AQUAVENGERS

FINAL REPORT

From nature, for nature.

A? Aalto University Design Factory

pdp | PRODUCT DEVELOPMENT PROJECT

CleanWaters

Glassomer

ATTRACT

Executive Summary

Microplastic pollution is one of the most complex environmental issues that doesn't receive the attention it needs. These plastics not only cause potential health risks to sea life but also to human life. One significant influence of microplastics on human health is the consuming of water.

To improve water quality and minimize the amount of microplastics in drinking water, Team Aquavengers has developed a micro-filter which is reusable and utilizes an organic material, nanocellulose. The developed filter can even filter microplastics with the size of 2 microns and therefore really can make a difference in improving water quality around the world.

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Project Brief

The main objective for the PDP project, sponsored by CleanWaters and Glassomer, was to create a solution for detection or removal of microplastics. The objective was therefore very broad and allowed several specification possibilities in order to meet the task.

The main goal was to find a solution which tackles the problem of microplastics and leads the way to a cleaner and more sustainable future.

Background

To put into figures the microplastics pollution has increased from 50 million metric tons in 1976 to around 450 million metric tons in 2024 which is around 900% increment in less than 50 years. Around 35% comes from synthetic textiles while, car tires, city dust, road markings and marine coatings adds up to 98% of the total microplastics pollution in oceans. Polyethylene (PE) is the most produced polymer with 27% of the global production, which is around 135 million metric tons and is equivalent to around 84 Million normal cars weighing 1600 Kilograms each. The second most produced polymer is Polypropylene (PP) which accounts for 25% of the global production at 105 million metric tons, to put into perspective it is equivalent to 15 million Elephants (3x the population of Finland) each weighing 6800 kilograms. The third most common polymer is Polyethylene terephthalate (PET) that makes up 10.2 percent of global plastic production, which accounts for around 81 million metric tons.

For a tangible illustration of the total plastic waste present in the world, consider this: As of recent estimates, humans have produced around 8.3 billion tons of plastic since the 1950s. If each ton were condensed into the size of a van weighing about 1.5 tons, this total plastic production would equate to the weight of approximately 5.53 billion cars.

The Players

Our Team: Aquavengers

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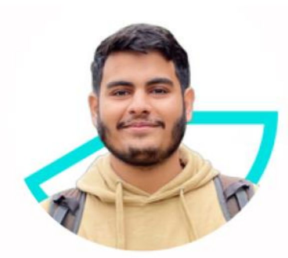

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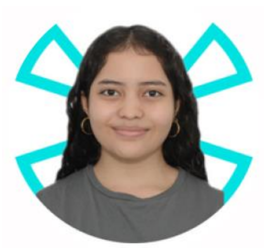

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The Sponsors

The three sponsors involved in our PDP Project are CleanWaters, Glassomer and the ATTRACT organization.

Clean Waters

Our project sponsors and mentors are Miran Ghafoori and Arkar Nan Htike which are the founders of the CleanWaters Startup. The two of them were part of last year's Product Development Project and worked on an innovative automated system that replaces the cumbersome and costly manual sample processing procedures currently in use. Their startup CleanWaters is a spinoff project from this PDP Project & ATTRACT EU course. As they are working on finding new solutions for tackling microplastics, they work together with Glassomer and this year's PDP course.

Glassomer

Glassomer acts as our second main sponsor as they cooperate with CleanWaters and try to work on a mutual solution for tackling the problem of microplastics. Glassomer was founded in 2018 and is offering customized glass solutions with high quality and purity. They are especially famous for their invention of high-resolution 3D printing and also patented the first process for injection molding of transparent glass in 2020. The goal of having Glassomer as sponsor was on the one hand to incorporate their solution in the final product but on the other hand also to get more familiar with their futuristic technology.

Attract Organization

The ATTRACT organization is a collaborative initiative aimed at fostering innovation and advancing technology in Europe. It is supported by the European Union's Horizon 2020 research and innovation program and involves collaboration between various research institutions, universities, and industrial partners across Europe. The goal is to stimulate collaboration between academia and industry to bring cutting-edge technologies from the lab to the market.

Key aspects of the ATTRACT organization include research funding, collaboration and technology transfer. It is divided into two phases. In the first phase, breakthrough technologies should be identified from fundamental research and in the second phase, prototypes and premarket products should be developed. As CleanWaters is part of the ATTRACT group, the organization also acts as support framework for the project.

Stakeholders

During the full year of the project, Team Aquavengers was in contact with lots of different people or rather stakeholders. In addition to the above-mentioned sponsors, there were collaborations with many other stakeholders, in order to get closer in finding a solution for tackling the problem of microplastics. The main stakeholder involved in the project and in the final solution are mentioned in the following subchapters.

Ilona Leppänen, VTT

In the research phase, many different options and especially research papers were discovered and analyzed. From an early stage, Nanocellulose raised our attention. One of the research papers gave some insight about using nanocellulose in combination with microplastics. One of the publishers was Ilona Leppänen, a Finnish researcher working at VTT. After reaching out to her, we talked to her about our ideas about incorporating nanocellulose in a filter for microplastics and got some helpful input. She therefore was one of the first people who strengthened our filter concept and pushed us into further exploring its possibilities.

Eero Kontturi and Nashwa Attallah, Bioproducts and Biosystems (Materials Chemistry of Cellulose)

Two other very important stakeholders were professor Eero Kontturi and PhD student Nashwa Attallah. Both work in the Aalto Bioproducts and Biosystems department and specifically in the field of Materials Chemistry of Cellulose. They were a huge support for us in working with nanocellulose and mainly specialized on camera visualization of the cellulose. Even though this is not the field we are working in, she was a great support as she was always providing us with nanocellulose jelly and showed us the process of creating different concentrations of CNF as well as the process of creating the films. She also gave us general input about the general characteristics of microplastics and always tried to apply her knowledge to our project.

Masi Järvinen, Biorefineries Department

Another important contact person for our project was Masi Järvinen, a PhD student in the Biorefineries department. He was helping us with creating a testing apparatus for testing our created nanocellulose films. It was helpful as it made it possible for us to test the films in regard to their possibility of letting water pass through as well as their ability of filtering microplastics.

Even though it was not the final test apparatus we were sticking with, it was a great start for generating our final test procedure.

Team Communication and Meetings

Good and steady communication ranked first in Team Aquavengers, which required a regular meeting and agreement with the clients and sponsors. A fixed team meeting was held every Wednesday, 17:00-19:00 and in the second semester every Thursday, 18:00-20:00 in the Design Factory at Aalto University. All team members are expected to attend in person, other than the global team in Colombia who attend over Microsoft Teams. During this fixed team meeting, team decisions were made, task status was checked, and any concerns or opinions were addressed. In addition to the fixed team meeting, several team workshops were held as well as individual tasks and meetings in dedicated subgroups were executed.

The other important communication channel in our Team was Telegram as it was used for all other kind of communication related to the project, besides the face-to face communication. The MS Teams was used to share and store files related to the project.

As mentioned, decisions were made during team meetings. When all team members were stakeholders of a decision, the decision was made as a team. Otherwise, team members had authority to make decisions related to the tasks they were assigned.

Research

The first stage of our research was to obtain detailed information about microplastics. Research was conducted on the structure of microplastics and their sources to their impact areas. Then, we divided into four groups to investigate further how we can act for microplastics problem. The four main research topics were prevention, detection, removal and monitoring of microplastics. We have also investigated where to contact and from whom we can get more detailed information about microplastics.

Ways to Act

Detection of Microplastics

The biggest challenge in detecting microplastics is distinguishing microplastics from natural particles. In a study published in Nature, researchers introduced a method for detecting microplastics in environmental samples using the fluorescent dye Nile Red. This approach involves staining the microplastics, which then emit a bright fluorescence under blue light for easy identification. Following staining, the samples undergo density-based extraction and filtration to isolate the microplastics. The detection and quantification of these particles are achieved through image analysis, where photographs are taken through an orange filter to enhance the visibility of the fluorescence (Maes, T., Jessop, R., Wellner, N. *et al.* 2017).

The American company Draper developed an innovative detection system for microplastics in water. This system also employs a fluorescent dye technique, where water samples from the sea are treated with a dye that causes microplastics to emit a distinct fluorescence. This bright emission enables the microplastics to be distinguished easily from other non-plastic materials like plankton and organic debris. When the automated underwater vehicle (AUV) is deployed, it skims the top nine meters of the water where most microplastics are located, scanning for microplastics, testing for specific types, and ultimately relaying GPS coordinates into a heat map. With this system, people can rapidly identify and quantify microplastic content in water samples (Designboom, 2020).

One prominent method is Fourier Transform Infrared (FT-IR) Spectroscopy. By placing liquid samples on IR-transparent substrates and subjecting them to IR radiation, distinct patterns are created, aiding in the identification of microplastics based on their retained chemistry. This technique, particularly when coupled with robust machine learning algorithms and focal-plane array technology, ensures precise and reliable results (Bruker, n.d.)

Furthermore, several companies and research institutions have contributed significantly to the advancement of microplastic detection:

- Ocean Diagnostics, a Canadian company, has pioneered microplastics sampling, analysis, and sensing solutions, offering comprehensive tools for environmental monitoring. (Ocean Diagnostics, n.d.)

In Finland, a country deeply committed to environmental sustainability, numerous organizations have made notable strides in microplastic research:

- Apila Group, an environmental consulting firm, has developed a comprehensive method for identifying and quantifying microplastics across various environmental substrates, contributing valuable insights into the distribution of these particles within Finnish ecosystems. (Apila Group, n.d.)
- Vaisala, a global leader in environmental monitoring technology, has introduced the Multi-Scattering Sensor (MSS), a portable analyzer utilizing laser scattering and fluorescence spectroscopy to detect microplastics in diverse environmental samples. https://www.vaisala.com/sites/default/files/documents/WEA-MET-Listicle-LighterFootprint-B212669EN.pdf
- Tampere University is utilizing Raman spectroscopy to develop a non-destructive method for detecting microplastics in food samples, contributing to food safety and environmental health. (Anttola, 2021)
- University of Helsinki researchers are employing a combination of spectroscopic and chromatographic techniques to study the composition and degradation of microplastics in various ecosystems, offering insights into their fate and transport. (Raukko)
- Jyväskylä University of Applied Sciences is utilizing FTIR and micro-Raman spectroscopy to identify and characterize microplastics in soil samples, aiding in understanding their distribution and sources in soil environments. (Frère L., 2016)
- Finnish Environment Institute (SYKE) has developed a method combining microscopy and FTIR spectroscopy for the detection and quantification of microplastics in water samples, contributing to governmental research initiatives. (Emilia Uurasjärvi, 2021)

- Boreal Environics, an environmental consultancy firm, offers comprehensive microplastics monitoring and analysis services, utilizing various spectroscopic techniques for accurate identification and characterization. (Borealis, n.d.)

Removal of Microplastics

We have found various techniques that can remove microplastics from the water at any stage of its usage. Research for removal of microplastics was more in detailed than the other techniques since various removal techniques were existed.

Electrocoagulation

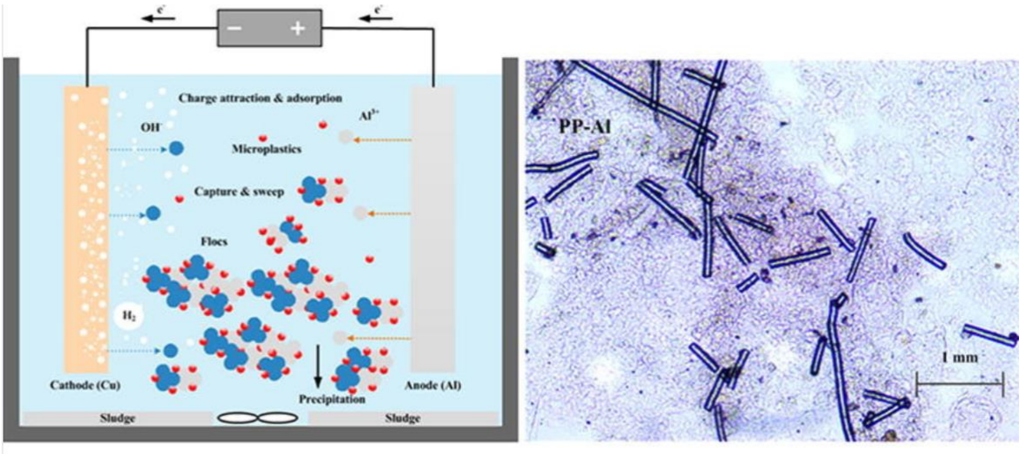


Figure 1: Electrocoagulation mechanism and under microscope

Electrocoagulation enables all microplastic particles to clump into particle composites regardless of type of polymer or type of water by using electricity, which positively charged metal ions and their complexes electrostatically interact with negatively charged MPs leading to MP aggregation. This is a low-cost and environmentally friendly solution for removing pollutants and contaminants from water. However, selection of optimized applied electrical field is crucial (Shen, 2022)

Metal-Organic Frameworks (MOFs)

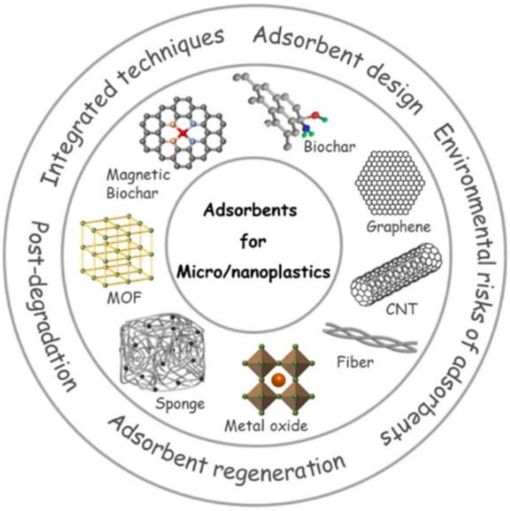


Figure 2: MOF diagram for adsorbents for micro/nanoplastics

Metal-organic frameworks (MOFs) are highly ordered crystalline metal clusters with very high porosity and composed of metal–oxide clusters and organic linkers, which have emerged as a viable option for removing microplastics (MPs) from water due to their high surface area, customizable porosity and chemical properties. Despite certain limitations of MOFs, such as their tendency to exist in an unstable powdered form, these challenges can be addressed by integrating MOFs onto alternative materials like aerogels or foams (Honarmandrad, 2023)

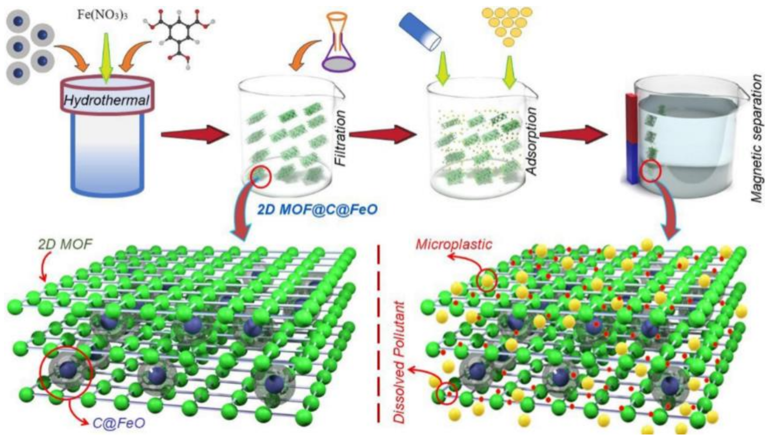


Figure 3: Diagram of nanopillars used in research

For instance, in one of the research, they have used C@FeO nanopillars between the sheets of MOF which significantly enhancing the surface area and enabling easy separation of adsorbent. This system can remove 100 % of microplastics only in 60 minutes (Haris, 2023)

Washing Machine Cartridges

Figure 4: Washing Machine Cartridges

One way to remove microplastics from the environment is filtering the water of our washing machines which creates microplastic waste from synthetic cloth fabrics. This company implements cartridges into the washing machines that can filter the microplastics before the water passes through dirty water canals. Easy usage and implementation with the replacement support for the product makes the system more adaptable to houses (PlanetCare, n.d.)

Cora Ball

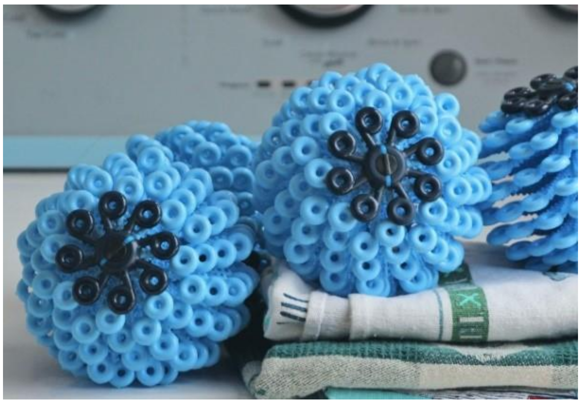


Figure 5: Cora Balls

Similar to the washing machine cartridges, this product aims to remove microplastics from the washing machine water. Inspired by corals filtering the ocean, it collects around %30 of microfibers that is coming from our synthetic clothes and traps them inside of it. It is used by simply putting it inside of machine while washing the everyday clothes and can be also used multiple times simply cleaning it with a hand (Coraball, n.d.)

Ultrasound Waves

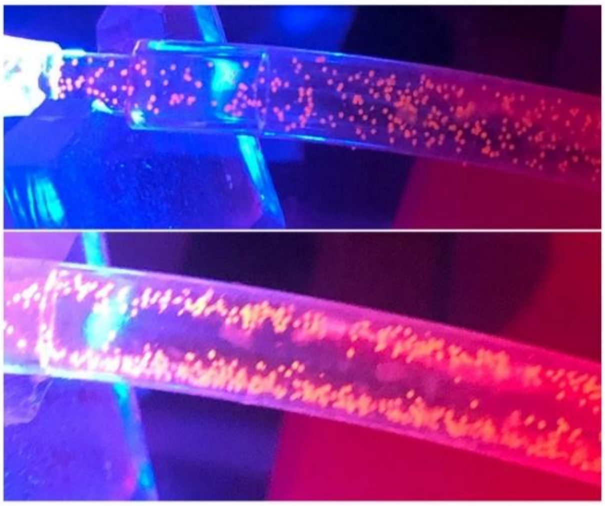


Figure 6: Microplastics pushed to the tube walls

Another way to remove microplastics is to use ultrasound waves which separate microplastics from the bigger ones. Ultrasound waves apply a force on particles which pushes larger microplastics to the wall of the tube and the smaller ones remained in the middle. This method removed about four in every five plastic bits from the water, and it is cheap to use which is about 10 cents. However, in the real system, water also contains other materials, such as dirt or salt, which should be considered. (Kowalski, 2023)

Magnetic

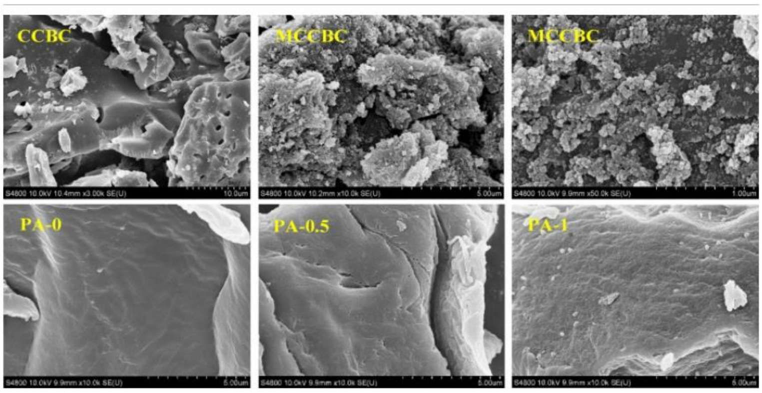


Figure 7: Imaging of Microplastics in Biochar

In this research, microplastics are adsorbed or magnetized by magnetic biochar, so that they can be removed by using magnetic force. They have used magnetic corncob biochar for the removal of polyamide (PA) plastics with various size and age. It has been concluded that this magnetic material can adsorb very small microplastics whereas, interact with the bigger sized microplastics, so that magnetic biochar makes it possible to remove them by using magnets. However, age of microplastics changes the efficiency of the method. (Li, 2023)

Centrifugation

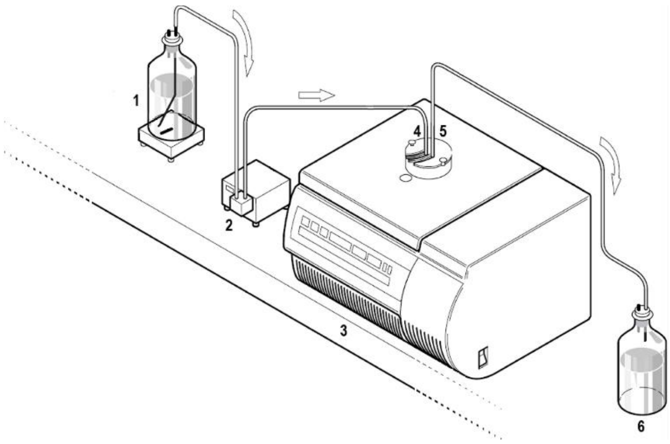


Figure 8: Continuous Flow Centrifuge Machine

Continuous Flow Centrifugation (CFC) is a technique that employs centrifugal force to separate microplastic particles from water. In this process, a mixture of water and microplastics is pumped through a continuously operating centrifuge rotor. Depending on the density of the microplastic particles, they are separated from the water. As the mixture flows through the centrifuge, the microplastics, which have a different density than water, move towards the rotor wall due to the high rotational speed, allowing them to be effectively retained and separated from the liquid. This method is advantageous for its ability to handle a wide range of particle sizes and densities, and it can operate continuously, making it a potentially effective and efficient means of sampling or removing microplastics from water bodies. (Hildebrandt, 2019)

Robots

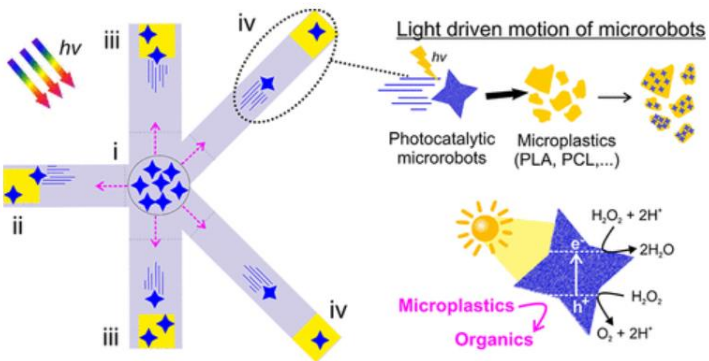


Figure 9: Plastic Waste Maze with tiny robots

Another method of removing microplastics from the water is by using very tiny robots that can capture the microplastics. In the research (Beladi-Mousavi, 2021), they have produced microrobots that are equipped with photocatalytic (BiVO4) and magnetic (Fe3O4) materials, enabling them to move autonomously in sunlight and navigate complex pathways. These robots can capture various synthetic microplastics, such as polylactic acid and polycaprolactone, and can also degrade them by creating local turbulence at the nanoscale and enhancing interaction with the microplastics.

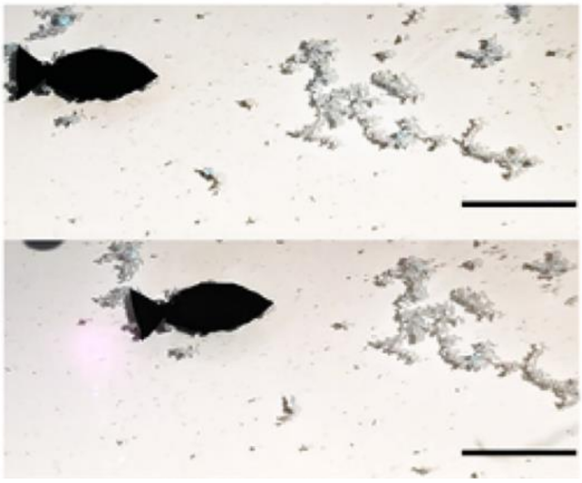


Figure 10: Self-propelled robotic fish

Another robot is a tiny self-propelled robot fish made of material inspired from interior covering of clam shells, known as nacre, which made the robot stretchy and flexible to twist and even has self-healing abilities. The robot can swim around, catch free-floating microplastics, which in the future can be used for trace adsorption, collection, and detection of pollutants, with high efficiency and low cost. (Quaglia, 2022)

Bacteria Eating Microplastics

Another method is using biological systems capable of consuming or degrading microplastics. Unlike other methods, which often involve mechanical or chemical processes, biological approaches harness the natural abilities of living organisms to break down or assimilate plastic materials. Some researchers showed that it is possible to use Fungus to efficiently degrade plastics. (Khan, 2017)

Ideation

Filtration Ideation

As discussed earlier, the team was divided into multiple sub-groups such as prevention, removal, and detection. While looking into multiple fields of dealing with microplastics, most of the team members felt it will be feasible and more impactful to spend the time on removal of microplastics. The removal has a more direct impact on the people and society than monitoring. From the viewpoint of designing a product, microplastics removal filters have a wider marker. Therefore, many removal methods are brainstormed and decided to research about the feasibility of the following removal techniques,

1. Chemical solutions – Magnetic, fluorescence, size & weight ratio.
2. Engineering solutions – Electrocoagulation, static electricity.
3. Filter Ideas – Glass, Nanocellulose, Membrane.

Upon researching and interacting with several people working in the corresponding domains, the team decided to continue to research the opportunities related to glassomer and nanocellulose filters. More detailed information about nanocellulose can be found in the solutions section.

Application Ideation Process

ATTRACT Workshop at CERN

In calendar week 06, the Aalto team visited CERN Idea Square in Geneva, Switzerland, organized for the PdP teams sponsored by the ATTRACT group. Team Cleanwaters (Aquavengers) and Team Hyger (Megamorph) participated in the workshop aimed at advancing their projects with support from the personnels at Idea Square.

There were many presentations on several aspects, first presentation was by Pablo (Chief scientist) on the topic “Who do you think you are?” He asked many difficult questions, gave everyone a new perspective. Ole werner and Catarina Batista gave presentations on the topics “System Thinking” and “Goal Setting”. One of the most important topics was “Exponential thinking and Impact” by Pablo. Although the talk was aimed at giving an approach to solve complex problems, he chose plastic pollution as one of the complex problems and gave the team a new spectrum of thinking to focus our solutions which is discussed below.

Ashwin from CERN Research inspired everyone further with his talk on "Loonshots," emphasizing the significance of nurturing early-stage ideas that are often initially dismissed or underfunded. His examples resonated with everyone, particularly in relation to the slow but growing awareness of microplastics' harmful effects. This inspired the team to decide to enhance microplastic awareness through a comprehensive website.

In addition to these talks, the team actively worked on and shared their project progress daily. This week was pivotal in finalizing the application of our nanocellulose-based water filter. The team brainstormed numerous potential applications and, after robust discussion, narrowed these down to ten feasible ones. Using a decision matrix that assessed factors such as feasibility, durability, cost, and social impact, every team member rated each idea. From this, the team selected five promising applications: wastewater treatment plants, washing machine filters, tap filters, recycling facilities, and sink drain filters. The assessment matrix is also submitted along with the report.

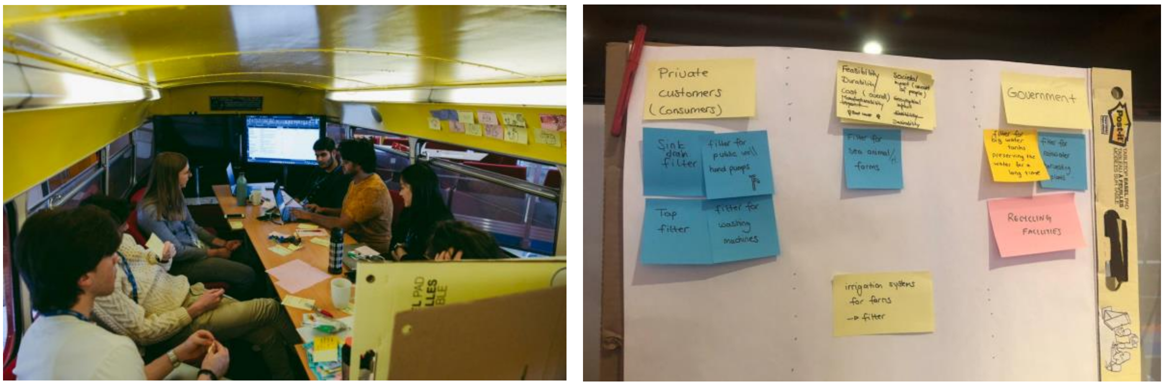


Figure 11: "Red Bus" meeting room in CERN

In conclusion, the concepts and workshop were instrumental in several ways: it strengthened our team dynamics, provided networking opportunities with influential individuals, introduced new concepts, and helped the team focus our applications.

Visit of Treatment Plants in Helsinki and Cali

In calendar week 04/05, both the Colombian Team and the Aalto Team visited a Wastewater Treatment Plant (WWTP) in their city. The Colombian Team went to the plant in Cali whereas the Aalto Team visited the Viikinmäki plant in Helsinki. The goal was to learn more about the filtration process and to analyze if the application suits the purpose of removing microplastics.

The visit of both WWTPs helped to better understand the filtration systems implemented in Domestic and Industrial WWTP. We learned that water is mainly treated by biological and chemical processes, e.g. coagulants/flocculants, bacteria, or air flotation. For both locations, it was mentioned that in the current process, the removal of microplastics is not part of the treatment process. However, it is predicted that there will soon come a requirement for detecting organic micro pollutants in Finland.

One of the main takeaways was that there is a minimum pore size for the filters used in the treatment plants to not disrupt the flow of the water. In Helsinki for example the minimum gap size of the filter can be 6mm. A filter for removing microplastics in nanosized is therefore hard to implement and could only influence as an end-process.

The Solution

Concept Selection

Definition of Nanocellulose

Cellulose is a natural polymer compound. It is made of microfibrils extracted from animal and plant fibers by mechanical shearing or by chemical oxidation. Nanocellulose are among the emerging material of this century, showing interesting properties in many fields such as medicine, functional additives, or water treatment. The most interesting of its aspect being its sustainability. Indeed, nanocellulose is widely available (being origin from biomass), easy and cheap to produce, it is also a degradable, non-toxic and renewable material (Zinge, 2020)

The use of nanocellulose as a material for filtration membrane is well studied as it presents interesting mechanical properties and good filtration properties. However, these studies are mainly focused on the removal of chemicals. (Voisin, 2020).

In a paper published in 2022, Ilona Leppanen describes the possibility to use nanocellulose to capture microplastic.
In this paper she explains: "*Hygroscopic nanocellulose assemblies display peculiar* ***water transport properties*** *involving* ***capillary action and diffusion****. With the aid of water flux, the small nano- and microplastics seem to be conveyed inside the CNF hydrogel network. Moreover, the large* ***surface area of the porous network*** *enhances cohesion facilitating the* ***entrapment of the particles****. The negative overall charge of CNF also promotes the accumulation of the positively charged particles, however, it does not prevent the accumulation of the negatively charged particles."* (Leppänen 2022).

This study shows interesting result. However, in this study, nanocellulose is used in a form of a gel. It shows interesting adsorption properties but doesn't demonstrate the opportunity to use it as a filtration membrane. Indeed, the casting of filtration film with nanocellulose is something that has never been done before. Our project is therefore a brand-new initiative.

Nanocellulose Filter

According to these results, this material seems to be a suitable and an innovative alternative to the existing water filtration membrane. The innovation of the material results mainly in its sustainability aspects and its efficiency. The idea was to use this material to cast a thin film that could be used as a filter.

The expertise of other searchers, including **Nashwa Attallah** (doctoral researcher of the department Materials chemistry of cellulose) gave us hope on the feasibility of this idea.

However, **nobody ever tried to use nanocellulose to filter microplastics from water before** and a **lot of uncertainty** was present. Nashwa first emit some reserve on the strength of the film, saying that the films might not resist high pressure. But she also said that we could probably increase the thickness of the film or use another material such as a Whatman filter to cast the film on and then increase its mechanical properties.

At the beginning, **the biggest challenge seemed to be the mechanical resistance.** Quickly, the biggest challenge was **to create enough porosity** so that the membrane let the water flow through.

Prototyping

Sketches

The initial idea for a nanocellulose filter involved a glass 3D printed cup with a removable slot which contained a glass membrane and a layer of nanocellulose. See the image below for a representation.

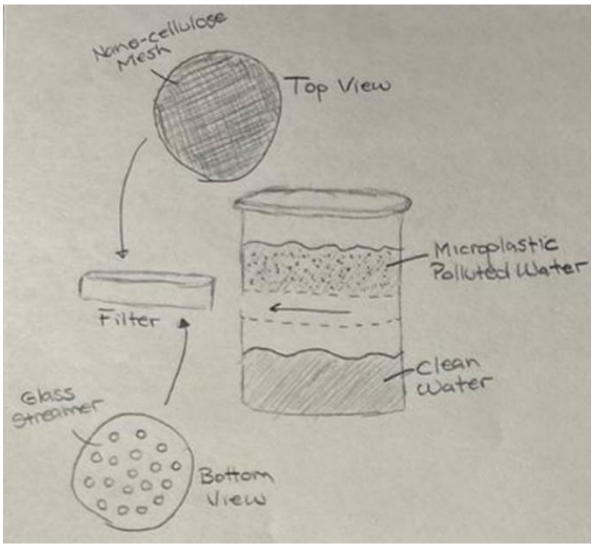


Figure 12: Sketch of initial glass printed prototype

Since Glassomer was not utilized, this concept was no longer pursued.

CAD Design of Filters

Initially when considering using Glassomer's glass 3D printing technology, we drafted the following membranes which would contribute to testing the nanocellulose. Figure 13 depicts a microporous filter surface which would be used as a structural support for the cellulose films, as shown in the sketch in Figure 12.

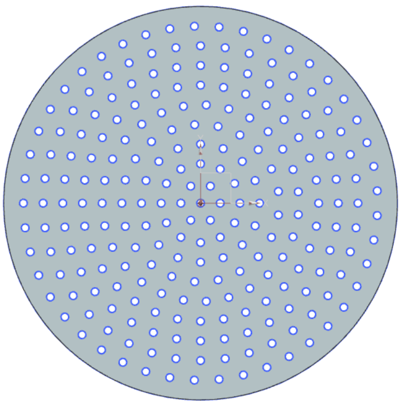


Figure 13: Microporous support structure for Nanocellulose Film

Figure 14 represents complex membrane geometries which would allow us to simulate the water flowing through wastewater treatment plants.

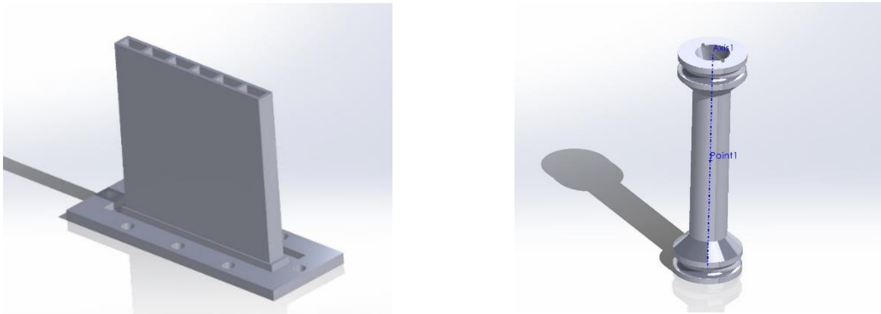


Figure 14: Created complex membrane geometries

These CAD designs ended up not being used as Glassomer was not able to assist in providing the prints and therefore other solutions were developed which do not rely on glass technology. The final solutions are shown in the following chapters.

Membrane of Colombian Team

Figure 15 Membrane Prototype

The prototype membrane developed and constructed resembles a sandwich-like structure, consisting of several layers assembled around a central tube. This tube features a circular fin along its length, specifically designed to accommodate screws that secure the assembly together. The layer sequence starts with a seal adjacent to the tube, followed by a cotton film intended to act as a pre-filter. Subsequently, a filter with 1 mm pores was added, followed by another seal to complete the assembly before attaching the outlet tube. Screws traversing all these layers were tightly fastened using nuts, ensuring the assembly's integrity and leak-free performance. For water movement through this setup, a 12W aquarium pump capable of delivering a maximum flow of 10.2L/min and reaching a maximum height of 1.08 meters, brand Evans, was employed.

Nanocellulose film creation

Manufacturing process of nanocellulose gel

The method used to manufacture the gel is called **tempo oxidation**. As the process is quite long and complex and she was used to doing it, the PhD student **Nashwa helped us with it.** She provided us with a 1% cellulose concentrated gel.

First Option: Manufacturing process of CNF film

The process of casting the film followed 5 steps: concentration adjustment, homogenization, de-bubbling, casting on a petri dish and drying.

Concentration adjustment

As said previously, the gel provided by Nashwa was 1% cellulose fibers concentrate. Following Nashwa advises, we reduced this concentration by adding water in the solution. According to her, a too high concentration would give a too viscous solution and it would be difficult to cast a film with it. Therefore, we created 2 solutions, a 0.3% concentrate and a 0.6% concentrate. The idea of having 2 different were to compare their properties (mechanical, resistance to water, water-flow, etc.).

Homogenization

After adjusting the concentration, it was important to mix the solution to make it homogenous. For this mixing process, the Ultra Turax device was used, shown in Fig. 16.

Figure 16: Mixing process with Ultra Turax

Debubbling process

The last step increased the quality of the solution by making it homogeneous but had the counter effect of creating a lot of bubbles in it. Air bubbles being avoided in our solution because it could have an impact on the properties of the film, we needed to put it out. For that, a debubbling process using vacuum was used. The air was sucked out of the container, attracting the bubbles with it. The suctions were not very strong; therefore, we can assume that it had no influence on the homogeneity of the gel.

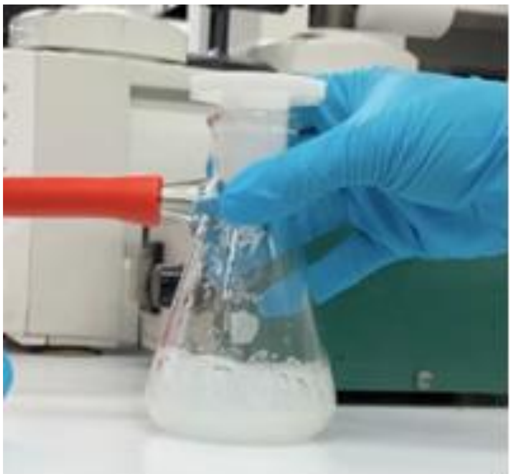


Figure 17: Debubbling process using vacuum

Casting of the film

The next step was probably the most important. It consisted in pouring the gel in a petri dish to create the films. The thickness of the film was controlled by choosing the amount of gel. The volume of gel poured was controlled with a graduated pipette. Indeed, the surface of the petri dish was known ($2 \times \pi \times r^2$),with r the radius of the petri dish. By choosing the volume of solution, $V = 2\pi r^2 \times t$ for a cylinder, it was possible to determine t, the thickness of the film. Therefore, we created films of different thickness with the 2 solutions. In total, we cast around 50 films.

Figure 18: Casting Process of films

Drying Process

This final step was the longest. It consisted in drying the films in a temperature and humidity-controlled room. The drying itself lasted between 1 and 4 days for the thicker films.

Second Option: Manufacturing process of CNF film incorporated with Whatman Filter

During the first tests, it was seen that the nanocellulose films didn't allow the water to pass through which would be a big issue for using the film as a filtration membrane. Therefore, it has been suggested by Nashwa to cast nanocellulose on Whatman filters in order to increase the porosity and let the water pass through as well as to make the filters more stable to withstand the water pressure. A Whatman filter refers to a type of cellulose filter paper or membrane and is widely used in laboratories and industrial settings for various applications such as filtration, clarification, and separation of solids from liquids or gases. For our tests, we utilized Whatman Filters of Grade 1 which show the smallest available pore size: 11 µm.

The step of the process being the same as the one explained previously, only that instead of casting on a petri dish, the nanocellulose was casted on a Whatman filter. Two different methods where used:

1. Pouring nanocellulose on one face of the Whatman filter with a syringe
2. Dipping the Whatman filter into nanocellulose.

The different filters were therefore tested, to see if they allow the water to pass through, if they resist the pressure of the flow and at a final stage if they capture a larger number of microplastics than normal Whatman filters. The testing is explained in the following chapters.

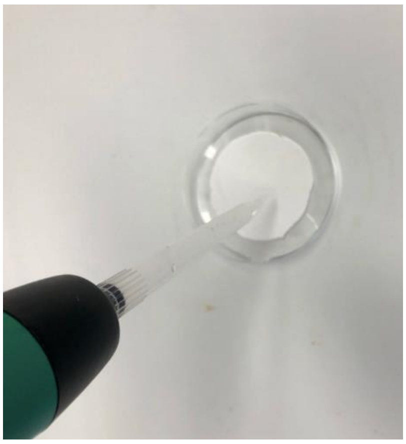


Figure 19: Casting of CNF on Whatman Filter

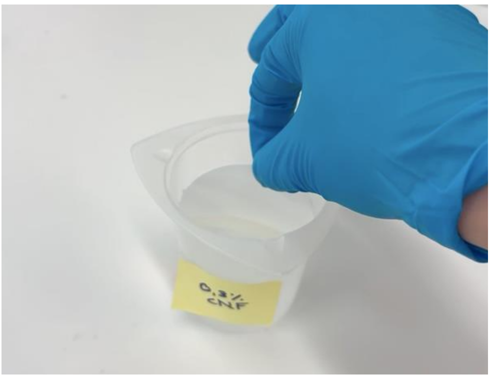


Figure 20: Dipping of Whatman Filter into CNF

Test Setup

Grinding Process of Microplastics

The most important part of testing our filters was to have microplastics to test with. Several methods were used in pursuit of acquiring microplastics small enough to resemble the ones found in drinking water, and close enough in size to conduct proper tests.

Filing microplastics

The first attempt of acquiring them was using a 10-12” filer to grind a piece of polyethylene for 30 minutes. Figure 21 depicts the shavings that were gathered, yet they were not fit for testing due to their inconsistency in size as well as the size itself.

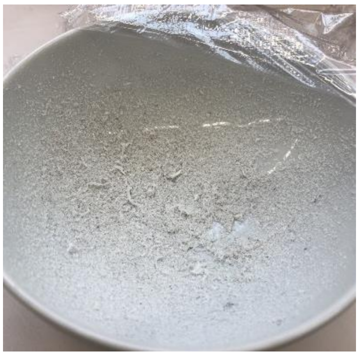


Figure 21: Filed microplastics

Mini Ball Mill

The mini ball mill’s purpose is to shake a capsule, filled with a steel ball and small fragments of the inserted item, until the items inside are crushed to powder, for 15 minutes at 500 rpm and Fig 22 depicts the result. Around the edges of the tube, it seems that it would be plastic shavings, which is correct, yet it is also combined with chipped pieces of the ball itself. There is also barely enough plastic to be used in a test, and most of the plastic could not be broken down due to its lack of brittleness.

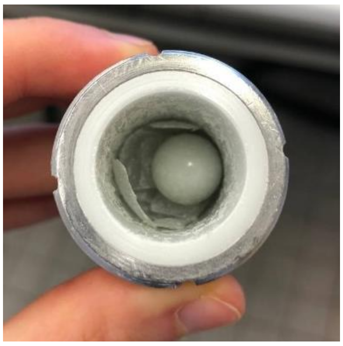


Figure 22 Mini Ball Mill

Planetary Ball Mill

Planetary ball mills are similar to the tiny ball mill except the tube is now a sealed jar halfway full with multiple smaller steel balls. The use of this ball mill resulted in the plastics heating up too much due to friction and there were still no plastics to test with.

Figure 23: Utilized planetary ball mill

Purchase of Microplastics

Eventually we opted to purchase microplastics used for research and development. Fluorescently labeled polystyrene (PS) particles (L3030 from Sigma Aldrich) of size ø = 2 µm) were used to analyze microplastic capturing ability, and to reveal the capturing mechanisms of CNF hydrogel and self-standing films. Below is an image of the microplastics outside of the capsule they were delivered in.

Figure 24: Purchased fluorescent microplastics

Test Apparatus

Initial Apparatus: Flange setup

The first test apparatus used involved 45mm diameter flanges which enclose the cellulose films. On the ends of the flanges are an inlet tube, where the water comes directly from the sink, and an outlet tube where the water which passes through the films flows out of (shown in Figure 25). The flanges were placed on a wooden support stand in order to have a exact vertical alignment of the setup.

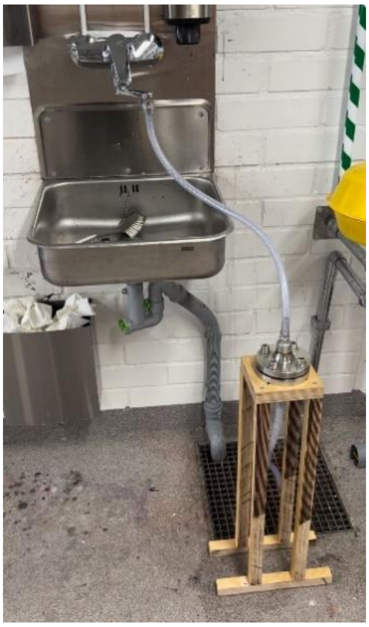


Figure 25: Initial Test Setup with flanges

This set up was only used temporarily because there were some films which were more resistant to water flow and the water would then return up the inlet tube and escape through the connection point of the tubes.

Final Test Apparatus: Sink Aerator

A sink aerator became the primary test set up for the films because of it's built in membrane and there were no other weak points where water would escape from other than the aerator itself. The diameter of the films used for the aerator were 18 mm and they were sealed in place by a rubber o-ring compressing against the faucet. The test setup is shown in the figure below.

Figure 26: Final Sink aerator test setup

Test Apparatus Colombia: Small Scale Wastewater Treatment Plant

The prototype's aim is to demonstrate the basic processes of filtration and sedimentation used in wastewater treatment to remove solids and other impurities, preparing the water for more advanced purification stages. The system consists of several key components arranged sequentially to simulate water flow through an actual treatment plant. Each component plays a specific role in cleaning the water, from removing large particles to filtering finer particles.

Figure 27: Wastewater treatment plant prototype

The water begins its process in a source tank positioned 60 cm above the floor. This tank acts as the starting point for the water to be treated, symbolizing the inflow of wastewater into the plant.

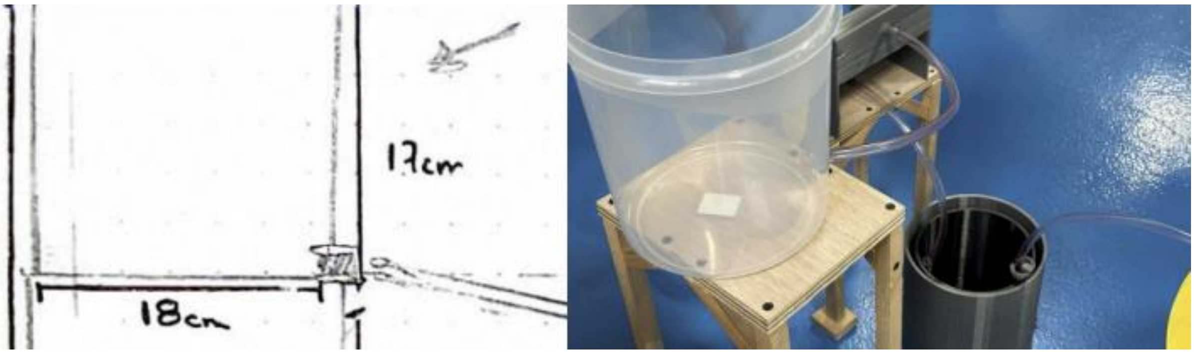


Figure 28: Water tank

From the tank, water flows through hoses to a static sieve located 33 cm above the ground. This sieve filters out larger solids present in the water, such as leaves, paper, and other debris.

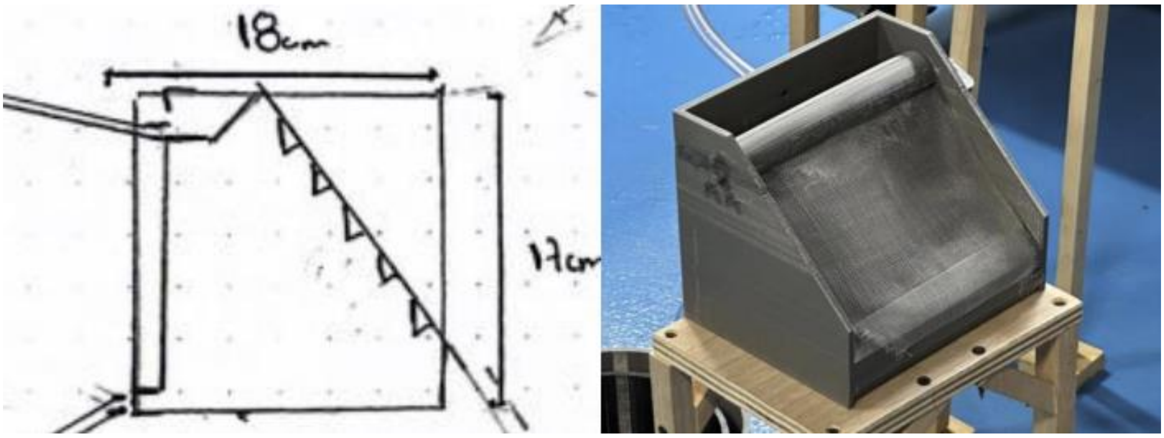


Figure 29: Sieve

Subsequently, the water moves to the sedimentation tank, which sits directly on the ground. In this stage, heavier particles not captured by the sieve settle at the tank's bottom due to gravity.

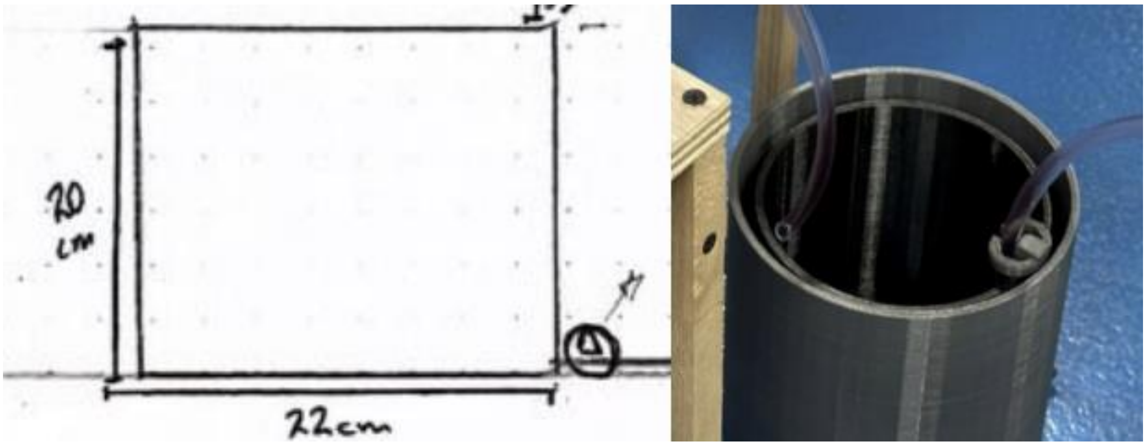


Figure 30: Sedimentation tank

After sedimentation, a small aquarium pump pumps the water towards the filtration system. This system is composed of:

- Inlet Tube: Channels the water into the filtration system.
- Seal: Prevents uncontrolled water leaks.
- Cotton in Sheet Form: Acts as a preliminary filter for fine particles.
- 1mm Filter: Provides additional filtration, capturing even smaller particles. o Second Seal: Ensures the system's watertightness.
- Outlet Tube: Allows the filtered water to continue its flow to the next step or outlet.

Figure 31: Filtration system

At the end of the process, a microscopic analysis of the cotton used in the filtration system will be conducted to identify the retained solids. Additionally, through a visual analysis, the water's clarity before and after treatment will be compared to assess the prototype's effectiveness.

Evaluation criteria and process

There are two main criteria which need to be analyzed during the testing. The main objective is to compare the created CNF films with the existing Whatman Filter. The tests follow the goal to show if our created CNF films can outperform the existing Whatman Filters. The first criterion which needs to be tested is the **water flow**. All films must be tested in regard to their ability of letting both low pressure as well as high pressure pass through as well as withstanding the pressure without breakage. The second criterion which is analyzed during the testing is the ability of the different films to trap or rather filter microplastics in the size of 2 microns.

To conduct the tests, specific evaluation methods are needed in order to compare the results of the different films. For the evaluation of the water flow, no specific equipment is needed. The results are gained by observing the water flow and the condition of the film after testing.

For the microplastic filtering ability of the films, some more equipment is needed. Two options were considered for this testing. The first option is to measure the **weight** of the film before and after water passes through, with the contingency that the films are dehydrated before reweighing them after water has passed through. The test steps include the following:

- Place microplastics onto the film
- Weigh and record the weight of the film
- Seal the film into the sink aerator and pass water through for a minute
- Remove the film
- Dehydrate the film in a 50° oven
- Weight and record the weight of the film

In that way, it can be calculated which amount of microplastics was filtered in the process.

A second option is to use visual inspection with the help of an **UV light**. The purchased fluorescent labeled microplastics absorb UV light and then re-emit light at a longer wavelength, typically in the visible spectrum. This allows for visual comparison of the amount of microplastics collected after water passing through the films.

Test Iterations and Observations

12 iterations of casted films + the existing Whatman Filter were tested for their ability to withstand water pressure from a sink and how many microplastics they are able to withhold. According to the casting process mentioned earlier, the films are labeled by consistency,

concentration of nanocellulose, casting method, the volume of the concentration, the area of the film which was covered in the solution, and the number of sides which are covered.

For example:

A casted (C) Whatman filter (WF) with one side fully covered (FC) with 2,5 g of nanocellulose (CNF) with of a concentration of 0,3 would be labeled as [WF+CNF, 0,3, C, 2,5g, FC, (1)].

Other key words would include partially covered (PC), almost fully covered (AFC), dipped (D) instead of casted, or a Whatman filter with both CNF and activated carbon (AC).

Water Pressure Test

Test execution and documentation

Due to the lack of a pressure gauge, we tested two pressure settings. Low pressure (LP), where the faucet is at its lowest pressure, and high pressure (HP), where the faucet is at its highest pressure. For each test the film was placed in the sink aerator under low pressure for one minute and then removed from the sink for visual inspection. If it was still intact it received a ✓; otherwise, it received an X. Then the aerator was placed back into the sink, and then in the same fashion the faucet was opened to its highest pressure.

The flow is labeled either as "drops" or "steady."

Table 1: Documentation of test iterations

Film	**LP**	**HP**	**Flow**
Whatman Filter only	✓	X	Steady
CNF only, 0.3, C, 12g	X	X	No flow
CNF only, 0.6, C, 12g	X	X	No flow
[WF+CNF, 0.3, C, 2.5g, FC, (1)]	X	X	Drops
[WF+CNF, 0.3, C, 1g, FC, (1)]	✓	X	Drops
[WF+CNF, 0.3, C, 0.6g, PC, (1)]	✓	X	Steady
[WF+CNF, 0.6, C, 2.5g, FC, (1)]	✓	✓	Drops

[WF+CNF, 0.6, C, 1.4g, FC, (1)]	✓	✓	Drops
[WF+CNF, 0.6, C, 1g, AFC, (1)]	✓	X	Steady
[WF+CNF, 0.6, C, 0.6g, PC, (1)]	✓	X	Steady
[WF+CNF, 0.3, D, (2)]	✓	X	Steady
[WF+CNF, 0.6, D, (2)]	✓	X	Steady
[AC+WF+CNF, 0.6, D, (2)]	✓	X	Steady

Interpretation

As the results in Table 1 show, many different results were collected for the water pressure analysis. Differences in their water flow as well as stability can be observed. Most of the created films lead to a steady water flow and can withstand the low water flow without any damage. For high pressure water flow, some of the films show a small hole after letting the water pass through. To overcome this problem, the created films can be combined with a normal Whatman Filter which gives support but does not have a big influence on the water flow. With the combination of the Whatman Filter + the created films, the films can also withstand the higher water pressure.

The only two films which are not able to allow water flow are the two CNF only films. The reason for that is that the CNF only film have less porosity than the CNF/Whatman Filter combination films, as the combination with the Whatman Filter gives the CNF films a porous structure. As a result of that, the CNF only films are not able to allow water flow and are therefore marked as red in the table and are not further considered for the following testing.

The “WF+CNF, 0.3, C, 2.5g” film is also not considered for further testing as the filter cannot even withstand a low-pressure flow.

In addition to these three tests, also the AC+WF+CNF filter is neglected for further evaluation as the activated carbon is not sufficiently water resistant and is therefore not compliant with our health requirements as the AC can be washed off and end up in the drinking water.

Microplastic Filtering Performance

As the observations and interpretations of the water pressure test showed, there are now 9 different films which can be further analyzed regarding their microplastic filtering ability. To compare and evaluate the performance of the tests, both the weight measuring method and the visual inspection via UV light were considered.

Text execution and observations

In the first trial, the weight method was tested. To obtain the weight of the film with the microplastics, the fluorescent microplastics need to be dried first. This was done by using a lab room with high humidity. To evaluate the microplastic capturing rate, the films were first weighted before placing microplastics and then weighted after placing the microplastics, to calculate the net weight of the placed MPs. In the next step, the test was conducted, and water was run through the faucet and the films.

However, the conducted tests showed that the dried microplastics were now clumped together in larger beads and not dissolving in the water. As a result of that, the tests were not following the purpose, as the used microplastics beads were now not in micro size but rather in millimeter size, as shown in the figure below.

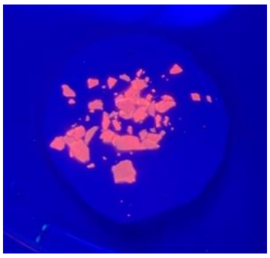


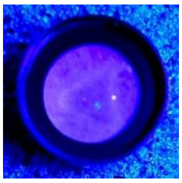
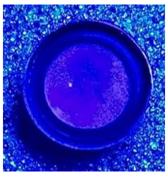
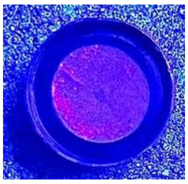
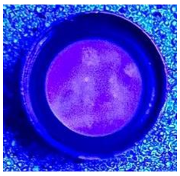
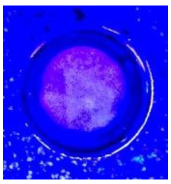
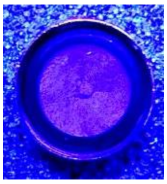
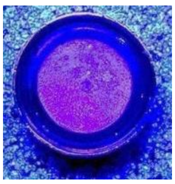
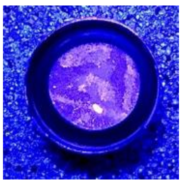
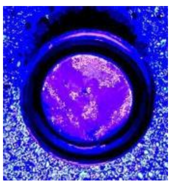
Figure 32: Large dried microplastic beads observed under UV light

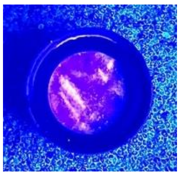
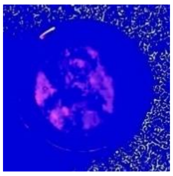
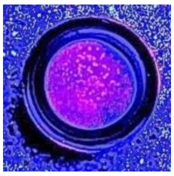
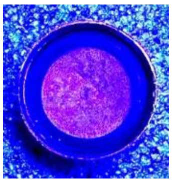
This led to the conclusion that the drying process of the microplastics is not suitable for our testing purposes and that they need to be used in their liquid fluorescent condition.

The second evaluation method was therefore executed: Using the fluorescent microplastics, placing them onto the film and then observing the amount of microplastics before and after testing via UV light. To do so, one capsule of microplastics was utilized for each trial, which means 1 ml of fluorescent containing 2 µm microplastic beads. The content of one capsule was then placed onto the film in the faucet and then it took several seconds for the liquid to pass through the filter. After that, a picture of the film containing the microplastics before running water through was taken, using the UV light to highlight the MPs. In the next step, the film was placed in the sink aerator and water was run through the film for one minute in low-pressure condition. After that, another picture of the microplastics on the film was taken, which allows visual comparison before and after testing. If the amount of microplastics after testing is similar to the amount before testing, the performance of the film can be evaluated as high, as the filter stopped the microplastics from passing through. If the amount is less, it means that some of the plastics passed through the filter and its filter ability is less.

The testing process was conducted for the remaining 9 films, after excluding the 3 tests which didn't meet the requirements in the water flow test. The results of all 9 films and their microplastic performance are shown in the figures below.

Table 2: Results of the conducted microplastic tests

Film	Before Testing	After Testing	Observations
Whatman Filter only (pore size: 11 µm, **baseline** for comparison to created films)			- Large reduction of MPs, lots of microplastics passed through the filter → **Bad performance** for 2 µm particles
[WF+CNF, 0.3, C, 1g, FC, (1)]			- Similar amount of MPs visible → **High performance**
[WF+CNF, 0.3, C, 0.6g, PC, (1)]			- Large reduction of MPs, lots of microplastics passed through the filter → **Bad performance**
[WF+CNF, 0.6, C, 2.5g, FC, (1)]			- Similar amount of MPs visible → **High performance**
[WF+CNF, 0.6, C, 1.4g, FC, (1)]			- Similar amount of MPs visible → **High performance**
[WF+CNF, 0.6, C, 1g, AFC, (1)]			- Similar distribution of MPs - Small reduction of MPs visible, some MPs passed through the filter → **Good performance**

[WF+CNF, 0.6, C, 0.6g, PC, (1)]			- Large reduction of MPs, lots of microplastics passed through the filter → **Bad performance**
[WF+CNF, 0.3, D, (2)]			- Small reduction of MPs visible, some MPs passed through the filter → **Good performance**
[WF+CNF, 0.6, D, (2)]			- No reduction of MPs visible, no MPs passed through the filter → **Very high performance**

Interpretations

After having conducted the tests and done the observation and analysis, it can be said that there are performance differences between the different films. Firstly, it can be said that the Whatman Filter which serves as a baseline for the comparison shows a bad performance in filtering the microplastics. This makes sense as the pore size of the Whatman Filter is 11 microns whereas the used particles show a size of 2 microns. The goal of the testing was to see if the combination with the nanocellulose can increase the performance.

As the results in Table 2 show, all the created films show a better performance than the Whatman Filter. However, there are big differences between the different casted films. The partially covered films also let a big amount of MPs pass through which can be evaluated as low performance. This makes sense as the CNF does not cover the whole film and therefore allows the particles to run through the uncovered parts.

The dipped CNF 0.3 film and the almost fully covered 0.6 film show a good performance. High performance is achieved by the casted films which were fully covered. A very high performance shows the dipped CNF 0.6 film as there is no visible difference between the filter before and after testing.

In conclusion, it can be said that the filters with the higher amount of added nanocellulose show a higher performance whereas the partially covered films cannot impress with sufficient filtering abilities.

Overall Results and Discussion

After having both conducted the water pressure tests as well as the microplastic tests, a final analysis and evaluation can be done. As the filter should both allow a steady water flow as well as showing a good microplastic filtering performance, both aspects must be taken into consideration for the final selection of the best film. The summary of both aspects is shown in Table 3.

Table 3: Overall performance of the created films

Film	Water Flow	Filtering Performance
Whatman Filter only	Steady	Bad Performance
[WF+CNF, 0.3, C, 1g, FC, (1)]	Drops	High Performance
[WF+CNF, 0.3, C, 0.6g, PC, (1)]	Steady	Bad Performance
[WF+CNF, 0.6, C, 2.5g, FC, (1)]	Drops	High Performance
[WF+CNF, 0.6, C, 1.4g, FC, (1)]	Drops	High Performance
[WF+CNF, 0.6, C, 1g, AFC, (1)]	Steady	Good Performance
[WF+CNF, 0.6, C, 0.6g, PC, (1)]	Steady	Bad Performance
[WF+CNF, 0.3, D, (2)]	Steady	Good Performance
[WF+CNF, 0.6, D, (2)]	Steady	Very High Performance

It can be seen that some of the films which show a high microplastic filtering ability only allow an unsteady water flow. The overall performance of these filters must therefore be rated as low and are marked red. The same applies to the filter with a steady water flow but a bad filtering performance.

The only films which allow both a steady flow as well as a good or high filtering performance are the following (marked yellow in the table):

- WF+CNF, 0.6, C, 1g, AFC, (1): Steady water flow, good filtering performance
- WF+CNF, 0.3, D, (2), Steady water flow, good filtering performance
- WF+CNF, 0.6, D, (2), Steady water flow, very high filtering performance

As the "**WF+CNF, 0.6, D, (2)**" film not only shows a steady water flow but also a very high filtering performance, it definitely outperforms the other films and shows the highest overall performance. It can filter microplastics in the size of 2 µm while still allowing a steady water flow. This film is therefore selected as the final solution.

Following steps and other opportunities for exploration

Application

As already mentioned in the "Application Ideation Chapter", several applications were considered for the final solution of the Nanocellulose filter. After having conducted several tests and analysis, the best film was selected and it was proved that this film increases the filtering performance of microplastics in drinking water, compared to existing sustainable cellulose films on the market. As a next step, this finalized concept must be formed into a final product with an influential application.

For the created Whatman/CNF film, especially the application of a sink or tap can be considered suitable and should be further explored. It is suitable as the films showed a good performance in filtering microplastics in the size of 2 microns as well as withstanding the water pressure of the faucet. Therefore, the tap or sink would be a great possibility to improve the drinking quality, rather in private households or public facilities. In the following steps, the exact maximum water flow must be analyzed over a longer period of time.

Further applications may involve utilizing nanocellulose films in conjunction with Whatman or SDI filters for various purposes such as washing machine filtration, hand pumps in public wells within developing nations, irrigation systems, and recycling facilities. However, it is imperative to assess the resistance to water flow in accordance with specific applications. These potential applications serve as a foundation for further exploration and development in this field.

For the membrane created by the Colombian Team, especially the application of the Wastewater Treatment Plant should be further discovered.

Business model

Our project doesn't end with a final product due to time constraints, but the proof of concept was conducted. If our film can be further improved to the point where it can be applied to the market, this business model could be used. Based on the application, the target customers of our film can be divided into two groups. For individual consumers, filters will be sold as a one-time purchase with additional maintenance services. We also provide subscription services where users pay a monthly fee for regular filter replacements and upkeep. For corporate clients, we offer customized filtering solutions and collaborates with government agencies to install filters in public spaces like schools and hospitals. The model includes gathering and analyzing water quality data post-filter usage to enhance service quality. Additionally, we will conduct various promotional activities to increase brand awareness among household users and corporate sectors.

Reflection of Course

Evaluation of Work

Having validated our assumption of nano-cellulose improving the filtration of today's standard filter, we are happy with our result. The project forced us to develop the skill of research because only so much information is out there about using nanocellulose for microplastic filtration. Had we known in the first semester how to properly look for what helped us advance our project to the testing stage, we might have been able to reach conclusions we made at a much earlier stage which would have allowed us room to develop the concept further. All members of the team worked cohesively throughout the project and each contribution was just as crucial to the advancement of the project as the others. Given the complexity of the problem of microplastics and the broadness of the project objective, we feel like that our delivered proof of concept was worthwhile and a great outcome. Everyone stepped out of their comfort zone in terms of what their educational background was to contribute to the project. With our research of nano-cellulose being used as a microplastic filter, other researchers can advance the concept into market use. Overall, we believe our project ended up having an impact towards the cause of removing microplastic pollution.

Learning Experiences and Feedback

Simone: During the two semesters of the PDP project, I gained a lot of new knowledge. I especially gained new knowledge regarding researching existing concepts and solutions and moreover develop them into own solutions. In addition to that, I gained a lot of new knowledge in the biological/chemical field as the work with nanocellulose required these skills. It was fun to get familiar with that new field of study. Moreover, it was a great experience to work in a diverse, multidisciplinary, and multicultural team. The PDP project also was a great course as it really helped to experience product development in a practical way, to see how complex it can be and what challenges might occur during the development process.

Manoj: Learned several things about product development through theoretical and mostly practical works. We were operating in a new realm – Bio-based chemical solutions. Learned many biological and chemical processes. Working with the diverse team was the most interesting part of all. The course really taught me how difficult is to create something and making a start-up out of it is whole another mountain to cross. The objective of the project is really motivating as we will be solving one of the serious problems of the planet. It would be nice to continue working on this solution. Throughout the project we got help from many people. We are grateful for the Aalto & DF staff, my friends and our sponsors.

Jean-Baptiste: When I started the PDP project, I aimed to work on a meaningful project. I was therefore delighted to be part of the CleanWaters team and work about microplastics. Having tried to find a feasible solution for a year, I now have a better understanding of the complexity of this problem and why so few solutions exist now. The subject of nanocellulose was also a discovery for me, as a materials science student, I was fascinated to learn more about this innovative material. Finally, I learnt a lot about how to work in a team with so much diversity.

Areeb: Our project tackling microplastic pollution was a fulfilling journey from start to finish. We delved into various methods for detection, prevention, monitoring, and removal, learning a great deal along the way. It's clear that microplastic pollution is a significant yet often overlooked issue, making our work more crucial. We ultimately decided on a nanocellulose-based solution, which covers prevention, detection, monitoring using UV-vis or microscopy, and even removal from the environment. This comprehensive approach reflects our commitment to addressing microplastic pollution comprehensively. Working in a diverse team was a highlight, fostering strong bonds that made our collaboration incredibly rewarding. I'm proud of what we accomplished together and excited to continue our efforts in making a positive impact.

Sebastian: This project was an incredible learning experience starting from the most beneficial mindset I adopted of seeing the project for what it was. We had spent so much time in the research stage for this project because we felt this pressure of delivering the most groundbreaking solution that would revolutionize the removal of microplastic pollution; as if we hadn't done that then the project would have been an ultimate failure. As if it would cost us our livelihood. That's the beauty of PDP; at the end of the day this is just a course that's meant to help us grow. This mentality allowed me to approach the problem with more willingness to fail for the sake of succeeding. As a manager I had a unique element of the project where I was also learned how to lead people towards the same vision, and not by delegating but by example. I also learned how to bring a group of multidisciplinary people from diverse backgrounds together and foster a cohesive work environment. I learned the consequences of not removing myself from the project and thinking about the well-being of my peers; and how to respect their wishes of leaving and adapting afterwards. I also had the privilege of being a good representative of my team and speaking in a variety of public settings. I learned how to trust and rely on my peers in their parts to advance the project when naturally I'm a do-it-yourself kind of person. Similarly, I learned how to grow a network of external people to help the advancement of the project. This project forced me to think outside the box and really use my creativity for how to approach a field I had no experience in. I gained a new perspective and appreciation of environmental sustainability after developing awareness of many dangers in our ecosystem. I was able to exercise my ability to overcome adversity when the direction of the project seemed to be going lower and lower. I also developed an appreciation for the skill of research; being able to filter through hundreds of research papers just to find one article that would help your project is an art. I also got to exercise some of my engineering skills when it came to designing and manufacturing test fixtures and amongst conversations with other engineers over the fixtures. If I could take this course again I absolutely would, and I'd be glad to recommend it to anyone else who is looking to integrate themselves into the realm of product development.

Nydia: As the only member with a background other than engineering, I have some difficulties following all the things during the project. But I really appreciate this process, I learned a lot from other members and through the project even sometimes I didn't understand some technical concepts. I learned that a project must go through a process, and sometimes it's hard to get a final product, which may make people working for it disappointed. But I think that's the meaning of these projects, we are trying our best to contribute to this area, and we learned a lot from last year's group and in the future, someone will improve it with our outcome. So, all in all, I'm satisfied with what we did and enjoyed the half year working with my teammates.

Natalia: Belonging to the PDP marked my life in a great way, as it was a very valuable opportunity to learn on a personal and professional level. This project allowed me to work in a transdisciplinary team solving a problem that affects today's society and I feel that having been able to contribute to something that could reduce its negative impact is super valuable. In addition, participating in the PDP showed me what I can do beyond the skills of my career. I was also able to practice my English and get to know a completely different country from the one I live in, getting to know its culture and enjoying its benefits. I will always be very grateful for this opportunity and for the people who accompanied me along the way, as each one was a fundamental piece for everything to develop in the best way.

Deivy: Throughout my participation in the product development project, I discovered a new universe of knowledge that merged theory and practice in an unparalleled manner. During this time, I delved into the realms of prototyping and 3D modeling, skills that became crucial for turning our ideas from concept to reality. Additionally, simulations and design became the core of our strategy to validate proposed solutions, allowing me to apply assembly principles and 3D printing techniques.

Moreover, for me, the project was not only a window to new technical skills but also an intensive course in soft skills. I learned about the importance of effective communication and teamwork in a diverse and multicultural environment, where each member contributed their unique perspective. Additionally, my fluency in English was enriched, interacting daily with colleagues and professionals from different parts of the world. Working on this project was transformative; it taught me not only to face technical challenges but also to navigate the complexities of collaborating in a multidisciplinary team. This learning is not only applicable in my field of study but also extends to any professional area I decide to venture into. I am grateful for this experience and for every person who contributed to my personal and professional growth.

Angelo: Through my participation in the PDP, I have been able to identify many strengths and points to improve. It has been a long and full of new knowledge, from knowing that it is microplastic to knowing a culture that was totally unknown to me as a person. On the other hand, put into practice all the soft skills to be able to coordinate with colleagues in another country, with another time zone, multiples cultures and almost eleven different paradigms, drive them all and bring everything to a single product that best meets the needs of our stakeholders. All this has been something magnificent, it has shown me that the development of projects is what moves me, to confirm that that desire for an area of work is really what I want to dedicate myself to for the moment.

I consider that the possibility of integrating more students into this type of project is a winning decision, in addition, it would be very important to create agreements with local means of transport or accommodation to help international students and in this way they are more in person, which could increase the quality of the solutions delivered by having complete equipment for longer.

Öykü: This project is one of the most challenging and rewarding experiences for me. This the first project for me that is out of my technical experience. When we first chose the project, I thought it was going to be more about 3d printing and manufacturing than chemical processes. However, going out of the comfort zone and seeing what we have achieved at the end gave me a new perception about product development.

Budget management

Managing the budget was not too difficult because we didn't end up using the glass technology of our sponsor, Glassomer. Additionally, our project revolved around the study of nano-cellulose which heavily involved looking through research papers, which luckily is free. Most of our resources were provided by the university; from the nano-cellulose itself, down to the test fixtures we used to test our films. The only major expense we made was for the microplastics we used for testing, the wastewater treatment plant visit, and the gala booth materials. As seen below the we used 3900,75€ out of the 10,000€ budget.

Table 4: Budget Expenses

No.	Material cost description	Date	Amount (EUR)
1	Pizza(workshop lunch)	12.10.2023	40,5
2	Suscription on research website	28/11/2023	2,99
3	Waste water treatment visit	02/02/2024	66,3
4	Microplastics	09/04/2024	2878
5	Flour stainers	24/04/2024	17,99
6	Gala decoration (temu supplies)	25/04/2024	75,88
7	UV lights	03/05/2024	20,98
8	Team shirts	26/04/2024	351
9	Poster design subscription	03/05/2024	29
10	Curtain		349,93
11	Gala decoration (jysk supplies)		14,25
12	Tokmanni supplies		53,93
Total			3900,75

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