the interview mainly related to the development and production of seagrass-based food packaging. The full interview can be found in

Appendix G.

The current version of the POC material consists of *P. oceanica* seagrass fibres and a binding agent derived from the plant's own cellulose. Mr. Pöttinger described the production process as follows: The cellulose was extracted by sulphate digestion at the Imperial College Materials Laboratory in London, which creates a binding agent. This is an industrial process and highly toxic. The binder is mixed with the seagrass fibres and water and pressed into a two-piece metal mould and then baked at 180° until completely dry. He advised us to use a cellulose-based binder available in hardware stores as an alternative to his binding agent. The POC material is technologically ready for large-scale prototyping. However, the material did not meet the EU requirements for food packaging, so funding for the project was cut.

The technical specifications of the material are as follows:

- 3-point flexibility test: 25 N Sample 1 / 15 N Sample 2
- Thermal conductivity AD <0.039 W / mK - Rated value <0.046 W / m
- Bulk density 65 to 75 kg / m3 - to be delivered 75 kg / m3
- Heat storage capacity c = 2.502 J / gK
- Fire protection class according to DIN 4102 B2 - normally flammable
- Mould resistance: was tested for antifungal activity against two fungal strains Pythium spp. and Aspergillus flavus using the fungal growth inhibition assay method. Reduced fungal colony growth by 33.33 - 50 %
- Water absorption capacity 1.6 to 3.4 kg / kg
- Salt content approx. 0.5 - 2%

Due to its high cellulose content (over 90%), *P. oceanica* is very well suited to produce a sustainable alternative to plastic food packaging. Mr. Pöttinger described his own material as similar to hard cardboard with the flexibility of felt board. The material could be used for packaging fruit or vegetables. However, seagrass is a difficult source of material because it is difficult and expensive to harvest and too expensive to produce, Mr. Pöttinger wrote. Apart from the mould resistance, which is unique, there are too many other materials with similar properties and competitors on the market, and it is doubted that it would be commercially feasible. Unfortunately, Mr. Pöttinger did not have the time for a personal interview.

Interviewee 3: Manager New Business Development Smartfiber AG

The answers from the interview mainly referred to the production process of SeaCell™ containing seaweed, which is developed by Smartfiber AG and produced at Lenzing AG. The complete interview can be found in Appendix H.

Smartfiber AG offers a cellulose-based staple fibre under the trademark SeaCell™. SeaCell™ contains the seaweed *Ascophyllum nodosum* from Iceland and can be produced as modal or lyocell fibre. In the production process, the seaweed is added in powder form to the dissolved cellulose before spinning. A schematic overview of the production process can be found in Figure 12, provided by Smartfiber AG.

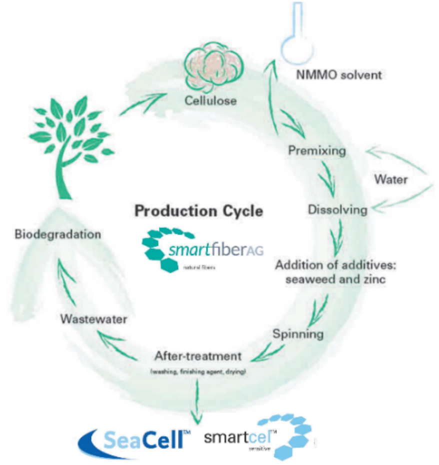

Figure 12 SeaCell™ production cycle

Smartfiber AG listed the following advantages of adding seaweed: rich in essential vitamins, minerals, amino acids, antioxidants, long-lasting performance, skin-friendly, biodegradable, organic, and comfort properties. The possibility of using seagrass instead of seaweed was not ruled out by Smartfiber AG, the response was: “Surely you can add other ingredients”, but this is an unproven concept. The company also asked to be kept in the loop of the project and the final research report will be sent at the end of the project.

Laboratory Research

In this chapter, the results of the laboratory research are presented by experiment. Three experiments were conducted: Determination of cellulose, antibacterial properties, and pulp production. These experiments are presented below with the main results.

Cellulose Determination

The first experiment was the determination of the cellulose content by hydrolysis and the Nelson determination. Cotton was used as the reference material since it consists almost entirely of cellulose. With the Nelson method, the determined concentrations were not accurate, as part of the lignin and hemicellulose was also determined. The cotton did not have a value of 100% cellulose, but about 80%, which means that the hydrolysis step did not work entirely. For this reason, the results of this method could not be used to determine the cellulose content of seagrass.

As it became clear that lignin and hemicellulose had to be washed out for the analysis of the cellulose content, another method was used to determine the cellulose content of the seagrass. This was the Updegraff method. In this method, the seagrass is incubated with a reagent that breaks down the lignin and the hemicellulose; the cellulose is resistant to this reagent. So, in the end, only the cellulose content is determined. The results for the cellulose content determined by the Updegraff method can be seen in Figure 13. Five different sample types of the same seagrass species were examined: new material (collected August 2021), old unwashed material (collected at the beginning of 2021), old, washed material, old material with glycerine treatment, and new home-grown material. The first thing to notice was that the home-grown material contains significantly less cellulose compared to the other samples.

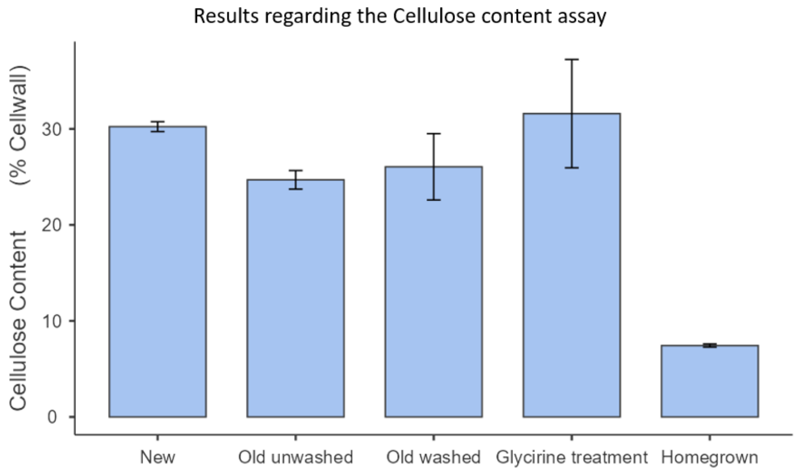

Figure 13 Bar plot based on the results of the cellulose content assay. Each bar represents a unique monster group, the small black lines represent the standard deviations.

In order to look more closely at the results found, it was necessary to examine the specific results. These results are shown in Table 4. With the exception of the home-grown material, all seagrass samples from the sea contained about 24-32% cellulose as a percentage of the total cell wall mass.

Table 4 *The percentage of cellulose in the cell walls of the different types of seagrasses with their standard deviation*

Sample Type	Average (%)	Standard Deviation
New Material	30,2	0,883
Old Material (unwashed)	24,7	1,37
Old Material (washed)	26,0	5,98
Old Material (Glycerine Treatment)	31,6	9,77
Homegrown Material	7,4	0,233
Control Group	99,5	0,741

It can be seen that the old materials contained less cellulose compared to the new material. However, this is not true for the glycerine-treated old material, which had the highest cellulose content of all samples. But it was associated with the highest standard deviation. The new seagrass has almost the same cellulose concentration as the seagrass treated with glycerine, but with a much lower standard deviation, which means that this sample is much more accurate. For the two old materials that were not treated with glycerine, the results show that the washed material contained slightly more cellulose. However, as with the glycerine treated samples, the average cellulose content had a higher standard deviation.

Antibacterial Properties
Customised nutrient agar plates were used for the research of the antibacterial properties of seagrass. Different amounts of powdered seagrass were added to the nutrient broth. In this way, unique agar plates were created. The aim of these plates was to obtain an estimate of the minimum inhibitory concentration of seagrass on *E. Coli*. Once an estimate was established, it would have been possible to perform a very precise MIC-test. However, the research showed no sign of bacterial growth inhibition. **Fout! Verwijzingsbron niet gevonden.** shows the growth of *E. Coli* (white) on the customised agar plates. The concentrations of powdered seagrass from upper left to bottom right were 0.5 g/L, 1.0 g/L, 1.5 g/l, and 2.0 g/L. The black spots on the plates were seagrass powder. The bacterial growth did not decrease

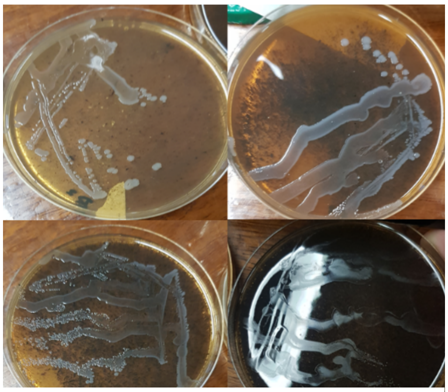

Figure 14 Growth of *E. Coli* on agar plates with different concentrations of powdered seagrass

when the amount of added seagrass increased. In fact, it looks like the amount of bacterial growth increased slightly.

Pulp Production
To produce a pulp, the lignin must first be removed. Lignin is like an adhesive that holds all the fibres of a plant together. To achieve this, the following procedure was followed: First, the seagrass was cleaned by soaking it in demi-water for 24 hours. Then a solution of demi-water and sodium hydroxide was prepared and brought to the boiling point. Once the solution boiled, the seagrass was added and boiled for 2 hours. The solution was no longer transparent but turned black even after the seagrass was taken out. This indicated that the first step was successful. The lignin is now part of the remaining liquid solution. The seagrass itself has also changed. The plants are no longer stiff and break even more easily.

The second step is to separate the fibres from the seagrass plant. By hand-beating the seagrass plant with a wooden mallet in a hit and pull motion, the seagrass plant breaks, and the fibres are pulled out. Due to the Covid-19 pandemic, we were unable to carry out this step.

Prototyping
Experimental research was performed to find out whether seagrass can be used for the applications studied. As it was not possible to produce the applications on a large scale, small samples/specimens were made. Prototypes of packaging material, leather, and a dye were produced. As a result, the most optimal production process for each application is described in the following sub-chapters.

Seagrass Packaging Material

This experimental research aimed to find out whether *Z. marina* can be used to produce seagrass packaging based on the process used by Felix Pöttinger for his POC material and what the optimal processes and conditions are for the material.

The material components can be seen in Figure 15. From left to right: Dried seagrass, wallpaper paste powder (brand: Methylan), and water.

Five test specimens were made (see Figure 16) in different mixing ratios (see **Fout! Verwijzingsbron niet gevonden.**). The ratio was measured in teaspoons.

Figure 15 Material components seagrass packaging

Figure 16 Test specimens seagrass packaging

Table 5 *Mixing ratio seagrass packaging*

Sample	Mixing ratio (binder: seagrass)	Comments
Sample 1	2:1	Colour whitened, excess binder
Sample 2	1:1	Still excess binder (white edges)
Sample 3	1:2	Excess binder (white edges), holes in structure
Sample 4	1:3	Excess binder (white edges)
Sample 5	1:4	No transparent regions, white edges, or holes

The most optimal process for making a seagrass-based packaging has been established with the following steps:

1. Drying of seagrass
2. Cutting the dried seagrass into pieces approx. 2 cm long
3. Mixing binding agent (wallpaper paste powder mixed with water in ratio 1:50)
4. Mixing binder and seagrass pieces in 1:4
5. Apply the mixture onto baking paper
6. Drying for 24 hours
7. Removing material from backing paper

An initial quality assessment showed that Sample 5 of the self-made packaging material was bendable to a certain extent but cracked easily as soon as force was applied. The material was stiff like cardboard but much thinner. A few samples were made but no actual product (e.g., a box).

Seagrass Leather

The experimental research aimed to find out if seagrass can be used to make seagrass leather based on the process commonly used for fruit leather and what the optimal processes and conditions are for the material.

The material components can be seen in Figure 17. From left to right: Dried seagrass powder, casein (from milk), and a solution of water and baking powder.

Figure 17 Material components seagrass leather

Three test specimens were made (see Figure 18) in different mixing ratios (see **Fout! Verwijzingsbron niet gevonden.**). The ratios were measured in teaspoons (TS).

Figure 18 Test specimens seagrass leather

Table 6 *Mixing ratios seagrass leather*

Sample	Mixing ratio solution (binder : seagrass)	Mixing ratio (seagrass powder, casein and solution)	Comments
Sample 1	1:1	1:1:1	Colour whitened, excess baking soda
Sample 2	1:4	1:1:1	Nice colour, but not bendable
Sample 3	1:4	1:1:1 (+ ½ TS olive oil)	Nice dark-brown colour, more bendable

A first quality assessment revealed that the self-made seagrass leather is not foldable and cracks easily. To prevent this, another sample of the seagrass leather was made with the addition of olive oil. An improvement in performance can be seen.

The most optimal process for making seagrass-based leather has been established with the following steps:

1. Drying of seagrass
2. Milling of dried seagrass to a fine powder with a mortar
3. Mixing vinegar essence with milk, filter the casein with a coffee filter
4. Mixing solution of baking soda and water in a ratio of 1:4
5. Mixing seagrass powder, casein, and solution in a ratio of 1:1:1
6. Option: Adding vegetable oil
7. Applying the mixture onto a 100% cotton base fabric
8. Ironing of material (ironing level 1)
9. Washing of material underwater
10. Heating of material
11. Option: Embossing the material for leather structure

However, no optimal process has been found for a material that meets the general quality requirements for textile and apparel applications.

Dyeing

An interesting by-product of seagrass pulpification is the black liquor that remained after boiling. This is a solution of sodium hydroxide, demi-water, and some waste material from the seagrass (possibly lignin, but this was tested). As shown in Figure 19, it was possible to dye untreated cotton fabric with this residue to obtain a light brownish colour with a burnt edge effect.

Figure 19 Dyed cotton cloth with black liquor

Discussion

This report aims to investigate the possibilities for producing a sustainable application from seagrass in the Netherlands. This was done by answering the sub-questions formulated by the group, literature research, expert interviews, laboratory research, and prototyping. The results showed that the cellulose content of seagrass was between 24 and 32%. Data from the research of antibacterial properties indicted that seagrass itself did not inhibit bacterial growth. The study also demonstrated concept ideas that could be used for bio-based applications with seagrass: Pulp production, packaging material, and artificial leather. However, an optimal process for novel materials that meet the general quality requirements for material applications was not found. The discussion of the research results is presented in this chapter.

Expert Interviews

Only a few experts have worked with bio-based material derived from seagrass. This means few people were able to provide the group with relevant and useful information. A total of 16 people from different research groups and companies were contacted. Unfortunately, the response rate to the interview requests was low. However, the interviews conducted were insightful.

The results of the expert interviews confirmed the hypotheses made after the literature review that little is known about seagrass as a material source. The general opinion from the experts about seagrass was sceptical. Due to its stiffness and fragility, many textile applications are not possible or feasible. In addition, it is difficult and expensive to harvest and too costly to produce. A high cellulose content was mentioned as a redeeming factor. Finally, it is worth highlighting that SmartFiber AG has only stated that they have not yet tried using seagrass for their SeaCell™ textile, but that they did not completely rule out the idea. They also wanted to be kept in the loop of the research, which indicates that there is interest in the industry in seagrass as a material resource and research like ours.

Laboratory Research

In this chapter, the results of the laboratory research are discussed by experiment. Three experiments were conducted: Determination of cellulose, antibacterial properties, and pulp production. These experiments are discussed on validation, credibility as well as on results.

Cellulose Determination

The validation of the study was ensured by the values found in the control group. A piece of filtration paper was used as the control group. Filtration paper is made up of almost a hundred percent cellulose and other cellulose-based components. The results showed that the control samples indeed contained almost 100% cellulose, the result was 99,5%, with a standard deviation of 0,741% to be exact. Another important statistic is the R^2-Coëfficent of the calibration line used to determine the cellulose content in the sample. The calibration curve used in this assay, determined with the same reagents used to treat the samples, contained $R^2 = 0{,}996$. Since $0{,}996 < 0{,}99$ all results found will be within a 99% confidence interval.

However, the validity of the results is not just determined by the confidence interval. Another important value for ensuring credibility is the standard deviation. *Table 4* shows the standard deviations of the average cellulose contents. All untreated materials have a relatively low standard deviation, in contrast to the washed and treated samples. This can be explained by the processing step of washing the seagrass. The seagrass is washed in batches (personal communication ArtEZ, 2021) and not all seagrass pieces are treated the same. This means that some plants are washed more intensively than others. Batch processing leaves room for irregular treated samples, due to working with large volumes. When preserving the cellulose in the cell wall, irregular treatment leads to uneven preservation. This means, when washing seagrass helps to preserve cellulose, the more intensively washed materials contain more cellulose than the less intensively washed materials. However, in the case of the glycerine-treated sample, a more plausible explanation for the higher standard deviation is the presence of the glycerine. The Updegraff method is based on the number of organic chemicals that can react with the reagent. This means that samples that have undergone more intensive pre-treatment contain more measurable organic molecules. Therefore, the more intensively treated samples contain a higher percentage of cellulose than the less intensively treated samples.

This theory leads to another important fact, namely that the glycerine present on the samples could falsify the results. As mentioned earlier, the Updegraff method is based on the number of organic chemicals that can react with the reagent. Glycerine is an organic substance that contains the same molecules such like glucose. Both are broken down when the sample is treated during the experiment. This means that glycerine is measured as cellulose and interfered with the cellulose content assay. Since glycerine was broken down in the same way as cellulose, the breakdown products of both substances reacted with the reagent. This leads to an incorrect cellulose content and explains why the glycerine-treated sample contains significantly more cellulose than the other materials. Due to this error, the actual cellulose content should be lower.

It is not possible to estimate the actual cellulose content because (1) the amount of glycerine added is unknown and (2) the high standard deviation of the glycerine-treated sample, due to batch production. Not all seagrass samples were treated equally therefore not all samples will contain the same amount of glycerine. To determine the actual cellulose content, either the glycerine must be removed by washing or the glycerine content in each sample must be determined.

The results of the cellulose content of the seagrass do not agree with the research of Davies et al. (2007). His research showed that the concentration of cellulose in the fibres of *Zostera marina* is 57%. In the present study, the cellulose content was found to be 24-32%. The difference between these two results lies in the different approaches of the studies. Davies et al. examined the fibres of *Zostera marina.* The present study, on the other hand, examined the cell wall of *Zostera marina*.

The study provides new insights into the use of seagrass for further applications. Firstly, when the leaves of *Zostera marina* are used for an application, the cellulose content is 30%. If the fibres of *Zostera marina* are used, the cellulose content is 57%. The fibres of the seagrass can be extracted by pulping, as mentioned in Chapter Pulp Production. With this method, the fibres could be extracted and used for further applications. Secondly, the more cellulose is contained in the cell wall of the seagrass, the stiffer the seagrass will be (Singh, Wasewar, &

Kansal, 2020). For research into possible applications, the results, therefore, suggest the use of new seagrass, as it would be the strongest type of seagrass based on its cellulose content.

Antibacterial Properties

When tested for antibacterial properties, seagrass was first only tested against *E. coli*, a gram-negative bacterium. These tests showed no sign of bacterial growth inhibition. However, the seagrass was not tested against gram-positive bacteria. Therefore, no statements can be made about the effect of seagrass on the growth of gram-positive bacteria. Another important point is that seagrass powder and not the complete strains were tested. It is possible that chemicals or structures were lost when the seagrass was pulverised. It would be possible that the lost chemicals contained antibacterial properties. However, the result, contributes to a clearer understanding of the technical specifications of possible applications. To produce an application such as seagrass leather or SeaCell™, the seagrass must be pulverised. The results, therefore, indicate that these applications will not have antibacterial properties.

The first reason for suspecting the antibacterial properties of the seagrass was a study by Newby et al. (2006) that shows the effectiveness of *Z. marina* acid in reducing biofouling. This theory was validated by a high iodine concentration in some seaweed species (Yeh, Hung, & Lin, 2014). Iodine is an element that is antimicrobial and commonly used for wound treatment. The iodine content of seagrass has not been examined in this research. However, if seagrass contains a lot of iodine, the iodine could be extracted and used for antibacterial purposes. One argument against this application, however, is that it does not solve the problem of seagrass waste. Once the iodine is extracted, the used seagrass mass remains. Another important question to ask is whether there are no other, more efficient sources of iodine. If other plants contain more iodine than seagrass, there is no reason to use seagrass as a source.

Pulp Production

Unfortunately, due to the Covid-19 pandemic, it was only possible to try the first step of pulp production in the laboratory. This involves removing the lignin from the plant to weaken it. As described by Syed et al. (2016), after boiling the seagrass for two hours, a black liquor remained, and the seagrass was weakened. It is assumed that the black liquor contained the lignin from the seagrass, but this has not been confirmed. The second step is to separate the fibres from the rest of the seagrass. This can be done by hand beating it with a mallet, as often used centuries ago. If this step had worked, it would be possible to test the use of the seagrass fibres for papermaking and confirm the possible application of seagrass as paper. An attempt was also made to dye a piece of untreated cotton with the black liquor. Unexpectedly, it worked. The cotton has a slightly brownish colour with darkened edges. It is unclear why the edges became darker than the inside of the fabric, as the entire fabric was submerged in the black liquor for the same amount of time.

Prototyping

In a later phase, experimental research in the form of prototypes was carried out to find out whether seagrass can be used for the applications investigated in the literature review and expert interviews. There was almost no literature and not a wide range of different products on the market that use seagrass. Experimenting with the material yielded, therefore, some interesting results and applications.

Prototyping of the packaging material was partially successful. The process to create a packaging material with seagrass worked. Possible applications could be food packaging, another packaging, decoration, homeware, etc. However, the self-produced material would not meet the general quality requirements. Further research could test the improvement of the strength of the material by using different binding agents.

Prototyping of seagrass leather was also partially successful. The creation of an alternative leather containing seagrass powder worked and produced a beautifully dark brown material. Potential applications could be shoes, bags, accessories etc. However, the self-produced material would not meet the general quality requirements for the textile and apparel industry. Further research could further develop this material and test an industrial process with mixing seagrass powder and PU. This process is commonly used for apple cultivation waste (Oliver Co. London, n.d). A schematic overview how the industrial production process could look like can be found in Figure 20.

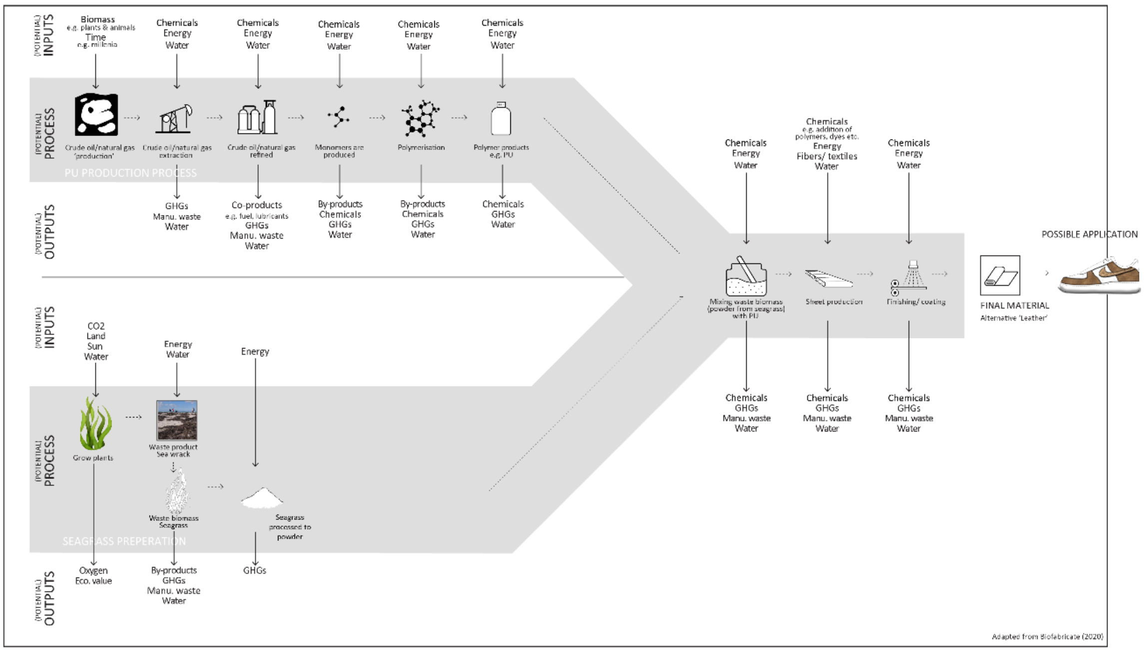

Figure 20 Seagrass leather production example

The overview has been adapted from Biofabricate & Fashion for Good (2020). A more environmentally friendly production process would be to refrain from the use of PU and use plastic derived from milk proteins (Galileo, 2016). However, detailed information on this process is lacking and it is therefore not clear whether it could be used for seagrass.

Current Applications

There are many species of seagrass around the world. And it has been used as a resource for many years. In the literature reviewed, seagrass itself is used as a bio-composite, stool seat, hand-woven homeware, insulation, pillow and mattress filling, natural-based coastal protection, fertiliser, food source, antifouling agent, and as a beauty extract. Food packaging has also been produced with the species *Posidonia Oceanica* but deemed too expensive and difficult to produce. The material innovation company Smartfiber AG uses seaweed powder in their textiles to produce materials that are good for the skin. This could also be an option for seagrass.

The research shows that there is a potential for using seagrass in new applications. Many concept ideas can be used for bio-based applications with seagrass. The findings can be divided into existing concepts such as the use of seagrass as nature-based coastal protection, fertilizer, filling material, or environmentally friendly surface and novel unproven concepts such as seagrass packaging material, seagrass leather, and pulp production. All novel applications need to be further validated, demonstrated, and most importantly commercialized.

However, with all the applications already in place, it makes sense to incorporate the seagrass waste in these existing concepts and supply chains. Further research could then look for ways to sell and market these applications. This would be easier, more feasible, and more realistic to achieve in the near future than developing a completely new application. Seagrass has value as it is a biodegradable material and can be a more sustainable material than current non-biodegradable applications.

Limitations

There were several limitations to the research. Firstly, the topic of this research is quite new, this means there is close to no prior research. Since there is almost no prior knowledge, theories, or concepts on technical specifications, or how to produce new material from seagrass, it was difficult to make progress during the research. In addition, not many experts have worked with bio-based materials derived from seagrass. This means that they have not been able to provide answers and relevant and useful information to the group. It is therefore difficult to draw a conclusion as the research was not specific enough and not all options could be explored due to the time frame of the project. This research was exploratory, as no other research could be identified that investigated potential applications for seagrass. While we reviewed literature, conducted expert interviews, laboratory research, and prototyping, we are aware of the limitations associated with such reasoning, namely how such results might or might not be generalised. Finally, research methods and work were still limited by the Covid-19 pandemic at the time of writing.

Conclusion

From this research, it can be concluded that *Zostera marina* has the following technical specifications. With an accuracy of 99%, it can be said that natural seagrass contains around 24 to 32% cellulose as a percentage of the total cell wall mass. The concentration of cellulose in the cell wall was determined using the Updegraff method. Older seagrass contains less cellulose than newer material. Pre-treated seagrass by washing has a higher cellulose content but has less cellulose than new seagrass. Therefore, when using seagrass for an application, using new seagrass (collected in September 2021) is recommended. The home-grown material contains 7,4% ±0,233% cellulose, which is significantly less than the natural seagrass. There is no evidence that seagrass powder has antibacterial properties on *E. coli*. Various tests were performed in which the *E. Coli* bacterium was incubated with the seagrass powder at various concentrations for at least 24 hours.

Possible fibre production methods include pulp production and adding seagrass powder as an additive to modal and lyocell fibres. Potential applications for seagrass (in form of leaves or powder) range from existing concepts such as the use of seagrass as stool seats, food packaging, homeware, surfaces, insulations, pillow fillings, nature-based coastal protection, fertiliser, or beauty extract and novel unproven concepts that were tested such as seagrass packaging material, seagrass leather, and pulp production. Finally, finding new applications for a natural material like seagrass is not simple. Generally, the research and development process of a new material starts with a solution or a gap in the market. In this research, the starting point was a problem: the excessive seagrass waste on beaches. Finding a completely new application for seagrass would provide a sustainable solution to this problem. However, this was not feasible in the time frame of this project. In the end, this research shows several paths that can be taken to solve this problem and forms the basis for further research projects.

Recommendations

Based on the findings from the results, discussion and conclusion, the following recommendations are made for the researchers of similar studies, as well as for the client.

Technical specifications

In the laboratory research, the cellulose concentration was determined for the cell wall. The cellulose content of the fibres was not tested in the laboratory. However, found in the literature. In future research, the fibres of the seagrass could be extracted and used to determine the cellulose content of the fibre. The different types of seagrasses could also be tested, and the impact of the pre-treatment methods determined. This research would give an understanding of whether seagrass is a potential source of cellulose and can be used as a raw material to produce cellulosic man-made fibres.

The antibacterial properties have not been found yet. In this research, the antibacterial activities of the *Zostera marina* were determined without any pre-treatment. When the leaves were incubated with the *E. Coli*, no antibacterial activity has been found. But this does not mean that *Zostera marina* is not antibacterial. Researchers found that the extract of the *Zostera marina* has antibacterial properties (Liu, Jiang, & Wu, 2010). The preparation for making an extract out of the *Zostera marina* seagrass can be found in Appendix I.

To determine if the extract is indeed antibacterial, a dilution range should be made from the extract and a bacterial suspension like *E. Coli* for example. Firstly, prepare nutrient agar plates and prepare an *E. Coli* stain. Make form the *E. Coli* stain a solution of 0.5 McFarland. Incubate six nutrient agar plates with the concentrations *E. Coli* and seagrass extract as listed in Table *7*.

Table 7 *Extract and E. Coli stain concentrations on nutrient agar plates*

Plate	*E. Coli* solution (in µl)	Seagrass extract (in µl)
1	0	100
2	20	80
3	40	60
4	60	40
5	80	20
6	100	0

These plates should be incubated at 37°C for 24 hours. After 24 hours, the colonies on the plates should be counted and put into a graph. If a linear correlation occurs, that means that the seagrass extract would not influence the growth of the *E. Coli.* The linear correlation is the result of putting less *E. Coli* suspension on the agar plates. If an exponential correlation occurs, that means that the extract does influence the growth of *E. Coli.* An exponential correlation would mean that seagrass extract is an extra factor if *E. Coli* will grow or not. If the seagrass extract turns out to be not antibacterial, higher concentrations of seagrass extract could be used. If the extract does turn out to be antibacterial, this could be used for further applications.

It is also an idea to investigate if the seagrass is antibacterial to a very wide range of bacteria, or only to some specific species. To determine this, the test as described above can also be done by other bacterial stains. It is also good to investigate what in the extract makes the extract antibacterial. This could be the iodine content for example. The specified technical specifications could be used as a basis and marketing tool for future applications.

6.2 Potential applications

This study shows that is not easy to find a new application for seagrass. With the new applications that were found through experiments and literature research, the reader has enough information to look further into one application. Having identified the potential of the pulp, the client should investigate further. The success of pulp production could lead to multiple applications such as paper. In terms of prototyping, more thorough research is advisable. Measuring how many grams or millilitres are used in making the samples could give a clear view of what works and what does not.

Finally, we recommend keeping a close eye on the development of seagrass materials and other bio-based materials derived from aquatic plants. There are already many applications for seagrass, but none of them are widely used or marketed. Trying to market these products using seagrass waste and selling them to the right consumer could be more beneficial in the long run than developing a completely new material. Therefore, start-ups, companies, and material innovators should work together on more in-depth research, as many of the current production processes and applications could be used for seagrass but have not yet been explored

Seagrass in the Netherlands research

General research: seagrass in the Netherlands

Why should awareness be created about seagrass as a new sustainable product?

Currently, nature is struggling with an excess of seagrass. The grass grows on the bottom of the sea and is being washed up on the beaches. This seagrass is being removed every night before sunrise at popular beaches where beachgoers go to enjoy their day. Some of this grass is used for insulation, fertilizer, or as a base for dunes. With the impending tightening of laws, this may not be possible in the future. Eventually, there will be no place for the seagrass and no money to dispose of it.
Because the planet is not in the best state right now, it is important to create awareness for sustainable materials and products. Seagrass, which is a waste product from the ocean can potentially be used to create textiles/products. This way, it will offer a solution to the excess seagrass and will contribute to a more sustainable planet. In order to produce products from this material, it is important that people know what it is made of. When awareness is created for seagrass, people will more likely choose to buy products made from this textile over a not sustainable textile (Vastelastenbond, z.d.).

Why is it necessary to change the textile industry in the Netherlands?

Sustainability is on the political agenda in the Netherlands. In 2013, the Netherlands laid down various sustainable agreements in the Energy Agreement. In addition, the Netherlands is one of the 195 signatories of the international climate agreement. Based on both agreements, concrete plans are being developed to make our country and the world more sustainable. It can be stated that The Netherlands is a country that is focusing and investing in a more sustainable future. Creating products that are made from a sustainable textile will contribute to this goal.
The textile industry is one of the most polluting sectors. The production of clothing and shoes together account for around 8 percent of global greenhouse gas emissions, of which clothing accounts for 4 to 6.8 percent. But it's not just greenhouse gas emissions that are a problem. There is a lot of water pollution from textile dyeing. Besides this, extreme drought is also a result of the huge water use for the growth of crops like cotton. In terms of use and consumption of clothing, the Netherlands is in a very bad position. We are one of the worst countries in Europe. The number of textiles that we throw away per person in the Netherlands is a lot higher compared to other countries. It is clear that the way textiles are produced and used need to change in The Netherlands and worldwide to contribute to these goals (De Weert, 2021).

Which companies and municipalities are involved in activities in seagrass?

There are multiple companies that sell products made from a sort of seagrass, but this is not the same seagrass that is being researched in this project. Many times, they sell it as seagrass, even though it is seaweed or a different type of seagrass. Most companies do not produce clothing from seagrass but use it to create furniture or accessories. A few big companies that sell these products are:

H&M
H&M is committed to leading the change to a better fashion future. They are planning to do this by improving sustainability performance in their own value chain and demonstrating the resilience of sustainable business.

Reuse and recycling

''At H&M Group, we believe it's senseless that so many clothes and discarded textiles end up in landfill. Upcycling, and eventually recycling, is two of many ways to fulfil our goals towards a more sustainable fashion future.'' In 2019, H&M Group collected 29,005 tonnes of textiles for reuse and recycling through our garment collecting initiative — equivalent to about 145 million T-shirts.
The fashion industry weighs heavy on natural resources, which is one reason H&M Group has set up clear goals going ahead: our mission is to only use recycled or other sustainably sourced materials by 2030. Also, far too many textiles end up in trash bins and landfills — we're talking thousands of tonnes, regularly thrown away with household waste (Lombard Odier, 2020).

Materials

H&M Group is committed to ensuring that sourcing the raw materials used in their products is done in a sustainable way and that social and environmental impacts are taken into consideration during the entire sourcing process.

Some highlights from their Material Ethics policy:

1. Suppliers of natural raw material must comply with all applicable environmental, health & safety, labour and social laws and regulations (including applicable land tenure and use rights).
2. They do not allow any wood or other forest-derived materials, including man-made cellulosic fibre, to originate from ancient and endangered forests, or forests operations damaging high conservation values.
3. By 2020, all cotton sourced for H&M Group will come from more sustainable sources.
4. By the end of 2025, 100% of all wood used in their products, including man-made cellulosic materials, will be sourced from well-managed and FSC™ -certified forests.
5. H&M sells 3 different types of products made from seagrass. Baskets, mats and lightshades. All the product look like they are made of reed, even though it should be 100 percent seagrass (H&M Group, 2021).

Zara Home

Zara works with new processes and raw materials that help them to reduce the impact of their products. Their products are made with the most sustainable raw materials such as ecologically grown cotton, TENCEL™ Lyocell or recycled fibres and also seagrass. They also produce products made with technologies that use less water and items that have been produced using renewable energy sources or processes that reduce emissions
Zara home has almost the same inventory as H&M in terms of products that are made out of seagrass, they sell many baskets for fruit, for towels and even for dogs (Zara, 2021).

Ikea

Like Zara home and H&M, Ikea also sells the same type of products made from seagrass. Baskets, lamp shades and mats.
Ikea has set a few sustainability ambitions for 2030. They want to:

- Inspire and enable more than 1 billion people to live a better everyday life within the boundaries of the planet
- Become circular and climate positive, and regenerate resources while growing the IKEA business
- Create a positive social impact for everyone across the IKEA value chain

The IKEA business aims to assess materials as holistically as possible. That means considering all relevant aspects, including climate footprint, water use, biodiversity impact, land use, and human rights impact, among others.

All these companies sell products advertised as seagrass. If this is hundred percent true, is not clear. The color of the product is not the same, it probably is a different type of seagrass than the one that we are researching. What all the companies have in common is the fact that most products are baskets, lampshades, and mats.

Sustainability in the interior/furniture industry

Awareness for sustainability is growing worldwide. More and more companies are putting more effort into changing and reduce their environmental footprint, this is no different in the furniture industry (Van der Hoeven, 2018).

How is this market getting more sustainable?

Bio based materials

An example of sustainability in the furniture industry is working with so-called biobased materials. These are materials from nature that don't just run out, like seagrass. Another example is bamboo. Bamboo can grow again and again and quickly, making it a valuable and sustainable raw material. Biobased materials are often better for the environment, but this is not always the case. This is because it is not a protected term. So, when a supplier uses this label, you will have to do even more research into the materials and their origin. Like stated in the paragraph above, big companies like Ikea, Zara home and H&M home are already producing products made from seagrass and bamboo (Recycling Furniture: Sustainable, High Quality & Creative | Imm, 2021).

Recycling

Recycling is another good method of how the furniture industry is getting more sustainable. Customers can provide residual materials and household waste with a second life. I some cases, the materials are biologically degradable and look really food.
Unfortunately, furniture is not made to be recycled easily. The cost of processing is high and often outweighs the value of the materials. Many wood items are treated with paint or varnish, which makes is difficult to be composted. The best and easiest way to contribute to a more sustainable furniture market is to repair the items, donate or recycle as bulk waste as a last resort.

Refurbished

Buying refurbished furniture also contributes to a more sustainable market. Refurbished products are used items that are repaired and made into almost new products. This way there will be less waste and old products are getting a new life. (Earth911.com, 2021).

Milestone 2 – Introduction of Fatboy

In this milestone a description of Fatboy is given. Fatboy researches several possibilities to be more environmentally friendly, in which seagrass is a serious contender as a new application. The history of Fatboy and more specifically the lack of sustainability in Fatboy's industry make it hard to change their complete way of working.

Company description of Fatboy

Fatboy is a Dutch company focused on furniture based in 's-Hertoghenbosch, the Netherlands. For over twenty years they have been showing customers furniture can be different. It all started after

Finnish Designer Jukka Setälä designed an obscure beanbag while listening to music by Fatboy Slim; the Fatboy beanbag was born. After Alex Bergman took over and started introducing new products, Fatboy became a brand instead of a product. Nowadays Fatboy distributes several different products like beanbags, lighting, benches and chairs to over 65 countries (Business Insider, 2021).

Fatboy's mission is to design with a smile. They want to create their own versions of classic favourite furniture in homes and gardens. The iconic parts of the furniture will remain, although Fatboy designs with a twist and full of ingenuity. Besides that, all products must have a function. Vision wise that means that Fatboy designs with an own design team of external designers who share the vision of Fatboy. These designs should at least last for ten years for customers, this is the main reason why Fatboy wants its products to be capable of taking a beating. This has to be with materials that are water-resistant, do not fade and are preferably recycled. This way, Fatboy wants to have as little impact on the environment as possible. This also translates in the way Fatboy chooses their produces, with requirements like safety, health and environmental regulations. Fatboy wants to do their bit for a healthier and happier planet (Fatboy the original B.V., 2021).

What are the products of Fatboy?

Fatboy designs both indoor and outdoor furniture. This furniture has to put a smile on the customers face, is a bit different than 'standard' designs and always has a function. The aim of Fatboy is that the products will be used by clients for at least five to ten years. Keeping this is mind, Fatboy does not introduce a lot of new products, because all newly launched products need to be durable and long-lasting. This way Fatboy does not only guarantee quality to their customers, but also provides them with durable products that are environment friendly (Fatboy the original B.V., 2021).

The products

After Jukka Setälä introduced the Fatboy beanbag, Alex Bergman took over and after that Fatboy started introducing a lot of new products and product types. This resulted in Fatboy having the following products in their product range:

1. Beanbags
2. Footstools
3. Lighting
4. Stools and chairs
5. Tables
6. Hammocks
7. Lounge sets
8. Rugs
9. Accessories like bags

The products above vary from indoor to outdoor used products and often have own creatively chosen names. For instance, the Lamzac. This product is an air-filled bag meant for relaxing. The name Lamzac refers to the Dutch word 'lamzak' which translates to a lazy person. Also, the word 'zak' means bag, this way Fatboy shows their playful way of working and creativity to customers (Fatboy, 2021).

Collaborations

Fatboy frequently collaborates with designers and other companies to increase their branding and launch special products. Brands like Daily Paper, Saint Laurent and Vilebrequin have worked with Fatboy in the past (Fatboy the original B.V., 2021).

Fatboy X Daily Paper
When Daily Paper opened their office in New York, they wanted furniture that suited their target group: playful and affordable. This is in line with the philosophy of Fatboy and so they reached out to Fatboy. Fatboy provided the interior of parts of the Daily Paper office and launched a limited edition Lamzac O in collaboration with the Clothing Brand (Fatboy the original B.V., 2021).

Fatboy X Saint Laurent
In contrary to the Daily Paper collaboration, the collaboration with Saint Laurent was not based on providing products for Saint Laurent. Saint Laurent reached out to Fatboy to increase branding for both parties. This led to Fatboy designing a chic original Fatboy beanbag. The bag is exclusively for sale at Saint Laurents main store named Saint Laurent Rive Droite for a price of €7000, -. In comparison, the normal beanbag can be bought for €219, - (Fatboy the original B.V., 2021).

What is Fatboy's sustainability strategy?
Because the furniture industry is way behind on sustainability, Fatboy has a lot of catching up to do. After introducing a small department purely focused on sustainability the sustainability strategy of Fatboy has become clearer, although results are not measured yet (van Amelsfort, 2021).

Fatboy's sustainability actions
To be sure Fatboy's entire logistics chain is becoming more and more sustainable, Fatboy checks whether their partners are innovating in sustainability. This forces partners to focus on helping to get the market more sustainable and helps Fatboy become more sustainable as well (van Amelsfort, 2021).

Also, Fatboy is always researching where new innovative product solutions can help Fatboy become more sustainable. This can be through using new or recycled resources, changing the way a product is produced or using different chemicals. Fatboy is for instance checking whether some products can be assembled at location to reduce the travelling by the products (van Amelsfort, 2021).

Fatboy aims to produce products that last five to ten years for the customer. This way products are used longer, which means less products have to be produced in order to satisfy the costumers. This of course helps Fatboy's sustainability program but also shows quality towards customers which may help in branding and marketing the Fatboy products.

Fatboy's Sustainability pillars
Fatboy states brightening interiors with green products is a gradual process. This gradual process involves all suppliers, producers and other partners. Sustainability is all about continuous innovation which means Fatboy is always looking for ways to go further, in both big steps and small steps. This way of working – one step at a time – makes things that seem impossible today, feasible in the future.

Fatboy has three pillars which they call 'sustainability focus areas. These areas are there to keep an overview of the sustainability activities.

The first pillar is called **Fatboy supply chain**. This pillar is divided in three sub pillars. The first is focused on fair labour and worker conditions. Of course, in their headquarters in the Netherlands there are a lot of laws and restrictions which means workers and the working environment is safe, but in the countries in which Fatboy produces this might be different.

To make sure Fatboy's supply chain contains a safe work environment, they created these laws and restrictions themselves to ensure producers and foreign partners are treating their workers right. This also means the supply chain has an increased extent of transparency. Because of this consumer know how and where Fatboy products are produced. The focus in this area also lays on minimizing environmental impact of production.

The second pillar is called **Fatboy product**. In line with the supply chain methods, this pillar is focused on a more sustainable way of producing products with better chemicals and less impact on the environment. To be more durable, Fatboy focuses on products that are longer lasting with better chemical usage and certificates. Also, Fatboy integrates circular design principles such as repair, reusage and recycling.

The last pillar is called **Fatboy Footprint**. This pillar is exclusively focused on reducing the impact of Fatboy's own operations such as logistics and offices. A way of achieving this is through smarter packaging, which means less transport is needed. Some of the actions in the pillars above are described below.

Examples of sustainable solutions

Fatboy started producing products from 100% recycled polyproline and thermoplastics. These products are called 'the Paletti' and 'Recycled Velvet' products. The smarter packaging as mentioned in the heading above, also is also a clear example of a sustainable solutions. The transporting process has been changed so empty covers of the beanbags are now filled in the headquarters in Den Bosch which reduces transport movements. Also, the covers and pillows are vacuumed before transport to reduce transport and emissions.
Fatboy also changed their white boxes to brown boxes. This means the boxes do not need an extra coating which contains unsustainable gasses. Besides using more durable boxes, the materials in these are almost always FSC Quality certified. The FSC Quality certification is focused on a more durable and sustainable way of managing forests (Homepage Netherlands | Forest Stewardship Council, 2021).

Another sustainable solution is the repair kit Fatboy delivers with certain products. Sometimes a product such as a lamp breaks but is fairly easy to repair. So instead of having to send the product to Fatboy which causes more transport movements or repairing the product before which caused costumers to lose warranty. Customers now get a repair kit with clear instructions to repair simple products. This also causes products to be more durable and last longer, which also heavily benefits the environment.

Lastly, Fatboy is focussing on using more sustainable fabrics. They do this through testing different types of fabric specifications in different environments such as indoor and outdoor. A fabric Fatboy uses because of this is called Olefin. This is a synthetic fabric and is produced from polyproline fibres. Because Fatboy does have certain quality standards, it can be difficult to implement these types of fabrics. However, Olefin has certain quality's which match those standards:

1. Loves sun, does not discolour
2. Wear-resistant
3. Does not crease

4. Water resistant
5. Stain resistant
6. Easy to clean
7. 100% recyclable
8. Long lifespan
9. Highest quality fabric for outdoor use

Possibilities for seagrass as a textile application for Fatboy

As mentioned in 2.3.1, Fatboy is looking into new solutions for their products. The beanbag is an example for this. These beanbags are filled with plastics and can cause serious harm towards the environment. Seagrass can be a material that might be substitute into the products instead of plastics. However, recent tests have not shown the desired reliability and quality Fatboy desires. This means the beanbags are not as comfy or durable when using seagrass.

Different options for using seagrass as a material for Fatboy products are using the colours of seagrass or using seagrass as stitching material. In collaboration with Wageningen University, Saxion University of Applied Sciences and ArtEZ Future Makers, Fatboy wishes to find new solutions for their products. Students from the earlier mentioned schools are investigating and researching what possibilities seagrass gives and what possible changes can be made without losing quality, durability or prestige. This also means that the solutions have to be a lot more efficient or environmentally-friendly. Due to this fact the usage of chemicals to make the products longer lasting, has to be reduced to a minimal. This is thanks to the fact that Fatboy wishes to at all costs avoid greenwashing.

Fatboy's Corporate identity

Fatboy produces their own versions of classic furniture in houses and gardens. Fatboy wants to appear bold and functional, and this also translates into the corporate identity. Telling the customers that life is a party, the fact that Fatboy designs with a smile and an informal way of communicating proves this. Besides using humour and focusing on fun and positivity in communicating with customers, Fatboy also uses this strategy in naming their products, such as given in paragraph 2.2.1 (Fatboy, 2021).

The focus also has been laid upon sustainability and binding customers and co-creators for a longer period of time to the company. Through an ongoing newsletter and special offers to costumers, Fatboy tries to enlarge customer loyalty and engagement. For the dealers and co-creators Fatboy uses a portal where all information about all products can be found (Fatboy, 2021).

Milestone 3 – Sustainability in the Netherlands

How important is sustainability to consumers nowadays?

Sustainability & Consumer Behaviour 2021 | Deloitte UK

Deloitte is a global leader in auditing, consulting, financial advising, risk advisory, tax, and other associated services. Ethical sustainability about a year ago. This was before the COVID-19 pandemic reached its peak. They repeated the survey in March 2021, adding some new questions to acquire a better understanding of how sentiments have changed.
Deloitte investigates how consumers are adopting a more sustainable lifestyle, discusses the main barriers to consumers behaving more sustainably, considers consumers' most valued environmentally

sustainable and ethical practices, asks what consumers require to live a more sustainable lifestyle, and evaluates the impact of COVID-19 on consumers' adoption of a more sustainable lifestyle (Sustainability & Consumer Behaviour 2021, 2021).

Key findings

Methodology of the research:

Deliotte states; ''These findings are based on a consumer survey carried out by independent market research agency, YouGov, on Deloitte's behalf. This survey was conducted online with a nationally representative sample of more than 2,000 UK adults aged 18+ between 5 and 8 March 2021.'' Although this research is done in the United Kingdom, I still think it is relevant for the final product, the communication plan.

Reasons why businesses need to be more sustainable is shown in Deliotte's research done in 2021, the following reasons and facts are mentioned. ;

1. Sustainability remains a key consideration for consumers in 2021 with **32% of consumers** highly engaged with adopting a more sustainable lifestyle.

– Equally important, **28% of consumers** have stopped buying certain products due to ethical or environmental concerns.
– **Gen Z** are adopting more **sustainable behaviours** than any other groups: 50% reduced how much they buy and 45% stopped purchasing certain brands because of ethical or sustainability concerns. As wealth transfers to younger generations, sustainability and ethical considerations will need to become the standard and should be transparent throughout the value chain.
– Overall, **lack of interest** remains the main barrier to adopting a sustainable lifestyle, followed by the **perceived expense and issues** around accessing relevant information.
– Consumers want to do more but many **want brands to take the lead** with 64% of consumers wanting brands to reduce packaging, 50% want information on how to recycle and 46% need clarity on sourcing of products.
– It is in **frequent, essential purchases** like groceries, household items, personal care and clothing that consumers say they most often consider sustainability.
– The **five sustainable brand practices** that consumers value most include: waste reduction, reducing carbon footprint, providing sustainable packaging, committing to ethical work practices, and respecting human rights

The main reasons why people do not adopt a more sustainable lifestyle

There are three main reasons for this, and they out rank all other reasons.

- The lack of interest for a sustainable lifestyle, 22%
- A sustainable lifestyle is perceived as too expensive, 16%
- Not enough information to have a more sustainable lifestyle, 15%

Other reasons for not embracing a sustainable lifestyle are:

- There is economic uncertainty (i.e. impact of covid-19), 10%
- Some people do not believe it makes a difference, 10%
- It is too inconvenient, 9%
- It is to complicated, 8%
- It is time-consuming, 8%

How does the adoption of a sustainable lifestyle, effect the Furniture & Homeware sector?

Because the communication plan is focused on the interior company Fatboy, this will help give a perspective of what consumers find most important in this category. This will give action points Fatboy needs to focus on.

- 35% of consumers have reduced the number of new products and goods they buy.
- 12% of consumers have chosen brands that have environmentally sustainable practices/ values.
- 10% of consumers have chosen brands that have ethical practices/ values.

Which form of sustainability is the most popular now?

According to Deliotte, Avoiding the use of single-used plastic is the most widespread way people show that they are committed to a sustainable lifestyle. 61% of consumers have reduced the usage of single-use plastics. Other important areas of focus in the near future are focus on seasonality (49%) and buying more local products (45%).

After these two focus areas, there are also other common ways people adopt a more sustainable lifestyle, the following manners are listed from mostly done to less done (in the UK).

1. Reduce the number of new products bought, 39%
2. Choose brands that have environmentally sustainable practices, and values, 34%
3. Choose brands that have ethical practices/ values, 30%
4. Stop purchasing certain brands or products because I had ethical or sustainability related concerns about them, 28%

What are the best possible ways to motivate people to be sustainable?

How to get everyone to care about a green economy

First, we want to explain some of the reasons why sustainability is not enough a priority in many countries. The climate crisis can feel insurmountable, this means that many people feel like the climate crisis is not something we can fight against. The second reason is that many politicians and governments are not acting at the pace or scale required because they believe the public expects them to do something else first. A third reason is that combating the climate crisis is usually set on ''the top of the list'' by politicians, but this can sometimes feel discouraging as small steps also need to be taken, to get real successes.

So, what is the plan? Rather than dismissing sustainability as an impossible challenge, we must demonstrate to the public how a green economy addresses the issues that are now causing concern. Whether they care about the environment or not, it improves their quality of life. We also need to remind people that, people have been working on climate change and nature restoration for years and they know what we need to do, and they know the sooner we act, the easier it will be. We do have to keep the mindset to not only change a few green sectors, we need to change the whole economy, using investment and policy to reward people and businesses for the decisions they take that lower carbon and restore nature rather than degrade it.

We need to move rapidly to a green economy, but at the same time a lot of people are facing economic challenges. These two issues need to be handled at the same time; we cannot afford to only deal with one challenge. In many countries the focus is mostly on the economy. In order to great a green community, the focus needs to shift to agriculture and manufacturing. We need to find new ways to produce goods and food sustainably.

The message we need to put out in the world is that everyone can lower their carbon footprint, and help create a green economy, by making decisions based on what is possible for them. We need to show how delivering a green economy and investing in it will improve our health and our well-being and our quality of life, how it will deliver better jobs, a better economy, more opportunities.

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Solving for the retail profitability value chain | Deloitte Insights

The future of retail is in consumers' hands

Three steps that retailers can take to survive in the era of consumer-to-business—an individualized, increasingly digitized, and complex shopping experience led by the buyer rather than the seller.

Our financial and strategic analysis of 100 retailers from 11 retail subsectors demonstrates how recent customer experience trends—including an individualized, increasingly digitized, and complexified shopping experience led by the buyer rather than the seller—are compounding a margin crisis that was already playing out before the pandemic. Welcome to the era of consumer-to-business (*Consumer Industry*, 2021).

How should retailers adapt?

Here are three steps retailers can take to embrace it.

- **Remove friction.** Make shopping easier by offering various purchasing formats, such as text, livestream, social media, and web as well as fulfillment options like "buy online, pick up in store."
- **Redefine service.** Treat consumers like merchants in their own right: Offer more thorough product descriptions. Expand return options, potentially including other retail partners.
- **Organize your operations by customer segment.** Create a designated customer management team for each segment, charged with owning that segment's data and smoothing their experience across touch points.

For more of Deloitte's insights on the consumer-to-business model, read *The retail profitability paradox* published by *MIT Sloan Management Review*.

What are the trends in marketing new sustainable applications/products?

Trend 1: Deliver your message in a positive way

Various studies show that change in behavior comes about when there is more positive attention for sustainability. It is successful thanks to people like Per Espen Stoknes, a Norwegian climate psychologist and researcher. Among other things, he wrote the book 'What we think about (when we try not to think about) global warming'. People are becoming increasingly aware that it is important to share large, but also small successes with the world. By doing so, you build up your authority and inspire others to do the same (Vermeulen, 2021).

Nespresso's recycling bike is a good example. Three hundred cups of coffee provide enough raw material to produce a city bicycle. Not all cups are recycled yet, but by showing consumers what great products can be made from the cups, you encourage people to hand in more cups - and without pointing fingers at each other. It's good publicity for Nespresso, as it gives the Swiss company a lot of positive attention for its small steps towards sustainability (Culy, 2020).

Trend 2: Be honest and avoid greenwashing

A term that has been around for a while and that you should definitely avoid is greenwashing. At the same time, distrust of sustainability claims is on the rise, after a few years of decline. Consumers are therefore becoming more critical and sensitive to greenwashing or unreliable promises. The facts are checked, and companies are punished immediately if it turns out not to be true. Be sincere as a company and show what you do and be honest about your ambitions.
A good example of this is Shell, which has gone wrong time and time again when it comes to sustainability. In 2017, Anna Nooshin posted a water bottle on Instagram, promoting hydrogen-powered vehicles in a beautiful campaign video. This turned out to be not quite true, as this hydrogen turned out to be produced from gas (*Volgers van vlogger Anna Nooshin pikken Shell-post niet*, 2017). Shell then launched the 'CO2 neutral driving' campaign, in which the consumer himself pays for compensation by paying 1 cent extra per litre. This money is invested in tree projects to compensate CO2 emissions. Seems nice, but here too Shell received a lot of criticism that it was not sincere (Rijksen, 2021).

Trend 3: Upcycling

A trend that is especially popular among high-end fashion brands is upcycling. Within this initiative, old, leftover products or materials are transformed into something new. The use of unsustainable materials, such as textiles, is one of the biggest problems in the fashion industry today. Making the textile industry sustainable is a difficult process that takes a lot of time.

For example, Louis Vuitton transformed its unsold 'LV Trainer' trainers from the old season into new 'LV Trainer Upcycling' trainers (Li, 2021). Prada introduced a line of completely used recycled nylon, also known as econyl (The Times, 2019). Dutch duo Victor & Rolf recently presented an entire collection made from leftover products (Dubbeldam, 2021). Even Burberry, previously known as the brand, that burned leftover products, is now donating old materials to fashion students within the UK (Phillips, 2020).

Trend 4: Re-issue
Besides the use of old materials, it is also increasingly common for brands to reissue older collections. Before, companies destroyed old items, or sold them in sales or outlets. Both contribute to the fast fashion problem. Because too much is produced, brands offer products at lower prices and a high textile waste is created. Re-issue means that brands do not sell or destroy their products anymore but start offering them again at a later moment.

Trend 5: Transparency in the supply chain
Brands are increasingly confronted with the rise of conscious consumers. Consumers are increasingly interested in where their clothes come from, but also how and under what conditions companies produce clothes. Initiatives like Fashion Revolution try to make these processes transparent for consumers. There you see that almost every brand scores poorly (*ABOUT*, 2021).

Untransparent and unethical practices carry significant reputational risks that can deeply damage the business. To counteract this, more and more brands are investing in new Blockchain technologies. These should make the production processes in the supply chain more transparent for their stakeholders.

Trend 5: Vintage
Consumers are also doing their bit to make the fashion sector more sustainable. The second-hand clothing platform Vinted became a great success in the Netherlands, and even took over United Wardrobe. It is a website that acts as a platform for buying and selling second-hand goods, including mainly clothes and accessories. Zalando also responded to the demand for second-hand clothing with its used category. And vintage and second-hand clothes shops have also seen a positive increase in recent years (Retailtrends, 2021).

What are the big companies doing to create sustainability awareness? Top 10
Greenchoice, Tony's Chocolonely and Tesla are the three companies that Dutch consumers think contribute most to solving social problems. They score the highest from a list of 60 large well-known brand companies and some sustainable niche players. The top 10 is as follows:
1. Greenchoice
2. Tony's Chocolonely
3. Tesla
4. Vattenfall
5. NS
6. IKEA
7. ASN Bank
8. Eneco
9. Essent
10. FrieslandCampina

(Van der Molen, 2020).

MADE
Their goal is to make better choices that minimize impact on people and the planet. In 2021, they revealed four key pillars in which they can make a difference.

<u>Responsible sourcing</u>

They believe that sustainability starts with responsible sourcing. They ensure that the main materials used to make the furniture have less impact on the environment. In addition, they carefully select suppliers who fit in with their core values.

Product packaging

They make every effort to make better choices so that when you receive their products, it is easier to recycle the packaging responsibly. Some of their items require protective packaging due to their size and weight. Therefore, they are looking at innovative ways to reduce the amount they use, with an additional focus on plastic.

A second home

In the future, they will work together with a donation platform, so that you as a consumer can give your old favourite furniture a second home. Good for the planet and good for people says Made (Made.com, 2021).

IKEA

At IKEA they work every day to make life better for as many people as possible. That's why their goal is to inspire and help 1 billion people to live a responsible and healthy lifestyle. They also want to become fully circular by 2030. This means that they want to reduce the use of new raw materials and our CO_2 emissions to zero. We're also working hard to make a positive social impact on everyone in the IKEA supply chain (IKEA, 2021).

H&M

When H&M talks about product sustainability, they mean the impact it has on the environment and the people who make, process, transport, sell and buy it. That is why it is very important for them to ensure that all products are made with care and responsibility for the planet and the people involved in the product's life cycle. They constantly strive to improve the sustainability of the products. They want to be at the forefront of creating a more sustainable future for fashion (H&M, 2021).

Marketing-communication plan

Marketing communication plan

This marketing communication plan has been developed by Saxion University students and originated from the question: new application for seagrass. The goal of this plan is to make people (companies and consumers) aware of a new material/product made from the sustainable resource seagrass. We need to convince people that this material is good for people and the environment in the long term and offers benefits in the short term.

Seagrass

Currently, nature is struggling with an excess of seagrass. The Seagrass grows on the bottom of the sea and is being washed up on the beaches. This seagrass is being removed every night before sunrise at popular beaches where beachgoers go to enjoy their day. Some of this grass is used for insulation, fertilizer, or as a base for dunes. With the impending tightening of laws, this may not be possible in the future. Eventually, there will be no place for the seagrass and no money to dispose of it. Because the planet is not in the best state right now, it is important to create awareness for sustainable materials and products. Seagrass, which is a waste product from the ocean can potentially be used to create textiles/products. This way, it will offer a solution to the excess seagrass and will contribute to a more sustainable planet. To produce products from this material, it is important that people know what it is made of. When awareness is created for seagrass, people will more likely choose to buy products made from this textile over a not sustainable textile.

The textile industry

Sustainability is on the political agenda in the Netherlands. In 2013, the Netherlands laid down various sustainable agreements in the Energy Agreement. In addition, the Netherlands is one of the 195 signatories of the international climate agreement. Based on both agreements, concrete plans are being developed to make our country and the world more sustainable. It can be stated that The Netherlands is a country that is focusing and investing in a more sustainable future. Creating products that are made from a sustainable textile will contribute to this goal.
Vastelastenbond. (2021).

The textile industry is one of the most polluting sectors. The production of clothing and shoes together account for around 8 per cent of global greenhouse gas emissions, of which clothing accounts for 4 to 6.8 per cent. But it is not just greenhouse gas emissions that are a problem. There is a lot of water pollution from textile dyeing. Besides this, extreme drought is also a result of the huge water use for the growth of crops like cotton. In terms of the use and consumption of clothing, the Netherlands is in d position. We are one of the worst countries in Europe. The number of textiles that we throw away per person in the Netherlands is a lot higher compared to other countries. The way textiles are produced and used need to change in The Netherlands and worldwide to contribute to these goals.
Changeinc. (2021, 25 mei).

Macro environment analysis (DESTEP)

Demographic developments

Demographic factors concern the characteristics of the population, such as the number of inhabitants, age and income and their impact on developments in the sector.

Sustainable living in the Netherlands

Global Sustainability Index, Netherlands – Ranked 13th in the Global Sustainability Index

Earth.Org Global Sustainability Index, is an index made by Earth.Org. They examine the policies and actions regarding the environment of every country on earth. It studies the most esteemed global indexes on pollution, climate change, policy, energy, oceans, biodiversity they have produced an overall Global Index, which is updated every year. This is the Global Sustainability Index scorecard for the Netherlands.

The Dutch government has endeavored to reduce greenhouse gas emissions by 55% below 1990 levels by 2030, and are working towards carbon neutrality by 2050, along with the rest of the EU. These goals are laid down in the Climate Act on May 28, 2019. The Climate Plan, the National Energy and Climate Plan (NECP) and the National Climate Agreement contain the policy and measures to achieve these climate goals. The government is required to draw up a Climate Plan setting out measures to ensure that the targets stipulated in the act are achieved. The National Climate Agreement contains agreements with the sectors on what they will do to help achieve these climate goals. The participating sectors are electricity, industry, built environment, traffic and transport, and agriculture.

In April 2020, the Dutch government announced a set of climate policies designed to reduce annual carbon emissions by 10 megatons; several new coal power plants are to be closed or run at minimum capacity, a €3bn spending package will subsidize renewable energy projects and home refits, and there are a few policy adjustments, for example on livestock numbers, reforestation and lowering the national speed limit.
While this is no doubt a positive step, the government had little choice; a court case brought by environmental groups in 2014 and upheld by the supreme court last year forced the government to act to reduce emissions to 25% below 1990 levels by the end of 2020. This is the first climate change case that has forced the government to enact policy and sets a precedent for future similar cases. The annual additional costs for the Netherlands associated with the Climate Agreement are less than 0.5% of GDP in 2030. The country should be able to afford this transition.

- The Netherlands have aimed to reduce greenhouse gas emissions by 49% by 2030 (compared to 1990 levels), and a 95% reduction by 2050.

- The National Climate Agreement, concluded in June 2019, aims to share the costs of the transition fairly between individuals and businesses. The annual costs represent less than 0.5% of GDP in 2030.

- A case brought to the Supreme Court ruled that climate change could have impacts on the rights to life and well-being of Netherlands' citizens. The government was therefore instructed to achieve 25% reduction by the end of 2020.

Netherlands - Ranked 13th in the Global Sustainability Index. (2020, 27 July).
Delft University of Technology. (2017).

Economic developments

Economic factors are characteristics and influences of developments in the economy, such as economic growth, employment, and unemployment.

   a. Economic growth in sustainable material usage, specifically seagrass in the Netherlands.
   b. How much more will people spend on sustainable products. (Fatboy)

1. **Socio-cultural developments:**
   These factors concern characteristics and influence of culture and lifestyle habits, such as norms and values, subcultures, and educational level.

c. Lifestyle of fast-moving consumer goods, norms, and values in the Netherlands.
d. How many people in the Netherlands are more concerned with sustainability.

2. **Technological developments:**
These are often referred to as the engine of the economy. Thanks to technological developments, there is a continuous improvement of production methods and innovations of goods and services.
   e. **Technological developments connected to seagrass in the Netherlands.**
3. **Ecological developments:**
Ecological factors concern characteristics and influence of developments on the physical living environment, such as the environment and climate, but also the working environment.
   f. The current state of seagrass meadows in the Netherlands.
4. **Political-legal developments:**
Political-legal factors concern characteristics and influence of developments in the field of government decisions, such as current legislation, changes in the law, and subsidies.

Important legislation on the use of sustainable materials by companies in the Netherlands.

On 25 September 2015, 'the 2030 Agenda for Sustainable Development' was adopted by the United Nations General Assembly. The core of this Agenda is 17 Sustainable Development Goals (SDGs), and 169 underlying sub-goals or targets. The goals and targets expand on the Millennium Development Goals (MDGs) that ended at the end of 2015, among other international agreements on sustainability. However, whereas the MDGs primarily set goals for poverty alleviation in developing countries, the 2030 Agenda is a wide sustainability agenda for all countries, including the Netherlands.
The agreements are not binding by law but are an obligation to perform to the best of one's ability. Countries are urged to translate the global SDGs into national objectives and policy. For the Netherlands, the 2030 Agenda can provide guidance for development cooperation policy, international sustainability policy and national sustainability policy. It is up to the central government to set the level of ambition for the Netherlands and to provide a comprehensible long-term vision that indicates what policy is to be achieved with the 2030 Agenda (Netherlands Environmental Assessment Agency, 2016).
The most important goals relating to the Seagrass project would be the following goals.

1. Goal 12 Ensure sustainable consumption and production patterns.
2. Goal 14 Conserve and sustainably use the oceans, seas, and marine resources for sustainable development.

Goal 14 concerns the natural environment in the Netherlands. Goal 12 concerns the Production, distribution and supply of goods and services in the Netherlands. These goals are the focus of a better world in a sustainable context. These goals are meant for the government, citizens, and companies. So, following these rules is important, when creating a new sustainable product. This will help shape our communication message by following the goals and targets shaped by the National government. This will show us what is most important for the Netherlands to be more sustainable, and this will connect to the sustainable new material seagrass, and the possible new application of the product.

Sub-targets of Goal 12 are the importance of sustainable management of natural resources, encourage companies to adopt sustainable practices and to integrate sustainability information into their reporting cycle, and ensure that people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature. These goals are key to a more sustainable country, and companies in the Netherlands could use these goals to better their companies, products, and services.

If there will be a sustainable product made from seagrass. It needs to be taken into consideration that the harvesting of seagrass needs to be managed well to keep the product a sustainable alternative, because in the SDG's goals it is mentioned that we should not exhaust the natural resources but use them sustainably. For seagrass this means harvesting in areas where there is an overload on seagrass or even better implementing and growing more seagrass to maintain a healthy ecosystem. Also, companies should inform people with more relevant information and create awareness for sustainable development and lifestyles in harmony with nature, as this will help achieve the SDG's. So, when there is a new seagrass product, people should be informed of its benefits to the climate and to the people, to create awareness for the product and sustainability in general.

Sub targets of Goal 14 are formulated similarly they all place importance on conserving, protecting, and strengthening the coastal and marine areas in the Netherlands. This should be done by the government, but companies need to help as well. Possibilities could be by strengthening the coastal and marine areas in the Netherlands by planting new seagrass in the sea, this way we keep the ecosystems intact.

Companies who plant new seagrass for environmental impact.

It could be interesting for seagrass products, although I think if companies want to invest in this, they should plant more than they take from the sea as this stops damage to the sea.
DEME Group. (2020, 8 oktober).

Target group

According to research by IBM, consumers are mostly brand driven. These consumers also mostly care about the purpose of a product or brand. Sustainability is also a considerable influence in this, which is important for the positioning by brands marketing wise.

Source: IBM Institute for Business Value.

The figure above shows that consumers do care about the environment, sustainability, and the purpose of a brand. However, the willingness of changing habits to reduce environmental impact scores lowest in the index. This means that used brands and products cannot change to much to be sustainable.
For an application of seagrass this means look, feel and function of a product should not be that different from the products that are already being used. *IBM. (2020).*

The type of person

According to Latana, the types to be targeted can be divided into four personas. The first is the Enthusiastic Expert. Who prioritizes the **entire system of sustainable thinking**. The enthusiastic expert is mostly between 35 and 45 years of age. The live in rural areas and are mostly well-educated. Education often leads to a higher income, and this persona is aware that higher taxes for environmental damage is an effective way to manage the environment. Also, the enthusiastic expert is a lot more vocal about environmental matters and is, also through higher education, more knowledgeable about sustainability and sustainable brands. This enthusiastic persona is also sustainable-wise very aware because they want a good future for their kids, this is also in relation to their age; being mostly young parents.
Who Sustainable Brands Should Target. (2021, 24 augustus).

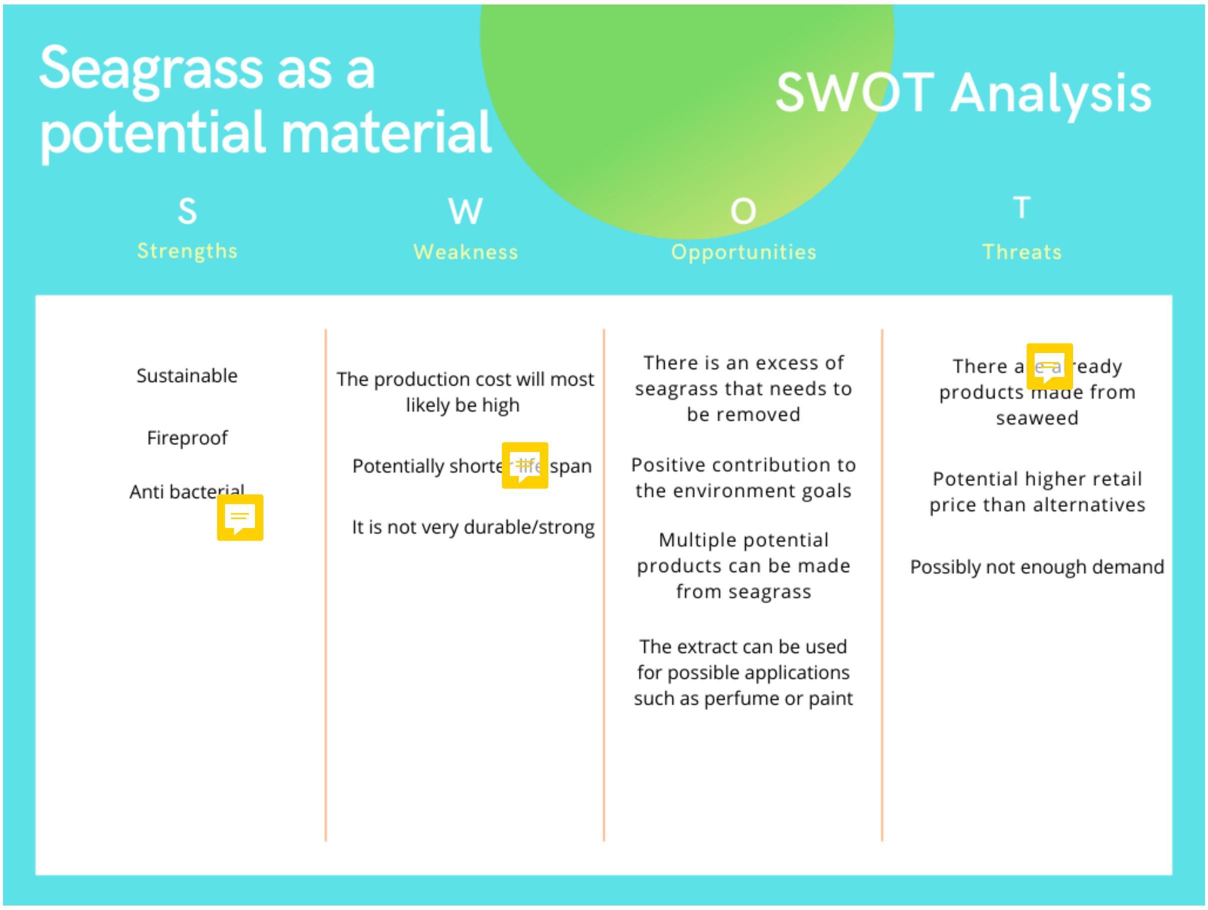
The second targetable type is the Inspired Innovator. These Gen Z and Millennials come from urban and higher-educated backgrounds. This persona prioritizes future and forward-thinking policies. In the adoption model of Rogers, this persona is mostly in the early-adopters stage. Gen Z and Millennials are the leading generations in purchasing **organic** products with 73% and 70%.

The third persona in this matter is the Considerate Conservative. This targetable type is mostly between 45 until 65 years of age. Living in rural areas. This type prioritizes **transparency**, knowledge, and empowerment. This group is commonly the mainstream consumer. In the index of Rogers – as named before – this group would be the early majority or the late majority. This group might be harder to target because they are less heavily involved in sustainable thinking and have a more middle-of-the-road kind of mindset. Although they are educated about sustainability, sustainable brands are not often the most important for this group. Despite that fact, this group is willing to pay more for sustainable solutions and a positive impact on the environment. This group can be targeted best with simple sustainable highlights in marketing publications.

The last type according to Latana is the Reserved Rationalist. They not exactly in one certain group of age. They live mostly in rural and urban areas and are well-educated. This group is the hardest to target for sustainable applications. The figure above shows convenience is incredibly important for consumers. This highly relates to this specific group. This group are called the laggards in the product innovation index. This is the group who will change their habits or buy an innovative product last. Besides that, fact, this group also is less likely to care about sustainability. To target this group, convenience of the seagrass application should be noticeably clear and visible.

Swot Analysis seagrass

To have a clear understanding of where the opportunities for seagrass lie and which points will make it more difficult for seagrass to succeed, a swot analysis has been made. The strengths and weaknesses are part of the internal factors, where the threats and opportunities are external factors.



Confrontation matrix

		Opportunities			Threats			
		There is an excess of seagrass that needs to be removed	Positive contribution to the environment goals	The extract can be used for possible applications such as perfume or paint	There are already products made from seaweed	Potential higher retail price than alternatives	Possibly not enough demand	Total
Strengths	Sustainable	++	++	+	+	+	0	7
	Fireproof	0	0	+	++	++	0	5
	Anti bacterial	0	0	++	++	++	0	6
Weaknesses	The production cost will most likely be high	-	-	- -	-	--	-	8
	Potentially shorter life span	0	0	-	-	- -	-	5
	It is not very durable/strong	0	0	-	-	- -	-	5
	Total	1	1	0	2	-1	-3	

Conclusion Swot analysis

The most important strengths of seagrass are that it is sustainable, fireproof, and antibacterial. If seagrass is used as a material or resource, it is very sustainable. This goes together with the opportunity to contribute to the environmental goals that have been set by the EU and The Netherlands. Besides this, it also goes together with the opportunity of excess seagrass that can be removed. An important weakness is a fact that removing the seagrass costs a lot of time and money.

This will result in higher production and retail prices of a seagrass product. The fact that the material is also not strong, and the lifespan is still unknown, but shorter than alternative materials. Does not go together well with the threat that the demand might not be high, also because it is a new and unknown material. A higher retail price than competing materials will make it even more difficult to market it.

Unique selling points Seagrass

Fire resistance

Seagrass is fire resistance. This gives the possibility to make different kinds of products of the material. As an example, (if it can be turned into a textile), products like anti fire blankets or fireproof gloves could be produced.

Antibacterial

The lab team have researched if the seagrass is antibacterial to a very wide range of bacteria, or only to some specific species. To determine this, the test can also be done by other bacterial stains. It is also good to investigate what in the extract makes the extract antibacterial. This could be the iodine content for example. If seagrass is antibacterial, this creates more opportunities to apply it to different kind of applications.

Contributes to a more sustainable world

The sustainable collection and use of washed-up seagrass as a resource match European Union's Circular Economy model because there is reuse as material, waste prevention, having a safe and clean material, and it is locally produced. use of this new material, it also generates awareness to the public. It breaks paradigms of material sourcing and opens the possibilities in a variety of industries. Additionally, it gives the opportunity to relate economic activities to this marine plant, just as done historically. As well, using washed up seagrass might draw attention to restoration efforts to seagrass meadows and in some way even help increase funding to these projects.

Trends and developments: Sustainable trends in the interior business

Using bio-based materials

An important sustainable trend in the furniture (and clothing) industry is working with so-called biobased materials. These are materials that come from nature that do not just run out, like seagrass. Another example is bamboo. Bamboo can grow repeatedly and quickly, making it a valuable and sustainable raw material. Biobased materials are often better for the environment, but this is not always the case. This is because it is not a protected term. So, when a supplier uses this label, you will have to do even more research into the materials and their origin. As stated in the paragraph above, big companies like Ikea, Zara home and H&M home are already producing products made from seagrass and bamboo. Because Seagrass is a waste product, it is a good thing if it is removed and reused.

Recycling

Recycling is another good method of how the furniture industry is getting more sustainable. Customers can provide residual materials and household waste with a second life. In some cases, the materials are biologically degradable and look good as well.
Unfortunately, furniture is not made to be recycled easily. The cost of processing is high and often outweighs the value of the materials. Many wood items are treated with paint or varnish, which makes it difficult to be composted. The best and easiest way to contribute to a more sustainable furniture market is to repair the items, donate or recycle as bulk waste as a last resort.

Refurbishing

Buying refurbished furniture also contributes to a more sustainable market. Refurbished products are used items that are repaired and made into almost new products. This way there will be less waste and old products are getting a new life.
Earth911.com. (2021, 14 maart)

Trends to market sustainability

Deliver your message in a positive way

Various studies show that change in behavior comes about when there is more positive attention for sustainability. It is successful thanks to people like Per Espen Stoknes, a Norwegian climate psychologist and researcher. Among other things, he wrote the book 'What we think about (when we try not to think about) global warming'. People are becoming increasingly aware that it is important to share large, but also small successes with the world. By doing so, you build up your authority and inspire others to do the same.
Vermeulen, T. (2016, 11 april).

Nespresso's recycling bike is a good example. Three hundred cups of coffee provide enough raw material to produce a city bicycle. Not all cups are recycled yet, but by showing consumers what great products can be made from the cups, you encourage people to hand in more cups - and without pointing fingers at each other. It's good publicity for Nespresso, as it gives the Swiss company a lot of positive attention for its small steps towards sustainability.
Culy. (2020, 19 oktober).

Be honest and avoid greenwashing

A term that has been around for a while and that you should definitely avoid is greenwashing. At the same time, distrust of sustainability claims is on the rise, after a few years of decline. Consumers are therefore becoming more critical and sensitive to greenwashing or unreliable promises. The facts are checked and companies are punished immediately if it turns out not to be true. Be sincere as a company and show what you do and be honest about your ambitions.
A good example of this is Shell, which has gone wrong repeatedly when it comes to sustainability. In 2017, Anna Nooshin posted a water bottle on Instagram, promoting hydrogen-powered vehicles in a beautiful campaign video. This turned out to be not quite true, as this hydrogen turned out to be produced from gas.
Volgers van vlogger Anna Nooshin pikken Shell-post niet. (2017, 20 juli).

Shell then launched the 'CO2 neutral driving' campaign, in which the consumer himself pays for compensation by paying 1 cent extra per liter. This money is invested in three projects to compensate for CO2 emissions. Seems nice, but here too Shell received a lot of criticism that it was not sincere.
Rijksen, M. (2021, 12 april).

Upcycling

A trend that is especially popular among high-end fashion brands is upcycling. Within this initiative, old, leftover products or materials are transformed into something new. The use of unsustainable materials, such as textiles, is one of the biggest problems in the fashion industry today. Making the textile industry sustainable is a difficult process that takes a lot of time. For example, Louis Vuitton transformed its unsold 'LV Trainer' trainers from the old season into new 'LV Trainer Upcycling' trainers. *Li, J. (2021, 18 januari).*

Prada introduced a line of completely used recycled nylon, also known as econyl. *T. (2019, 31 juli).*
Dutch duo Victor & Rolf recently presented an entire collection made from leftover products. *Dubbeldam, S. (2021, 26 juli).*
Even Burberry, previously known as the brand, that burned leftover products, is now donating old materials to fashion students within the UK. *Phillips, S. (2020, 9 december).*

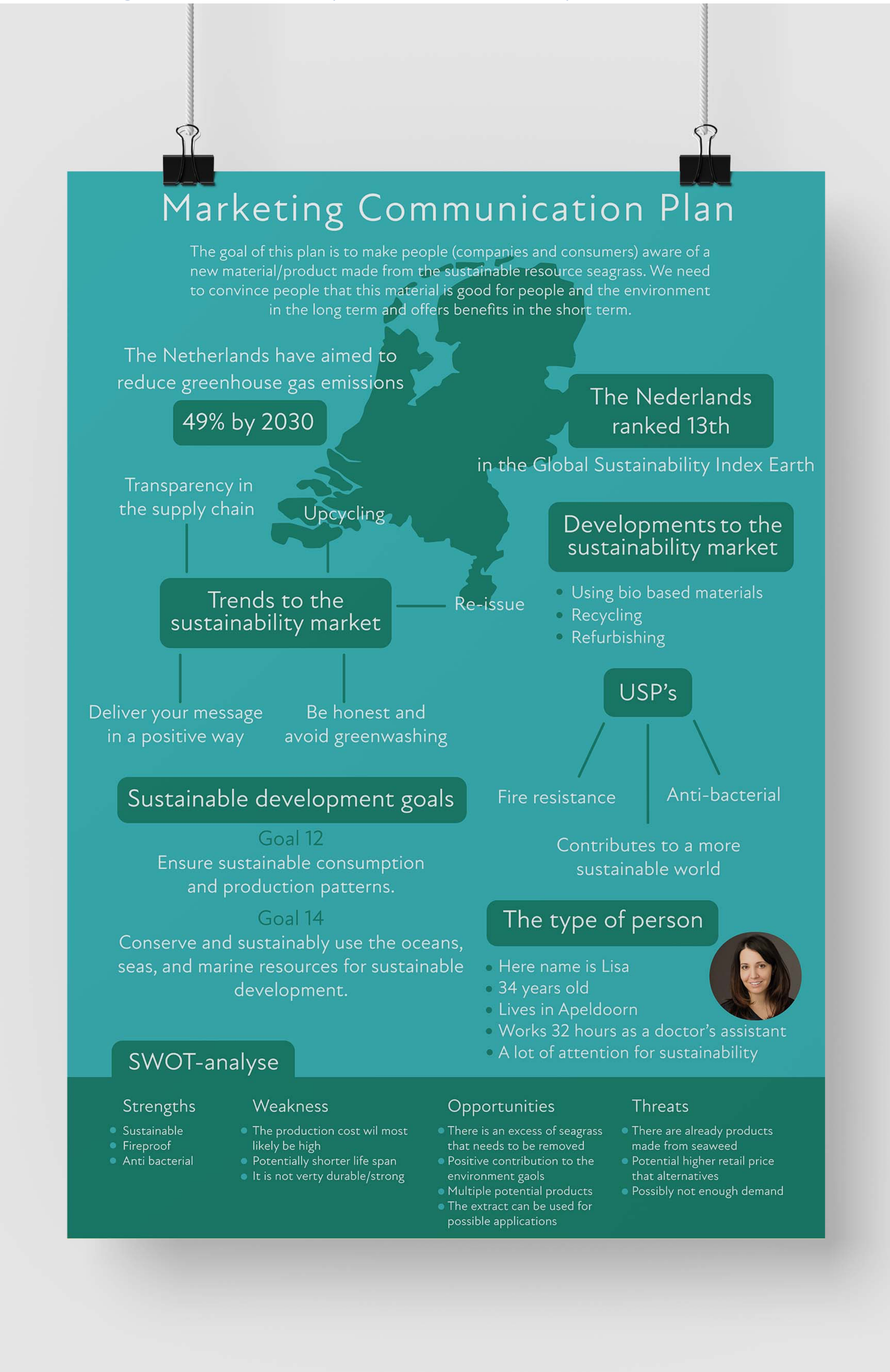
Re-issue

Besides the use of old materials, it is also increasingly common for brands to reissue older collections. Before, companies destroyed old items, or sold them in sales or outlets. Both contribute to the fast fashion problem. Because too much is produced, brands offer products at lower prices and a high textile waste is created. Re-issue means that brands do not sell or destroy their products anymore but start offering them again at a later moment.

Transparency in the supply chain

Brands are increasingly confronted with the rise of conscious consumers. Consumers are increasingly interested in where their clothes come from, but also how and under what conditions companies produce clothes. Initiatives like Fashion Revolution try to make these processes transparent for consumers. There you see that almost every brand scores poorly.
ABOUT. (2021, 8 december)

Marketingcommunicatie plan visualization poster



Project conclusion

The conclusion

I will explain the conclusion in three different parts. The first part is the most important findings and recommendations from the Lab research, secondly the marketing communication plan recommendations from the marketing research, then the combined and overall recommendation and conclusion of the project. Please keep in mind that the conclusion is based on the research report and the research report will help with further research on new seagrass applications.

Lab research recommendations

1. In future research, the fibres of the seagrass could be extracted and used to determine the cellulose content of the fibre. The different types of seagrasses could also be tested, and the impact of pre-treatment method determined. This research would give an understanding of whether seagrass is a potential source of cellulose and can be used as a raw material for the production of cellulosic man-made fibres.

2. The anti-bacterial properties have not been found yet. In this research, the anti-bacterial activities of the Zostera Marina were determined without any pre-treatment. When the leaves were incubated with the E. Coli, no anti-bacterial activity has been found. But, this does not mean that Zostera Marina is not anti-bacterial. The preparation for making an extract out of the Zostera Marina seagrass can be found in Appendix I.

3. If the seagrass extract turns out to be not anti-bacterial, higher concentrations of seagrass extract could be used. If the extract does turn out to be anti-bacterial, this could be used for further applications.

4. It is also an idea to investigate if the seagrass is anti-bacterial to a very wide range of bacteria, or only to some specific species. To determine this, the tests of this research can be used with other bacterial stains.

5. It is also good to investigate what in the extract makes the extract anti-bacterial. This could be the iodine content for example. The specified technical specifications could be used as a basis and marketing tool for future applications.

Marketing recommendations

The marketing recommendations are based on marketing a new sustainable product, most aspects relate to seagrass. Only there was not much information or a market for seagrass yet, we focused on how it could be marketed more generally. When there will be a specific application these recommendations will help create a profitable and sustainable market. Some of the recommendations are related to the company Fatboy as they were a part of this project

1. Legislation is important when bringing a new sustainable product made from seagrass to the market. The most important goals the Dutch government has formed for 'the 2030 Agenda for Sustainable Development' are Goal 12 Ensure sustainable consumption and production patterns. Goal 14 Conserve and sustainably use the oceans, seas, and marine resources for sustainable development.

2. If the seagrass will be harvested for the new application of seagrass, the company who will produce it should plant more seagrass than what they take from the sea, we think this will help create a more attractive sustainable message towards the consumers, as we do not know when taking too much seagrass becomes damaging, and seagrass has proven to be essential to marine life and global warming.

3. Target group; for the target group the alternative and new seagrass application should not be to different from the non-sustainable alternative, because it is shown in a study by IBM that the willingness of changing habits to reduce environmental impact scores lowest in the index.

4. The most important strengths of seagrass are that it is sustainable, potentially fireproof, and potentially antibacterial. If seagrass is used as a material or resource, it is very sustainable. This goes together with the opportunity to contribute to the environmental goals that have been set by the EU and The Netherlands. Besides this, it also goes together with the opportunity of excess seagrass that can be removed.

5. An important weakness is the fact that removing the seagrass costs a lot of time and money. This will result in higher production and retail prices of a seagrass product. The material is also not strong as seen by the lab research done, and the lifespan is still unknown. It also does not help that the demand might not be high, also because it is a new and unknown material. A higher retail price than competing materials will make it even more difficult to market it.

These were some recommendations and conclusions that we discovered from working with the different disciplines, there are many more aspects to the communication plan that will be useful to read.

This study has shown that is not easy to find a new application for seagrass. With the new applications that were found through experiments and literature research, the reader has enough information to look further into one application. Having identified the potential of the pulp, the client should investigate further. The success of a pulp production could lead to multiple applications such as paper. In terms of prototyping, more thorough research is advisable. Measuring how many grams or millilitres are used in making the samples could give a clear view on what works and what does not.

Finally, we recommend keeping a close eye on the development of seagrass materials and other bio-based materials derived from aquatic plants. There are already many applications for seagrass, but none of them are widely used or marketed. Trying to market these products using seagrass waste and selling them to the right consumer could be more beneficial in the long run than developing a completely new material. Therefore, start-ups, companies and material innovators should work together on more in-depth research, as the many of the current production processes and applications could be used for seagrass but have not yet been explored.

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Appendices

Appendix A

Preparation of the cellulose determination by using the Updegraff method

General information:
Naam: 3S New Applications for Seagrass
(Niels Masselink and Bart ten Den).
Saxion Deventer
09-11-2021
Title: Cellulose determination by using the Updegraff method.
Goal: To determine the concentration of cellulose in the cell wall of the *Zostera marina* by using the Updegraff Method.
Principle:
Cellulose is a polymer that is part of the cell wall of a plant. It provides the strength of the seagrass. To be able to use seagrass in the textile industry, the cellulose percentage is important. The Updegraff method is used to determine this percentage. A major advantage of this method over the Nelson method used previously is that this method removes lignin and hemicellulose at an earlier stage. These two components are also present in the cell wall and consist of (partly) of sugars. The hydrolysis method and the Nelson method would also have determined these components with the cellulose and therefore the exact percentage of cellulose could not have been determined by that method. During this method, the seagrass will first be treated with a reagent of acetic and nitric acid. This reagent causes the lignin and hemicellulose to break down and be removed from the cellulose. The cellulose is resistant to this reagent and will not break down. In this way, only the cellulose will be left and determined and contamination with lignin and hemicellulose is excluded. The cellulose is hydrolysed to monosaccharides by hydrolyses in 67% sulphuric acid. These monosaccharides can be determined by the use of the anthrone test. This is a sugar determination in which anthrone is used as a dye. The anthrone is made by dissolving anthrone in concentrated sulphuric acid. This reagent causes monosaccharides to be converted to furfural because of the sulphuric acid via the following chemical reaction, $C_5H_{10}O_5$ --> $C_5H_4O_2 + 3\ H_2O$. Furfural can react with anthrone and this results in a blue-green complex which can be measured at a wavelength of 620 nm.

Materials:

- Seagrass
- Water bath
- Sulphuric acid
- Anthrone
- Spectrophotometer
- Glucose
- Acetic acid
- Nitric acid

- Ethanol
- Acetone
- Pasteur pipette
- Fume hood

Working Method (Kumar & Turner, 2015)

6. Cut the seagrass sample into pieces of 50 mm. Divide this into approximately two equal pieces and place in a 2 ml Eppendorf tube containing 1.5 ml ethanol.
   Pause: The Eppendorf tubes can be left at room temperature for as long as required.
7. Incubate the Eppendorf tubes for 1 hour by 70°C. (mix after 30 minutes).
8. Remove the ethanol with the use of a Pasteur pipette.
9. Add 1.5 ml 70% ethanol and incubate for at least 45 minutes. (Mix after 30 minutes).
10. Add 1 ml acetone and incubate for at least 2 minutes.
11. Remove the acetone with a Pasteur pipette in the fume hood. Let the Eppendorf tubes dry for 3-4 hours in the fume hood. After that, the tubes can incubate overnight by 37°C. The tubes need to be covered with aluminium foil.
    Pause: Dried samples can be stored at room temperature until the next step will be performed.
12. Determine the dry weight of the samples and write them down. Weight the samples in weighing dishes on an analytical balance. Transfer the samples to a labelled glass tube in a metal rack. If the next step is not taken immediately, cover the tubes with parafilm.
13. Include a filter paper sample (around 10 mg) in a tube which acts as a positive control.
    Pause: The dried and weighed samples can be covered and stored until the next step is taken.
14. Prepare the acetic/nitric acid reagent. Prepare as follows.
    For 110 ml reagent: add 20 ml water with 80 ml acetic acid and 10 ml nitric acid.
15. Add 3 ml acetic/nitric acid reagent to each tube and cap the tubes in a fume hood.
16. Put the tubes in a boiling water bath for 30 minutes. Let it cool down and pipette off the acetic/nitric reagent in the fume hood. The samples will be very fragile.
17. Add 8 ml water to each sample and incubate for 15 minutes. Pipette off the water.
    Note: it is very easy to lose samples in this step. Wait until the sample has sunk to the bottom of the tube before taking off the water.
18. Add 4 ml acetone and incubate for 5 minutes in a fume hood. After 5 minutes, a pipette acetone in a fume hood.
19. After the acetone is removed, push the samples down to the bottom of the tube.
    Note: this step must be taken when the samples are still wet. If the samples are too dry and keep sticking to the wall of the tube, then the samples will not hydrolyse completely in the next step.
20. Prepare 67% sulphuric acid.

Preparation for 500 ml: add slowly and in little steps, 335 ml concentrated sulphuric acid to 165 ml water. Caution: this can become very hot. Keep the 67% sulphuric acid on ice for at least 2 hours.

21. Dry the samples in the fume hood for 3-4 hours. After that, they can be dried overnight at 37°C.

    Pause: Dried samples can be covered with aluminium foil until the next step will be taken.

22. Make sure that the samples are in the right order to avoid systematically errors. After the next step, it will be impossible to identify the different samples.
23. Add 1 ml 67% sulphuric acid to each sample. Make sure that the complete sample in the acid. Put the samples in a shaking incubator for 1 hour until no sample can be seen in the tubes. Vortex in between if necessary.
24. Raise the final volume of the paper samples to 5 ml by adding 4 ml sulphuric acid to the paper samples (this is necessary for the standard line). The other samples will keep their final volume at 1 ml.
25. Prepare a glucose standard line. Prepare a 10 ml glucose stock solution of 100 mg/ml. Do this by adding 1000 mg glucose to 10 ml demi water. Take 1 ml glucose stock solution and add 9 ml demi water to it. A solution with a concentration of 10 mg/ml has been made. Prepare the standard line with this solution following pipette schedule 1.
26. Aliquot 500 µl of each standard to 2 ml heat-resistant cups. For each sample, aliquot 500 µl to heat-resistant cups.
27. Add to the cups for the samples 20 µl sample.
28. Prepare the anthrone reagent. This is a 0.3% anthrone solution in concentrated sulphuric acid.

    Preparation for 100 ml: add 0.3 g anthrone to 100 ml concentrated sulphuric acid. Mix with a vortex and keep on ice for at least 5 minutes.

29. Add 1 ml of the anthrone reagent to each cup. Add the reagent to the sidewall of the cup so the sample is mixed as little as possible. If anthrone reagent is added to every cup, close every cup and mix them by inversion. Caution: the cups can get very hot.
30. Incubate the cups in a boiling water bath for 5 minutes. Cool the cups down on the ice.
31. Transfer the samples to heat-resistant cuvettes and measure the absorption by 620 nm with a spectrophotometer.
32. Calculate the concentration of glucose in the samples by linear regression.
33. Calculate the percentage cellulose by using the following formula:
    Cellulose concentration (percentage of the cell wall) = glucose in sample (µg) / weight cell wall weighted in ''step 7'' X 100 X total volume of sulphuric acid in ''step 19'' / 20 (the amount of µl that was added to the cup in ''step 22'').

Table 8 *Pipetting schedule 1*

Name	Concentration glucose (µg/ml)	Water (µl)	Glucose 10 mg/ml (µl)
S1	0	10.000	0
S2	10	9.990	10
S3	20	9.980	20
S4	40	9.960	40
S5	60	9.940	60
S6	80	9.920	80
S7	100	9.900	100

Timetable

This experiment cannot be done in one day. That is why a timetable for this experiment was made.

First day: step 1 till 6 (incubating overnight).

Second day: step 7 till 16 (incubating overnight).

Third day: step 17 till 28.

Safety:

Table 9 Safety form cellulose determination

Material	Hazard statement	Precautionary statement	Symbols	Waste container	Individual protection	spill
Glucose	none	none	none	3	Lab coat, Lab glasses	Take up mechanically
Nitric acid	H-272 H-290 H-314 H-331	P-220 P-260 P-280 P-303 P-305 P-310 P-338 P-351 P-353 P-361	  	1	Lab coat, Lab glasses, Work in fume hood	Take up mechanically
Acetic acid	H-226 H-314	P-210 P-280 P-301 P-303 P-305 P-310 P-330 P-331 P-338 P-351 P-353 P-361	 	1	Lab coat, Lab glasses, Work in fume hood	Take up mechanically
Acetone	H-226 H-319 H-336	P-210 P-233 P-305 P-338 P-351 P-403	 	3	Lab coat, Lab glasses	Take up mechanically
Anthrone	H-315 H-319 H-335	P-261 P-264 P-274 P-280 P-302 P-305 P-338		3	Lab coat, Lab glasses	Take up mechanically, prevent dust formation

		P-351 P-352				
Ethanol	H-225 H-319	P-210 P-233 P-305 P-338 P-351	 	3	Lab coat, Lab glasses	Take up mechanically
Sulphuric acid	H-290 H-314	P-280 P-301 P-330 P-331 P-303 P-361 P-353 P-310 P-305 P-351 P-338		1	Lab coat, Lab glasses, Work in fume hood	Take up mechanically

Appendix B

Preparation of pulp production

General information:

Name: 3S New Applications for Seagrass

(Anna Schäfer, Bart ten Den, Niels Masselink, Sieme van As).

Saxion Deventer

19-11-2021

Title: Pulp production from the seagrass species *Zostera marina*.

Goal: Producing a pulp made from the seagrass species *Zostera marina* with soda pulping.

Principle:

In this experiment, pulp will be made from the seagrass species *Zostera marina*. For this process, the fibres in the seagrass need to be treaded to remove the lignin. The first step is soaking the fibres overnight. The lignin can be removed by cooking the seagrass in a solution with NaOH. The function of the NaOH is to dissolve fat and dirt contained by the fibres so the fibres become clean. After the cooking, the residue which contains the NaOH, and the lignin will be washed away and the pulp will be leftover.

Materials:

- Seagrass
- Chopping board
- Peeler
- NaOH
- Demi water
- Beaker
- Cooking plate

Method:

10. Chop 10g seagrass is small fragments of 2 till 5 cm long with a peeler on a chopping board.
11. Put the seagrass in demi water and let it soak overnight.
12. Prepare 1L NaOH solution (water (L) : NaOH (g) = 1 : 2) by adding 2g NaOH to 1L demi water in a beaker.
13. Put the samples in the NaOH solution and cook it at a constant temperature of 160˚C for at least 2 hours on a cooking plate.
14. Let the seagrass solution cool down before removing the cooking solution.
15. Wash the fibres with demi water to remove the residue. The residue can be put in Waste container 3. The pulp will be left.

Safety:

Table 10 Safety form pulp production

Material	Hazard statement	Precautionary statement	Symbols	Waste container	Individual protection	spill
Sodium hydroxide	H-290 H-314	P-233 P-280 P-303 P-305 P-310 P-338 P-351 P-353 P-361		3	Lab coat, Lab glasses	Take up mechanically, prevent dust formation.

Appendix C

Table 11 Literature Review Matrix

Authors	Type of source	Title	Date	Purpose	Subjects	Data	Comments / Outcomes / Implications	Reference	Link
Cabello-Pasini, Alejandro; Muniz-Salazar, Raquel; Ward, David H.	Journal Article	Biochemical characterization of the eelgrass *Zostera marina* at its southern distribution limit in the North Pacific	2004	This paper analysis the biochemical data of the seagrass *Zostera marina* distributed along the Mexican coast	Technical specifications; fibre content	Laboratory research	Outdated. *Zostera marina* from different beaches was examined. The results suggest that the biochemical properties of the seagrass are impacted by the environmental conditions to which *Z. marina* is exposed.	(Cabello-Pasini et al, 2004)	http://dx.doi.org/10.7773/cm.v30i11.123
Chand, Navin; Fahim, Mohammed	Journal Article	Natural fibres and their composites	2008	This chapter introduces the types of vegetables fibres that can be extracted from different parts of plants and their sources.	Textile processing; fibre extraction; Technical specifications	Literature research	Outdated. Their chapter gives an understanding of textile processing methods for natural fibres as well as it identifies mechanical and chemical properties of different natural fibres.	(Chand & Fahim, 2008)	https://doi.org/10.1533/9781845695057.1
Syed, Nurul Nur Farahin; Zakaria, Muta Harah; Bujang, Japar Sidik	Journal Article	Fibre Characteristics and Papermaking of Seagrass Using Hand-beaten and Blended Pulp	2016	This article evaluated fibre characteristics of five species of seagrass and their potential in papermaking.	Textile processing; Pulp making; Potential applications	Laboratory research; Peer-reviewed	Fibre dimensions were studied, and the results show their potential for the papermaking production. A detail work plan was described for handmade papermaking.	(Syed et al, 2016)	https://bit.ly/3ttGelQ
Davies, P; Morvan, C; Sire, O; Baley, C	Journal Article	Structure and properties of fibres from sea-grass (*Zostera marina*)	2007	This paper presents results from a study of fibres extracted from *Zostera marina* eel-grass collected from the Baltic coast.	*Zostera marina*; Technical specifications	Laboratory research	Outdated. This research shows that *Zostera marina* contains small diameter fibres composed of ~57% cellulose, ~38% of non-cellulosic polysaccharides and ~5% of Klason lignin. Single fibre stiffness values up to 28 GPa were measured. This stiffness combined with a low density could provide an attractive reinforcement for composite materials and may be particularly suitable for use in bio-degradable structures.	(Davies et al, 2007)	DOI 10.1007/s10853-006-0546-1

INNOVA	Website Article	Urban Climate Adaptation	2018	These articles about the INNOVA project describes the Innovation Hub Kiel Bay on the Baltic shore of Germany describes the effects and opportunities of beach wrack washed up on shores.	Seagrass; Potential Applications	Qualitative research	Beach wrack is a mix of algae and seagrass that is naturally washed onto the beach. Changes to the character of the beach, and the beach experience, can have an impact on tourism. The research explores therefore applications for seagrass in the past and today. Several applications are named such as fertilizer, pillows, insulation, and dunes.	(INNOVA, 2018)	https://www.urbanclimateadaptation.net/ezine3-2018/
Tarchoun, Ahmed Fouzi; Trache, Djalal; Klapötke, Thomas M	Journal Article	Microcrystalline cellulose from Posidonia oceanica brown algae: Extraction and characterization	2019	In the study, the seagrass was chemically treated through delignification and alkali treatment followed by acid hydrolysis to produce pure microcrystalline cellulose (MCC).	Potential applications; Textile processing	Laboratory research	This research detailly explains the production of MCC. The prepared microcrystalline cellulose was also examined by comparing its physicochemical properties with those of commercial MCC. Based on these analyses, the novel MCC showed tremendous potential to be used in several applications such as cosmetic, pharmaceutical compounds, food, bio-composites, and packaging materials.	(Tarchoun et al, 2019)	https://doi.org/10.1016/j.ijbiomac.2019.07.176
Eberle, H; Gonser, E; Hermeling, H; Hornberger, M; R, Kilgus; Kupke, R; Menzer, D; Moll, A; Ring, W	Book	Clothing Technology	2014	Up-to-date basic book and reference work with a focus on clothing technology.	Textile processing	Revised by Europa Lehrmittel	Gives an overview and basic explanations of current fibre and yarn processing methods for natural and man-made fibres.	(Eberle et al, 2014)	Printed form

Ansell, M; Mwaikambo, L	Journal Article	The structure of cotton and other plant fibres	2009	The structure and properties of plant fibres are reviewed with emphasis on the deposition of cellulose microfibrils in the plant cell wall and mechanical properties such as strength and stiffness.	Technical specifications; fibre content	Literature research	Offers the possibility to compare the chemical composition as well as the physical properties of different plant fibres.	(Ansell & Mwaikombo, 2009)	10.1533/9781845697310.1.62
Hulle, A; Kadole, P; Katkar, P	Journal Article	Agave Americana Leaf fibres	2015	This article looks at the Agave Americana fibres as a sustainable resource for manufacturing and technical applications. Extraction, characterization and applications of Agave Americana fibre is also covered.	Fibre processing	Literature research	There is a need to design products by using natural resources. Natural fibres seem to be a good alternative since they are abundantly available. There are three major fibre extraction methods: mechanical extraction, chemical extraction and retting process.	(Hulle et al, 2015)	10.3390/fib3010064
van Delden, Rozemarijn; Fuchs, Jonas; Hoekstra, Ruben; Jacobs, Merjin; Kusuma Radjasa, Septhy; Kollerie, Nicole	Report	ACT Report	2020	This report focuses on three different alternative natural fibre sources including seagrass. The report gives an overview on which of these natural fibre sources have the most potential to be further investigated for textile applications.	Alternative fibre resources, cultivation, some production processes	Literature research, expert interviews	From our data and approach seagrass has the least potential as a sustainable source for textiles in the Netherlands.	(van Delden et al, 2020)	provided by ArtEZ

Rudin, A; Choi, P	Book chapter	The Elements of Polymer Science and Engineering	2013	This book chapter is an introduction to biopolymers.	Definitions; Biopolymers	Literature research	This book chapter was used to get an understanding of bio composites. A bio composite is a material composed of two or more distinct constituent materials (one being naturally derived) which are combined to yield a new material with improved performance over individual constituent materials.	(Rudin & Choi, 2013)	ISBN 978-0-12-382178-2
Sánchez-Safont, E. L; Aldureid, A; Lagarón, J. M; Gámez-Pérez, J; Cabedo, L	Journal Article	Bio composites of different lignocellulosic wastes for sustainable foodpackaging applications	2018	In this article the suitability of three local lignocellulosic wastes i.e. almond shell, rice husk and seagrass (Posidonia oceanica) as fillers in PHB/fibre composites applications has been studied.	Application; Bio composite	Literature research; Experiments	Few works that have been published to date on the use of seagrass as reinforcement in polymer composites. All the studied fibres were suitable for their application in the developmentof fully compostable bio composites for packaging applications.	(Sánchez-Safont et al, 2018)	https://doi.org/10.1016/j.compositesb.2018.03.037
Trache, D; Hussin, M. H; Hui Chuin, C. T; Sabar, S; Fazita, M. N; Taiwo, O. F; Hassan, T; Haafiz, M. M	Journal Article	Microcrystalline cellulose: Isolation, characterization and bio-composites application—A review	2016	This review assembles the current knowledge on the isolation of Microcrystalline cellulose from different sources using various procedures, its characterization, and its application.	Application; Microcrystalline cellulose; Bio composite	Literature research	The microcrystalline cellulose is an important ingredient in pharmaceutical, food, beverage. Cosmetic and other industries (as binders).	(Trache et al, 2016)	http://dx.doi.org/10.1016/j.ijbiomac.2016.09.056
de la Torre-Castro, M; Rönnbäck, P	Journal Article	Links between humans and seagrasses—an example from tropical East Africa	2004	This article approached to link a social-ecological system and describe the interaction between jumans and seagrasses.	Application; Food	Literature research; Interviews	Outdated. Seagrasses were used as traditional medicine and fertilizers.	(de la Torre-Castro & Rönnbäck, 2004)	doi:10.1016/j.ocecoaman.2004.07.005

Rengasamy, R. R. K; Radjassegarin, A; Perumal, A	Journal Article	Seagrasses as potential source of medicinal food ingredients: Nutritional analysis and multivariate approach	2013	The aim was to evaluate the nutritional composition of six seagrasses.	Application; Food; Nutrion	Literature research; Experiments	The seagrass biomass is used as human food especially bycoastal populations. In folk medicine, seagrasses have been used for a variety of remedial purposes. In India, seagrasses are used as medicine, food, fertilizer and livestock feed.	(Regasamy et al, 2013)	http://dx.doi.org/10.1016/j.bionut.2013.06.011
Newby, B. M. Z; Cutright, T; Barrios, C. A; Xu, Q	Journal Article	Zosteric acid - An effective antifoulant for reducing fresh water bacterial attachment on coatings	2006	In this study, the ability of zosteric acid in reducing the early stages of fouling was evaluated via two approaches.	Technical properties; Antifoulant	Literature research, Experiments	Outdated. Zosteric acid, a natural product present in eelgrass, has been found to prevent the attachment of some bacteria and barnacles. The results indicate that it may also be effective at reducing the early stages of biofouling, such as the attachment of bacteria that lead to a biofilm.	(Newby et al, 2006)	10.1007/s11998-006-0007-4

Appendix D

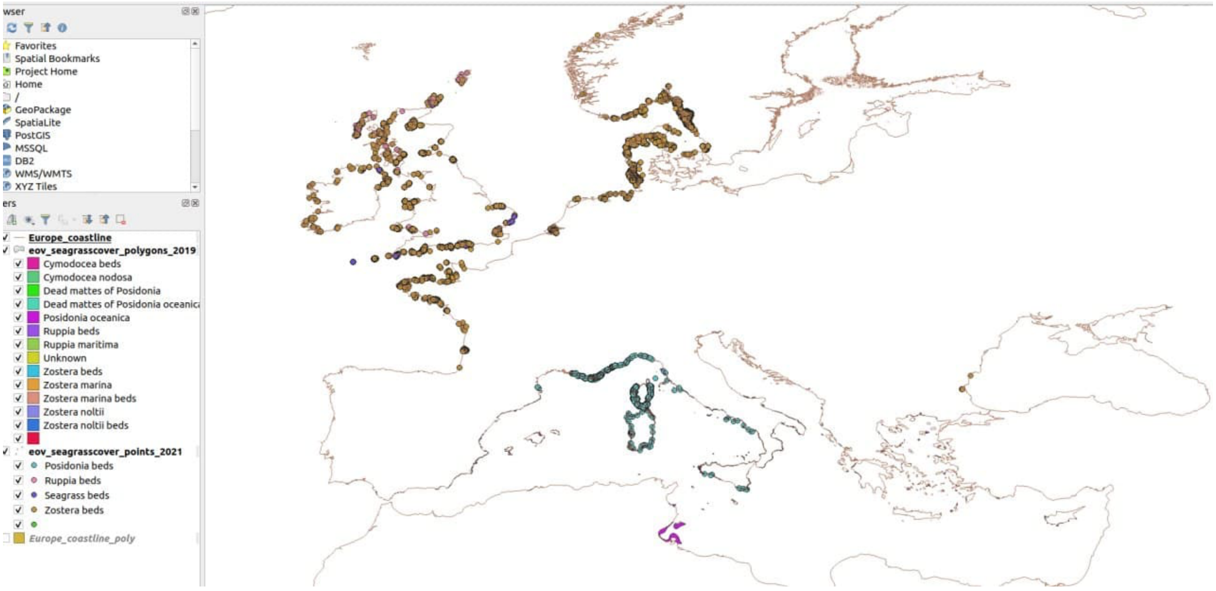

Figure 21 Distribution of Zostera Marina seagrass (brown) in the European region

Derived January 13, 2022, from https://www.emodnet-seabedhabitats.eu/access-data/launch-map-viewer/

Appendix E

Transcript of Face-to-face interview with Jens Oelerich
Participants:

- Interviewer 1: Student at Saxion University
- Interviewee 1: Jens Oelerich – Associate Lector Sustainable Textiles at Saxion University of Applied Sciences

Date: 08.10.2021
Place: via Teams

Interviewer 1: I also want my question about my Smart Solution Semester, if that's okay with you.
Interviewee 1: Yeah sure, I can see how I can help you.
Interviewer 1: We are very free in what we want to do. Basically, it's about finding applications for seagrass that is washed onshore at the Dutch coast. Of course, I would like to do some research in the material/textile direction. What do you think should I pay attention to?
Interviewee 1: Fibres are only made from cellulose, maybe hemicellulose. The process that is used is called pulping. It is used for wood or cotton, for example. Cellulose is extracted, regenerated, and then purified/cleaned. Conventional wood has a cellulose content of about 50 %. So, if you can determine the cellulose content of seagrass, you are already one step further.
Interviewer 1: Which components are not advantageous for fibre processing?
Interviewee 1: A high mineral content would not be good. With pigments, on the other hand, you could see if they can be extracted.
Interviewer 1: What do you think is a realistic target for half a year?
Interviewee 1: You can take a good look at what has been done so far. What biomass is currently being used and get an overview of these processes and evaluate them if necessary. Or see how other biobased materials from aquatic plants are processed. However, developing a completely new textile is a process of several years, not month.
NOTE: The interview was conducted in German, so the transcript is a translation. The interview was a short spontaneous conversation, so the transcript is based on notes taken during the interview.

Appendix F

Table 12 Open and axial coding expert interviews

	Open Coding	Axial Coding
Transcript of Face-to-face interview with Jens Oelerich Participants: - Interviewer 1: Student at Saxion University - Interviewee 1: Jens Oelerich – Associate Lector Sustainable Textiles at Saxion University of Applied Sciences Date: 08.10.2021 Place: via Teams		
Interviewer 1: I also have a question about my Smart Solution Semester, if that's okay with you. Interviewee 1: Yeah sure, I can see how I can help you.	Presentation	Introduction

Interviewer 1: We are very free in what we want to do. Basically, it's about finding applications for seagrass that is washed onshore at the Dutch coast. Of course, I would like to do some research in the material/textile direction. What do you think should I pay attention to? Interviewee 1: Fibres are only made from cellulose, maybe hemicellulose. The process that is used is called pulping. It is used for wood or cotton, for example. Cellulose is extracted, regenerated, and then purified/cleaned. Conventional wood has a cellulose content of about 50 %. So, if you can determine the cellulose content of seagrass, you are already one step further. *Interviewer 1: Which components are not advantageous for fibre processing?* Interviewee 1: A high mineral content would not be good. With pigments, on the other hand, you could see if they can be extracted. *Interviewer 1: What do you think is a realistic target for half a year?* Interviewee 1: You can take a good look at what has been done so far. What biomass is currently being used and get an overview of these processes and evaluate them if necessary. Or see how other biobased materials from aquatic plants are processed. However, developing a completely new textile is a process of several years, not month.	New applications for seagrass Pulping Regeneration, purification Cellulose determination Mineral content Extraction of pigments Existing research Currently used processes	Research description Fibre processing Cellulose extraction Cellulose content Disadvantages Fibre processing Possible Application Research management
Transcript of Mail interview with Felix Pöttinger Participants: - Interviewer 1: Student at Saxion University - Interviewee 1: Felix Pöttinger - a German designer who has developed a sustainable alternative to plastic food packaging using seagrass (*P. oceanica*) washed up on Mediterranean beaches Date: 31.10.2021 Place: via Mail *Interviewer 1: I am a Student at Saxion University of Applied Sciences in Enschede (the Netherlands) and am studying the course "Fashion and Textile Technologies". This semester we are doing a research project on bio-based materials and looking for new applications for seagrass. Our research includes literature research, expert interviews, and laboratory research. Later, we will*	 Presentation New Applications for seagrass	 Introduction Research description

use all the data to propose potential applications for seagrass. We are contacting you, hoping, that you might be able and willing to provide us with more information about the packaging made of seagrass you have developed. Perhaps you can tell us something about the production process of your material? Interviewee 1: Sounds like an exciting project and I'm happy to help. To your question: The current version of the POC material is (as the name suggests) Posidonia oceanica Seagrass Fibres and a binding agent made from the plants own cellulose (the plant is made from over 90% cellulose, so it made sense to extract it and use it as a binder). The extraction process is made by a lab with a process called "sulfate digestion". The binder is mixed with the fibre, water and is pressed in a 2-part metal form and then baked at 180° until completely dry.	Production process Posidonia oceanica Seagrass Fibres Cellulosic binding agent Cellulose extraction by sulphate digestion Mixing Pressing Baking	 POC material components POC material production process
Interviewer 1: And what is the technical specification of your material? Interviewee 1: Technical properties: - 3-Point-Flexibility test: 25 N Sample 1 / 15 N Sample 2 - Thermal conductivity AD <0.039 W / mK - Rated value <0.046 W / m - Bulk density 65 to 75 kg / m3 - to be delivered 75 kg / m3 - Heat storage capacity c = 2.502 J / gK - Fire protection class according to DIN 4102 B2 - normally flammable - Mold resistance: was tested for antifungal activity against two fungal strains Pythium spp. and Aspergillus flavus using fungal growth inhibition assay method. Reduced fungal colony growth by 33.33 - 50 % - Water absorption capacity 1.6 to 3.4 kg / kg - Salt content approx. 0.5 - 2% In a non-scientific language that means it is pretty much like hard cardboard with the flexibility of feltboard.	Flexibility Thermal conductivity Density Flammable Mold resistance Water absorption Salt content Comparison	POC material technical specifications
Interviewer 1: What state are you at with the product development? Unfortunately, the material did not pass EU - Food Packaging requirements and the business partners did not continue to fund the project. This is because seagrass as a material source is pretty hard and expensive to harvest and the material was too expensive to produce. Apart from the mold resistance (which is unique), there were too many other materials with similar properties and competitors on the	No funding Too expensive Not unique Withdrew patent	POC material technology readiness level

market. This is the reason the project was archived as a research project at the Royal College of Art in London, and we withdrew the patent to make the innovation available of everyone.		
Interviewer 1: Do you happen to have more information about the sulfate digestion process? For example, what amount of chemicals is needed? Or do you know anyone who can give us more information on this? As we want to try to make our own pulp of the seagrass. Interviewee 1: About the cellulose extraction process: For me it was only possible because I had access to the Material Lab at Imperial College in London with Scientists and Engineers helping me out and they only did a tiny amount for testing. It's an industrialized process with chemicals you can't access on the household market, and I would not recommend trying this at home as it is highly toxic. However, you can imitate it with buying cellulose based binding agents available on the market (DuPont, BASF or Papiermaché making etc.) to receive a comparable result for testing.	Sulfate digestion Industrial Highly toxic Cellulose-based binding agent	Cellulose extraction Out-of-the-box alternative
Interviewer 1: Maybe it is also possible for you to connect in a meeting. Then we could explain more about our project and asks our questions there. Interviewee 1: I'm happy to help. Unfortunately, I'm very busy with various projects until Xmas, so if you want to talk, it has to be after work hours. *Interviewer 1: No problem at all, we are available after working hours. A meeting on Teams would work great for me, then other members of my group can join as well. If you suggest a time and date, I will set up a meeting in Teams.*	Face-to-face interview Planning	Further connection
Transcript of Mail interview with Smartfibre AG Participants: - Interviewer 1: Student at Saxion University - Interviewee 1: Manager New Business Development Smartfiber AG Date: 08.11.2021 Place: via Mail		
Interviewer 1: I am a student at Saxion University in Enschede (the Netherlands) studying Fashion & Textile Technology. This semester we are doing a research project on bio-based materials and looking at new applications for seagrass. Our research includes literature research, expert interviews and laboratory research. Later, we will use all the data to propose	Presentation New Applications for seagrass	Introduction Research description

potential applications for seagrass. We are contacting you, hoping, that you might be able and willing to provide us with more information about SeaCell. We understand that much of the information is likely to be confidential, but perhaps you can tell us something about the production process. We are particularly interested in the pulp/fibre production process and what type of plants can be used for it, for example if it would be an option for seagrass.	Production process	
Interviewee 1: It is really nice getting in touch with you. I am very pleased to share some information with you about our sustainable Seacell fibre. I am also happy to share some information about our sustainable, intelligent fibres! Smartfibre AG is the fibre producer, supplying the raw fibres itself (see attached documentation and picture). The high-tech fibres under the labels SeaCell™ and smartcel™ sensitive are produced on modern fibre production plant at Lenzing AG in Austria exclusively for smartfiber AG. Our specialties are, the SeaCell™ fibre containing algae from Iceland, and the smartcel™ sensitive fibre which contains zinc.	Fibre producer Supplier SeaCell™ smartcel™ Lenzing AG Austria	Company information Produced fibres Production plant
For detailed information we provide you a nice video about our technology: https://www.youtube.com/watch?v=-msMROT31V4	Iceland	Seaweed harvest
SeaCell™LT and MT: the wellness fibre using raw and organic algae from Iceland SeaCell™ MT = Seaweed embedded into a Modal fibre SeaCell™ LT = Seaweed embedded into a Lyocell fibre - seaweed is rich in essential vitamins, minerals, amino acids and trace elements - algae has high content of antioxidants that successfully protects against free radicals - patented technology that ensures long-lasting performance - skin- friendly - biodegradable/ compostable - organic - ultimate wearing comfort due to the fibres soft feel and great moisture absorption - from FSC certified wood - the collect of seaweed is certified as sustainable harvesting	Algae/seaweed Modal fibre Lyocell fibre Vitamins, minerals, amino acids, trace elements, antioxidants, long-lasting, skin-friendly, biodegradable, organic, comfort	SeaCell™ Material components Seaweed advantages
From these cellulosic based staple fibres, yarns, woven and knitted fabrics, as well as ready-made clothing are produced from our partners - such as spinners, weaving and knitting companies or nonwoven producers. Technology in accordance with the environment – that is important to us! Harvesting of the seaweed is a gentle, selective and, most importantly, sustainable process. It removes only the part of	Cellulosic based staple fibre Yarns, woven fabrics, knitted fabrics, ready-made clothing	Produced fibres SeaCell™ Application

the seaweed that is able to regenerate. The seaweed is entirely untreated and all its ecological value is retained.	Regenerative	Seaweed harvest
The best example for the sustainable thinking and acting of smartfiber AG: The SeaCell™ seaweed is harvested in a gentle and sustainable way. Only every 4 years a certain section above the so-called regenerative region of the seaweed is harvested. SeaCell™ is environmentally friendly and meets the growing demand of today's consumer for green, sustainable and ecological friendly products. SeaCell™ is a perfect medium to bring nature's beneficial properties into one's daily life. Therefore, the European Union has awarded this process with the European Environmental Award 2000 in the category "technology for sustainable developments". Thanks to its ecological and sustainable harvesting together with the gentle process, SeaCell™ received the EU Ecolabel and meets the requirements according to OEKO-Tex Standard 100 certified for baby products.	Sustainability efforts Environmentally friendly product EU Ecolabel OEKO-Tex Standard 100	Company information Certifications
SeaCell™ or smartcel™ sensitive can be used in blends with any other kind of fibres and give an extraordinary functionality to a textile. We recommend that finished textiles need to contain min. 10% smartcel™ sensitive (15-20 % if a high UV +50 or for a hygienic application) or 20-25% SeaCell™ fibres to obtain the specific features and characteristics. This is the precondition for a certification. We test and certify the products of our customers in our laboratories on the content of smartcel™ sensitive or SeaCell™. Every fibre has a marker inside, therefore we can verify the content in all textiles. After a positive result we offer a trademark agreement which allows you to use our logo, hang tags, claims and advertising material. We support our partners as best as we can in marketing. The certification procedure takes around 2-5 working days and is free of cost, as well as the advertising materials.	In blends Trademark	SeaCell™ Application Certifications
On our brand new homepage you can find any brochures, certificates, studies and test reports proving the function of the fibres SeaCell™ Modal or Lyocell based. https://www.smartfiber.de/en/seacell-fiber/	Link	
There is also a nice video about the seaweed harvest in Iceland. Harvest of seaweed : https://www.youtube.com/watch?v=hDTuBitv8jU	Video	Seaweed harvest
If you have further questions, please contact me anytime. We would be pleased if you keep us in the loop about your project.		
Interviewer 1: Thank you very much for your kind and informative email! We do have a few more questions		

now that we hope you will be able to answer for us. What is the species of seaweed you are using? Interviewee 1: We are using the seaweed (Ascophyllum nodosum) – all this information you can find on our website as well.	Ascophyllum nodosum	SeaCell™ material components
Interviewer 1: If we understood correctly, the seaweed is added in powder form to the dissolved cellulose before spinning. As we are currently researching possible applications for seagrass. We were wondering if it is possible to add other plants to the dissolved cellulose, for example seagrass instead of seaweed?	Seaweed powder added to dissolved cellulose	SeaCell™ Production process
Interviewee 1: Your understanding of the production process is correct, surely you could also use other ingredients, but we have never tested e.g., seagrass so far.	Add seagrass powder in modal/lyocell process Unproven concept	Possible application

Table 13 Categorising open and axial coding

Axial Coding	Participant who mentioned	Corresponding Open Coding
Introduction	Oelerich, Pöttinger, Smartfiber AG	Presentation
Research description	Oelerich, Pöttinger, Smartfiber AG	New applications for seagrass, Production process
Fibre processing	Oelerich	Pulping
Cellulose extraction	Oelerich, Pöttinger	Regeneration, purification, sulphate digestion, industrial, highly toxic
Cellulose content	Oelerich	Cellulose determination
Disadvantages fibre processing	Oelerich	Mineral content
Possible application	Oelerich, Smartfiber AG	Extraction of pigments, Add seagrass powder in modal/lyocell process, Unproven concept
Research management	Oelerich	Existing research, currently used processes
POC material components	Pöttinger	Posidonia oceanica Seagrass fibres, cellulosic binding agent
POC material production process	Pöttinger	Cellulose extraction by sulphate digestion, Mixing, Pressing, Baking
POC material technical specifications	Pöttinger	Flexibility, Thermal conductivity, Density, Flammable, Mold resistance, Water absorption, Salt content, comparison
POC material technology readiness level	Pöttinger	No funding, too expensive, not unique, withdrew patent
Out-of-the-box alternative	Pöttinger	Cellulose-based binding agent

Further connection	Pöttinger	Face-to-face interview, planning
Company information	Smartfiber AG	Fiber producer, supplier, sustainability efforts, environmentally friendly products
Produced fibres	Smartfiber AG	SeaCell™, smartcel™, cellulosic based staple fibre
Production plant	Smartfiber AG	Lenzing AG, Austria
Seaweed harvest	Smartfiber AG	Iceland, regenerative, video
SeaCell™ material components	Smartfiber AG	Algae/seaweed (Ascophyllum nodosum), Modal fibre, Lyocell fibre
Seaweed advantages	Smartfiber AG	Vitamins, minerals, amino acids, trace elements, antioxidants, long-lasting, skin-friendly, biodegradable, organic, comfort
SeaCell™ application	Smartfiber AG	Yarns, woven fabrics, knitted fabrics, ready-made clothing, in blends
Certifications	Smartfiber AG	EU Ecolabel, OEKO-Tex Standard 100, trademark, link
SeaCell™ production process	Smartfiber AG	Seaweed powder added to dissolved cellulose

Appendix G

Transcript of Mail interview with Felix Pöttinger

Participants:

- Interviewer 1: Student at Saxion University
- Interviewee 1: Felix Pöttinger - a German designer who has developed a sustainable alternative to plastic food packaging using seagrass (*P. oceanica*) washed up on Mediterranean beaches

Date: 31.10.2021
Place: via Mail

Interviewer 1: I am a Student at Saxion University of Applied Sciences in Enschede (the Netherlands) and am studying the course "Fashion and Textile Technologies". This semester we are doing a research project on bio-based materials and looking for new applications for seagrass. Our research includes literature research, expert interviews, and laboratory research. Later, we will use all the data to propose potential applications for seagrass. We are contacting you, hoping, that you might be able and willing to provide us with more information about the packaging made of seagrass you have developed. Perhaps you can tell us something about the production process of your material?

Interviewee 2: Sounds like an exciting project and I'm happy to help. To your question: The current version of the POC material is (as the name suggests) *Posidonia oceanica* Seagrass Fibres and a binding agent made from the plants own cellulose (the plant is made from over 90% cellulose, so it made sense to extract it and use it as a binder). The extraction process is made by a lab with a process called "sulfate digestion". The binder is mixed with the fibre, water and is pressed in a 2-part metal form and then baked at 180° until completely dry.

Interviewer 1: And what is the technical specification of your material?

Interviewee 2: Technical properties:

- 3-Point-Flexibility test: 25 N Sample 1 / 15 N Sample 2
- Thermal conductivity AD <0.039 W / mK - Rated value <0.046 W / m
- Bulk density 65 to 75 kg / m3 - to be delivered 75 kg / m3
- Heat storage capacity c = 2.502 J / gK
- Fire protection class according to DIN 4102 B2 - normally flammable
- Mold resistance: was tested for antifungal activity against two fungal strains Pythium spp. and Aspergillus flavus using fungal growth inhibition assay method. Reduced fungal colony growth by 33.33 - 50 %
- Water absorption capacity 1.6 to 3.4 kg / kg
- Salt content approx. 0.5 - 2%

In a non-scientific language that means it's pretty much like hard cardboard with the flexibility of feltboard.

Interviewer 1: What state are you at with the product development?

Unfortunately, the material did not pass EU - Food Packaging requirements and the business partners did not continue to fund the project. This is because seagrass as a material source is pretty hard and expensive to harvest and the material was too expensive to produce. Apart from the mold resistance (which is unique), there were too many other materials with similar properties and competitors on the market. This is the reason the project was archived as a research project at the Royal College of Art in London, and we withdrew the patent to make the innovation available of everyone.

Interviewer 1: Do you happen to have more information about the sulfate digestion process? For example, what amount of chemicals is needed? Or do you know anyone who can give us more information on this? As we want to try to make our own pulp of the seagrass.
Interviewee 2: About the cellulose extraction process: For me it was only possible because I had access to the Material Lab at Imperial College in London with Scientists and Engineers helping me out and they only did a tiny amount for testing. It's an industrialized process with chemicals you can't access on the household market, and I would not recommend trying this at home as it is highly toxic. However, you can imitate it with buying cellulose based binding agents available on the market (DuPont, BASF or Papiermaché making etc.) to receive a comparable result for testing.

Interviewer 1: Maybe it is also possible for you to connect in a meeting. Then we could explain more about our project and asks our questions there.
Interviewee 2: I'm happy to help. Unfortunately, I'm very busy with various projects until Xmas, so if you want to talk, it has to be after work hours.

Interviewer 1: No problem at all, we are available after working hours. A meeting on Teams would work great for me, then other members of my group can join as well. If you suggest a time and date, I will set up a meeting in Teams.
NOTE: An arrangement of date and time was asked. But unfortunately, in the end he was too busy and did not reply any longer.

Appendix H

Transcript of Mail interview with Smartfiber AG

Participants:

- Interviewer 1: Student at Saxion University
- Interviewee 1: Manager New Business Development Smartfiber AG

Date: 08.11.2021
Place: via Mail

Interviewer 1: I am a student at Saxion University in Enschede (the Netherlands) studying Fashion & Textile Technology. This semester we are doing a research project on bio-based materials and looking at new applications for seagrass. Our research includes literature research, expert interviews and laboratory research. Later, we will use all the data to propose potential applications for seagrass. We are contacting you, hoping, that you might be able and willing to provide us with more information about SeaCell. We understand that much of the information is likely to be confidential, but perhaps you can tell us something about the production process. We are particularly interested in the pulp/fibre production process and what type of plants can be used for it, for it example if it would be an option for seagrass.

Interviewee 3: It is really nice getting in touch with you. I am very pleased to share some information with you about our sustainable Seacell fibre. I am also happy to share some information about our sustainable, intelligent fibres! Smartfiber AG is the fibre producer, supplying the raw fibres itself (see attached documentation and picture). The high-tech fibres under the labels SeaCell™ and smartcel™ sensitive are produced on modern fibre production plant at Lenzing AG in Austria exclusively for smartfiber AG. Our specialties are, the SeaCell™ fiber containing algae from Iceland, and the smartcel™ sensitive fibre which contains zinc.

For detailed information we provide you a nice video about our technology:
https://www.youtube.com/watch?v=-msMROT31V4

SeaCell™LT and MT: the wellness fibre using raw and organic algae from Iceland
SeaCell^{TM} MT = Seaweed embedded into a Modal fibre
SeaCell^{TM} LT = Seaweed embedded into a Lyocell fibre
- seaweed is rich in essential vitamins, minerals, amino acids and trace elements
- algae has high content of antioxidants that successfully protects against free radicals
- patented technology that ensures long-lasting performance
- skin- friendly
- biodegradable/ compostable
- organic
- ultimate wearing comfort due to the fibres soft feel and great moisture absorption
- from FSC certified wood
- the collect of seaweed is certified as sustainable harvesting

From these cellulosic based staple fibres, yarns, woven and knitted fabrics, as well as ready-made clothing are produced from our partners - such as spinners, weaving and knitting companies or nonwoven producers.

Technology in accordance with the environment – that is important to us!
Harvesting of the seaweed is a gentle, selective and, most importantly, sustainable process. It removes only the part of the seaweed that can regenerate. The seaweed is entirely untreated, and all its ecological value is retained.

The best example for the sustainable thinking and acting of smartfibre AG: The SeaCell™ seaweed is harvested in a gentle and sustainable way. Only every 4 years a certain section above the so-called regenerative region of the seaweed is harvested. SeaCell™ is environmentally friendly and meets the growing demand of today's consumer for green, sustainable and ecological friendly products. SeaCell™ is a perfect medium to bring nature's beneficial properties into daily life. Therefore, the European Union has awarded this process with the European Environmental Award 2000 in the category "technology for sustainable developments".
Thanks to its ecological and sustainable harvesting together with the gentle process, SeaCell™ received the EU Ecolabel and meets the requirements according to OEKO-Tex Standard 100 certified for baby products.

SeaCell^{TM} or smartcel^{TM} sensitive can be used in blends with any other kind of fibres and give an extraordinary functionality to a textile. We recommend that **finished textiles** need to **contain min. 10% smartcel^{TM} sensitive (15-20 % if a high UV +50 or for a hygienic application) or 20-25% SeaCell^{TM}** fibres to obtain the specific features and characteristics. This is the precondition for a certification. We test and certify the products of our customers in our laboratories on the content of smartcel^{TM} sensitive or SeaCell^{TM}. Every fibre has a marker inside, therefore we can verify the content in all textiles. After a positive result we offer a trademark agreement which allows you to use our logo, hang tags, claims and advertising material. We support our partners as best as we can in marketing. The certification procedure takes around 2-5 working days and is free of cost, as well as the advertising materials.

On our brand new homepage you can find any brochures, certificates, studies and test reports proving the function of the fibres SeaCell^{TM} Modal or Lyocell based.
https://www.smartfiber.de/en/seacell-fiber/

There is also a nice video about the seaweed harvest in Iceland. Harvest of seaweed: https://www.youtube.com/watch?v=hDTuBitv8jU

If you have further questions, please contact me anytime. We would be pleased if you keep us in the loop about your project.

Interviewer 1: Thank you very much for your kind and informative email! We do have a few more questions now that we hope you will be able to answer for us. What is the species of seaweed you are using?
Interviewee 3: We are using the seaweed (Ascophyllum nodosum) – all this information you can find on our website as well.
Interviewer 1: If we understood correctly, the seaweed is added in powder form to the dissolved cellulose before spinning. As we are currently researching possible applications for seagrass. We were wondering if it is possible to add other plants to the dissolved cellulose, for example seagrass instead of seaweed?
Interviewee 3: Your understanding of the production process is correct, surely you could also use other ingredients, but we have never tested e.g., seagrass so far.

Note: The final research report will be sent to Smartfiber AG by the end of the project.

Appendix I

Preparation of the Zostera marina seagrass extract
(Liu, Jiang, & Wu, 2010)

Working method:

5. Grind 30 g seagrass with a mortar.
6. Prepare 400 ml 95% (v/v) ethanol solution
7. Extract 30 g of ground seagrass with 150 ml of 95% (v/v) ethanol at 50°C for three days.
8. Filter the suspension under vacuum conditions and concentrate to dryness at 40°C using an evaporator.
9. Divide the dried extract into two parts. Extract one part with 250 ml ethyl acetate and one part with 250 ml demi water.
10. Dry these extracts with the use of an evaporator.
11. Dissolve the dried seagrass that was extracted with ethyl acetate to a concertation of 100 g/L with ethyl acetate.
12. Dissolve the dried seagrass that was extracted with demi water to a concertation of 100 g/L with demi water
13. Sterilize the extracts in an autoclave and store them at a temperature of 4°C until use.

Materials:

Dried seagrass (*Zostera marina)*, Mortar, Sieve, Ethanol, Evaporator, Ethyl acetate, Autoclave