_EWAP

↘ Bio-based material from Po River aquatic vegetation, a DIY design.

_ EWλP

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_ ABSTRACT

Freshwater ecosystems around the world are facing increasing challenges due to rising temperatures in urban areas, leading to the proliferation of invasive aquatic vegetation, among other consequences. This study focuses on the case of Elodea nuttallii in the river Po, Turin (Italy), where maual eradication has been identified as the most effective method of environmental control. However, this approach generates significant amounts of plant biomass that is currently treated as organic waste. To address this problem, this research investigates the potential of utilising aquatic plant biomass as a valuable raw material for the production of biobased materials to replace fossil-based plastics.
Through a preliminary analysis, various procedures were developed to explore the opportunities offered by aquatic plant biomass. The study was conducted in the laboratory, using a do-it-yourself approach as a method to understand the potential of this biomass. Subsequently, Material Tinkering was adopted to evaluate samples of biobased materials and assess their characteristics and properties.
The results of this study indicate that several samples of biobased materials derived from aquatic plant biomass show promising characteristics and properties. These results suggest interesting possibilities for full-scale applications in the context of the circular economy, particularly in sectors such as footwear. By exploiting the potential of aquatic plant biomass, it becomes possible to replace fossil-based plastics with sustainable alternatives, contributing to the reduction of the environmental impact associated with conventional materials.
Overall, this research highlights the potential of utilising aquatic invasive vegetation as a valuable resource, thus turning a significant environmental challenge into an opportunity for sustainable innovation. The results emphasise the importance of the transition to a circular economy model, in which waste materials can be transformed into valuable resources, fostering environmental conservation and promoting sustainable development.

_ INTRODUCTION

The discovery of fossil-derived plastics more than 100 years ago revolutionised the production of low-cost, durable and disposable items (Nielsen et al., 2020), but nowadays they cause critical environmental impacts that need to be addressed. Plastics' durability and extremely low degradation rate cause environmental pollution that is difficult to tackle. Mismanagement of plastics is a huge concern and a threat to both natural ecosystems and human health, releasing chemicals, toxins and microplastics into the environment. Sustainable consumption and production, developed within the framework of the circular economy, are promoted to achieve the transition to a greener and socially inclusive global economy, which includes reducing the use of fossil-based plastics. The market for recycled plastics has been boosted by increasing the percentage of secondary raw materials fed back into the production process and there is an increasing focus on new biobased materials made from organic waste and by-products (OECD, 2022).
Bioplastics show promise in reducing environmental impact, accounting for about 1 per cent of the 368 million-plus tonnes of plastic produced annually (European Bioplastics, 2019). The circular economy aims to maintain products, components and materials at their maximum usefulness and value over time, and is effective in addressing the complex problem of pollution, linked to issues of global warming, water quality and environmental conservation. In this perspective, the concept of waste and by-products has moved from being a burden to be disposed of to a resource that can be used to give biobased materials a second life. Biobased

materials are derived from biomass and are renewable, biodegradable and compostable. Furthermore, they represent a potential substitute for fossil-based plastics due to their sustainable characteristics. Biomaterials result in lower greenhouse gas emissions than the production of fossil-based plastics, aligning with the zero-carbon targets set by many national and international legislations (Venâncio et al., 2022).

The study focuses on the Po River in the Turin urban area, which is affected by numerous environmental pressures due to climate change. In recent years, this freshwater ecosystem has been affected by the proliferation of Elodea nuttallii, also known as 'alien algae', an invasive, fast-growing aquatic plant of North American origin.

Rising temperatures in urban areas and the prolonged lack of rainfall create the ideal conditions for the proliferation of Elodea nuttallii. It is a highly invasive aquatic plant that can transform ecosystems, clog drainage channels, impede navigation, and aggregate into dense vegetation mats that reduce the amount of light and oxygen available to other living aquatic organisms. In reality, environmental control consists in the manual eradication of Elodea nuttallii which produces a large amount of biomass per year which is collected and disposed of as special organic waste to avoid dispersion in the surrounding areas.

_ THE PROBLEM OF PLASTIC MATERIALS

↘ A brief history of plastic

Plastics are carbon-based polymers and were discovered about 100 years ago and most, more precisely 99% of the raw materials for plastic production are derived from nonrenewable elements (Nielsen et al., 2020). Plastics have historically been as a solution to the scarcity of rare materials, such as turtle shells, horn, and ivory (Science History Institute, 2016).
Currently, plastics constitute an essential element of the daily lives of billions of individuals and are widely employed in the industrial sector. They are synthetic materials formed through the process of polymerization, which involves a series of chemical reactions primarily utilizing organic raw materials such as natural gas and crude oil. Depending on the type of polymerization employed, different plastics can be produced with variations in hardness, opacity, and flexibility (Geyer, 2020).
The first plastic officially presented was named "Parkesine" in honor of its inventor, Alexander Parkes, during the 1862 Great Exhibition in London. This material was derived from cellulose and could be molded when heated, retaining the acquired shape once cooled. Subsequently, celluloid was developed as a plastic substitute for ivory and tortoiseshell in the production of billiard balls and combs, destined for a promising future in the film industry. During that period, these plastic materials were primarily derived from natural raw materials.
It was not until 1907 that Baekeland invented Bakelite, an insulating, durable, and heat-resistant plastic, representing the first plastic composed of molecules that

1839 Rubber - *Charles Goodyear*

1869 Celluloid - *John Wesley Hyatt*

1884 Artificial Silk - *Hilaire Bernigaud de Grange, Count of Chardonnet*

1892 Rayon/viscose - *Charles Cross, Edward Bevan, Clayton Beadle*

1907 Bakelite - *Leo Baekeland*

1908 Cellophane - *Jacques E. Brandenberger*

1910 Synthetic Rubber - *Fritz Hofmann*

1912 PVC - *Fritz Klatte*

1931 Polystyrene - *IG Farben*

1935 HDPE - *ICI UK*

1935 Melamine - *BASF*

1937 Polyurethane - *Otto Bayer*

1938 Teflon - *Roy J. Plunkett, Rack Rebok*

1938 Perlon - *Paul Schlack*

1946 Acrylonitrile butadiene styrene - *US Rubber Company*

1949 Expanded polystyrene - *Fritz Stastny*

1952 LDPE - *Karl Ziegler*

1953 Poly-carbonate - *Hermann Schnell*

1954 Polyacrylonitrile - *Bayer*

1954 Polypropylene - *Giulio Natta*

did not exist in nature. Five years later, PVC (polyvinyl chloride) was invented, which saw widespread adoption starting from the mid-20th century, thanks to the discovery that it could be derived from byproducts of the petrochemical industry and the increased demand during the Second World War. Therefore, despite being aware of the environmental and health risks associated with PVC production, a byproduct was transformed into a profitable product. Subsequently, polyethylene and polypropylene also experienced extensive dissemination.
During that era, the positive image associated with plastics contributed to its boom in usage, as it was seen as a trendy, clean, and modern material. Even today, PVC, PE (polyethylene), and PP (polypropylene) remain the most widely used plastics globally (Geyer, 2020).

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Source: Conversio Market & Strategy GmbH and nova-Institute

Distribution of the global plastics production in 2021

*Commonwealth of Indipendent States: Azerbaijan, Armenia, Belarus, Kazakhstan, Kyrgyzstan, Moldova, Russia, Tajikistan, Turkmenistan, Uzbekistan and Ukraine

↘ The management of plastics

The discovery of plastic has made life much more serene as it allows for durable yet disposable or low-cost items, but the durability of plastics and their degradability at an extremely low rate are the cause of pollution that is difficult to combat. Getting rid of plastics is indeed an extremely difficult process: some plastics degrade after hundreds of years, while some do not degrade at all (Thiruchelvi et al., 2021b), this poor degradability therefore makes them the most environmentally polluting materials (Cucina et al., 2021).
Their annual production has doubled in just under a decade, from 234 million tons in 2000 to 450 million tons in 2019 (OECD, 2022).
Moreover, "the current life cycle of plastics is anything but circular," as the OECD states in the opening of its study "Global Plastics Outlook - Economic Drivers, Environmental Impacts and Policy Options," which offers a detailed view of the life cycle of plastics globally. In fact, only 9% of the plastics that are produced are recycled, 19% end up in incinerators and nearly 50% in sanitary landfills; while, as the OECD points out, the remaining 22% of plastics are disposed of in uncontrolled landfills, burned open or dispersed in the environment.

The mismanagement of these materials is therefore a huge problem and threat to the environment and a major health risk to humans. In fact, their release into the environment causes the release of chemicals and toxins such as dioxins, which are a major cause of global warming.

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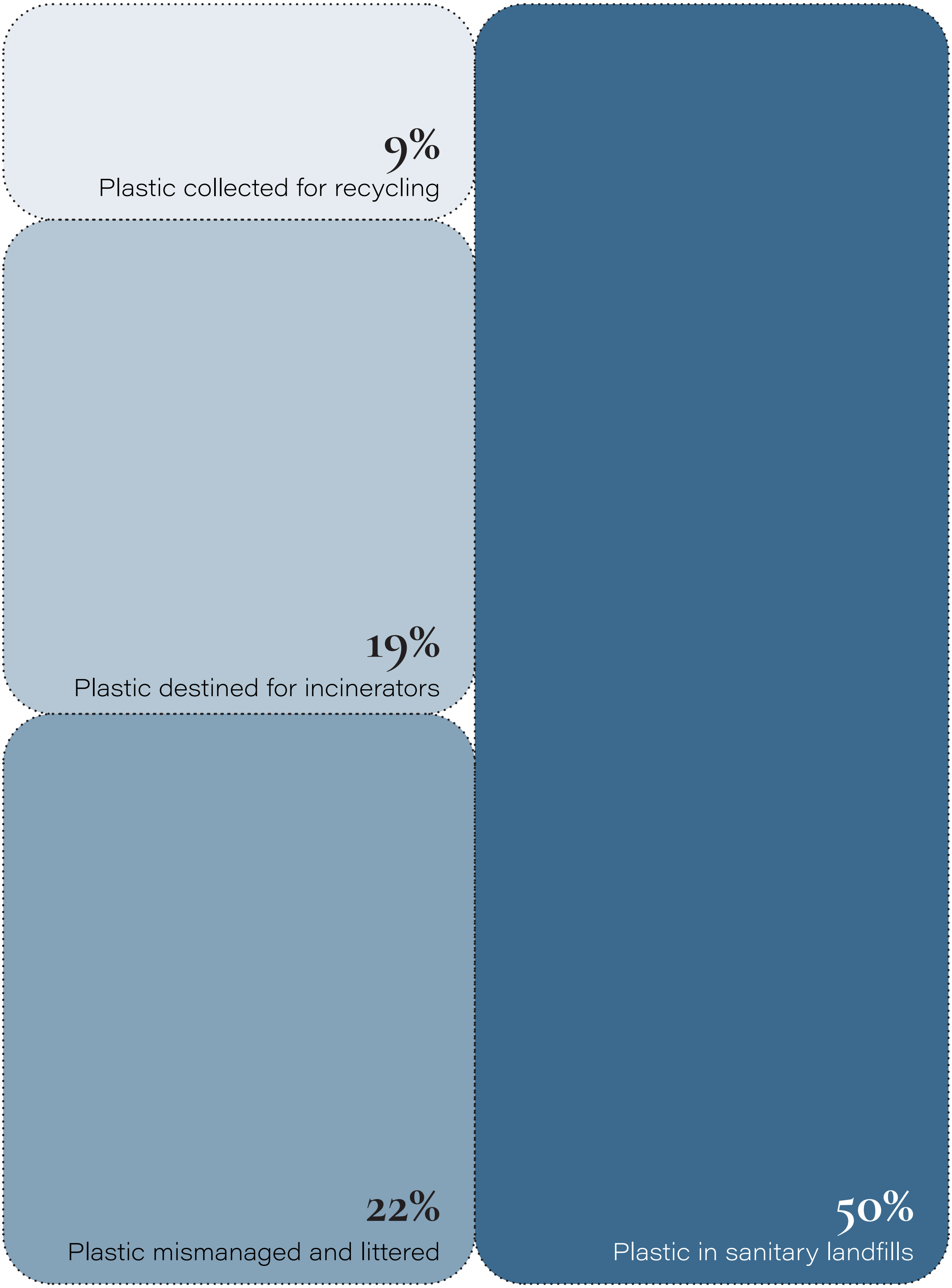
Source: OECD. (2022). Global Plastics Outlook. OECD. https://doi.org/10.1787/de747aef-en


9%
Plastic collected for recycling
19%
Plastic destined for incinerators
22%
Plastic mismanaged and littered
50%
Plastic in sanitary landfills

Another problem related to plastics is the dispersion of microplastics in the environment, "the documented presence - the OECD report states - of small particles in freshwater and the terrestrial environment, as well as various food and beverage streams, suggest that microplastics contribute substantially to the exposure of ecosystems and people to the effects of plastic dispersion and related risks".
The impact on terrestrial ecosystems, the atmosphere, fresh water, and the marine environment has prompted increasing attention to plastic waste. Today plastics, mostly fragments and single-use items such as bottles or packaging, account for 82%of the waste in Europe's oceans, and there are 30 million tons of plastics floating in the world's oceans, from the Arctic to the Antarctic (Dang et al., 2022a).

In contrast, there are already 109 million plastics accumulated in rivers around the world, causing the microbial balance to break down (MacLeod et al., 2021). Finally, the data report that in 2019, 6.1 million tons of plastic waste was leaked into rivers, lakes and oceans with a carbon footprint of 1.8 billion tons of GHG emissions, 3.4% of global emissions – with 90% of these emissions coming from their production and conversion from fossil fuels (MacLeod et al., 2021).
It is predicted that 11 billion tons of plastic will be accumulated in the environment by 2025 (Brahney et al., 2020), this due to flawed legislation that, until the 1990s, considered it completely legal to dump plastic into the sea. A study published in 2017 estimated that the amount of plastic dumped into the ocean each year is about 8 million tons (Plastic Oceans Foundation, n.d.). Thanks to ocean currents, a new continent, of the size of Europe, made entirely of plastic will be born before 2025 (Plastic Oceans Foundation. (n.d.), 2018).

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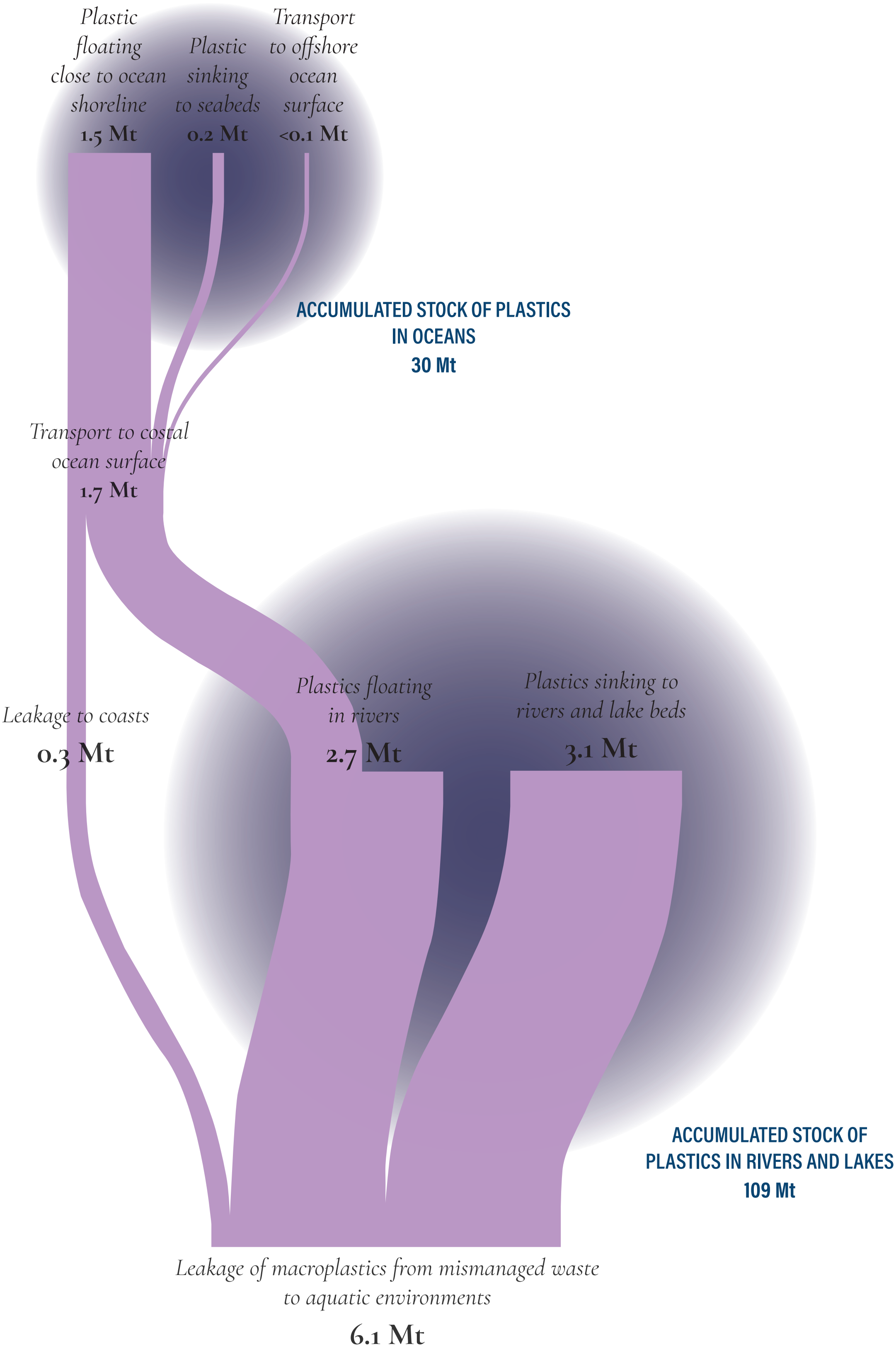
Source: OECD. (2022). Global Plastics Outlo-ok. OECD. https://doi.org/10.1787/de747aef-en


Plastic floating close to ocean shoreline
1.5 Mt
Plastic sinking to seabeds
0.2 Mt
Transport to offshore ocean surface
<0.1 Mt
ACCUMULATED STOCK OF PLASTICS IN OCEANS
30 Mt
Transport to costal ocean surface
1.7 Mt
Leakage to coasts
0.3 Mt
Plastics floating in rivers
2.7 Mt
Plastics sinking to rivers and lake beds
3.1 Mt
ACCUMULATED STOCK OF PLASTICS IN RIVERS AND LAKES
109 Mt
Leakage of macroplastics from mismanaged waste to aquatic environments
6.1 Mt

↘ Need to reduce the environmental impacts and the SDG'S

Thus, the need of the hour is to reduce the environmental impacts of plastics by taking tangible actions toward zero-waste production processes. Regarding the plastics market, this is made possible by increasing the market for recycled plastics, which can increase the percentage of second raw material re-injected into production (currently stuck at 6%) (MacLeod et al., 2021), or by finding green alternatives, which effectively convert food and non-food waste, which degrades quickly and naturally, into innovative materials.
This meets the goals of the UN's 2030 Agenda. The agenda consists of 17 goals for sustainable development, identified by the UN in 2015, with the intent to design "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Publications Office of the European Union, 2017), putting economic growth, social inclusion and environmental protection first. The term "sustainable" is thus being linked no longer only to the concept of "green", but also to economic and social dynamics.
One way used by the UN to summarize the content of the SDGs is the five P's: people (to eliminate poverty and ensure dignity), prosperity (understood as both economic ease and "harmony with nature"), peace, partnership (only collaboration between states and businesses makes it possible to achieve the goals) and planet (as an asset to be protected) (Pictet Asset Management Europe, 2019).
In particular, the development and use of new biobased compostable materials, responds to SDG 12 (United Nations, n.d.), which promotes increased resource

and energy efficiency to ensure a better quality of life, promoting sustainable lifestyles, and avoiding the increasing degradation of the natural environment.

It is about sustainable consumption and production, enabling people to do more with less. Ensuring sustainable consumption and production practices necessarily involves respecting the biophysical boundaries of the planet and reducing current global consumption rates to match the biophysical capacity to produce ecosystem services and benefits. Promoting therefore sustainable consumption and production patterns are necessary to make the transition to a greener and socially inclusive global economy. It is easy to think, then, that the circular economy is one of today's suitable sustainable economic models, in which products and materials are designed so that they can be reused, remanufactured, recycled or recovered and thus kept in the economy for as long as possible, along with the resources from which they are made, and the generation of waste, particularly hazardous waste, is prevented or minimized, and greenhouse gas emissions are prevented or reduced (United Nations, n.d.). Improved management of natural resources is necessary to address the trend of increasing global population, which could reach 9.7 billion people in 2050 (United Nations, 2015).

↘ Innovation in plastics field

In order to mitigate the impact of plastic waste on the greenhouse effect and reduce its spread in the environment, several innovative practices have been implemented to achieve three main objectives. The three macro-themes identified concern the prevention and recycling of plastic waste, the conversion and disposal of plastic waste and the elimination of plastic leakage into the natural environment, and the transition from fossil-based to biobased raw materials in order to limit the emission of greenhouse gases.

- Plastic waste prevention and recycling: aims to reduce the production of new plastics and the generation of plastic waste through the adoption of practices and policies that promote the responsible use of plastics and the implementation of effective recycling systems. This approach aims to limit the accumulation of plastic waste in the environment, thereby mitigating the impact on climate change.

- Conversion and disposal of plastic waste, play a crucial role in combating the dispersion of plastic into the natural environment. Innovative practices such as advanced recycling, energy recovery and the use of advanced processing technologies help reduce the amount of plastic waste going to landfills and

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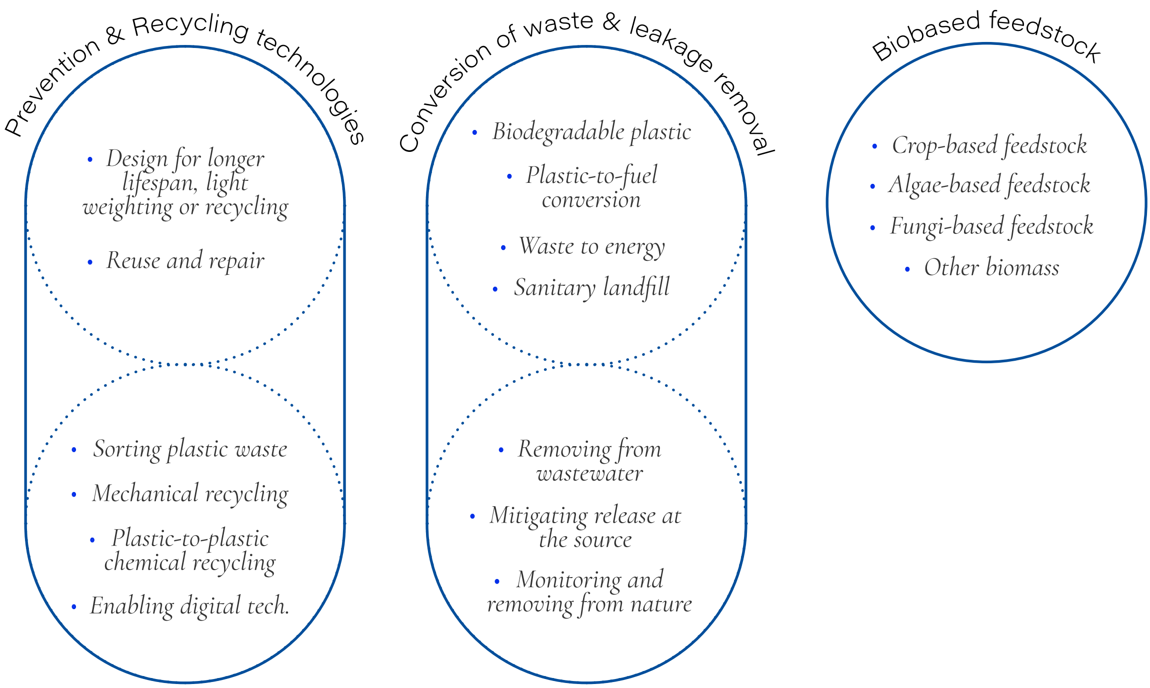
Source: Dussaux, D., & Agrawala, S. (2022). Quantifying environmentally relevant and circular plastic innovation: Historical trends, current landscape and the role of policy.

incinerators, limiting greenhouse gas emissions associated with these processes.

- Transitioning from fossil-based to biobased raw materials is an important strategy for reducing greenhouse gas emissions associated with plastics production. The use of materials from renewable sources, such as biomass and bioplastics, can help reduce the environmental and climate impact of plastics while promoting greater sustainability and less dependence on nonrenewable resources.

In summary, implementing innovative practices aimed at plastic waste prevention and recycling, responsible conversion and disposal, and switching to biobased feedstocks are key strategies for reducing the greenhouse impact of plastic waste and preserving the natural environment for the benefit of future generations (Dussaux & Agrawala, 2022).



↘ New sustainable horizons

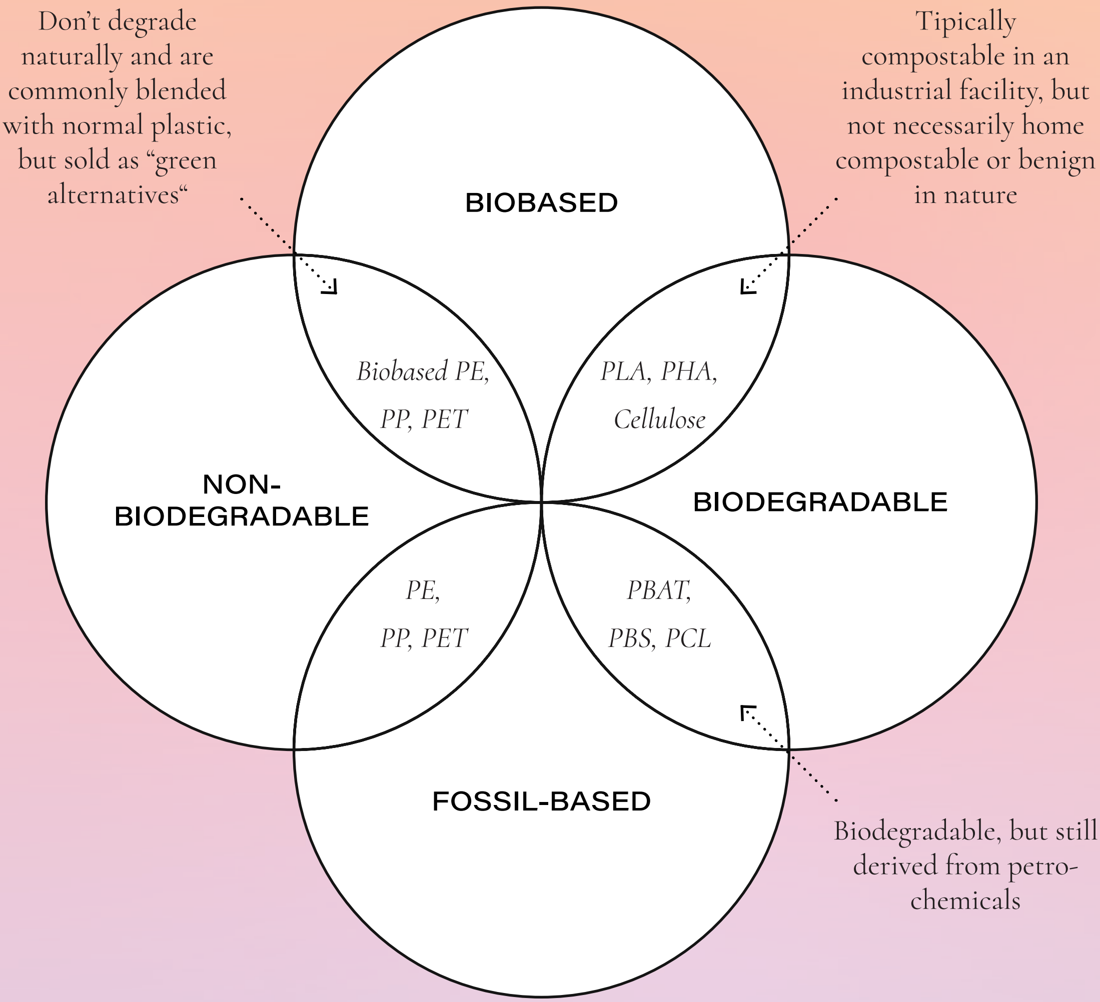
In the framework of public concern for environmental pollution, depletion of oil resources and pollution of aquatic ecosystems due to petroleum-based plastics (Venâncio et al., 2022), new materials are being searched to replace conventional plastics. Thus emerges the need for alternatives with greater ecological potential: bio-based materials, as a more sustainable alternative to conventional petroleum-based plastics that can reduce pollution from both the production and the disposal processes (Ghernaout & Elboughdiri, 2021). The estimations say that the research sector of bioplastics will take a leading position offering an increasing variety of bioplastics.

The attractiveness of bioplastics as alternatives to petroleum-based plastics depends on their ability to meet environmental and economic objectives, such as:

- Use of renewable resources, reducing dependence on fossil resources for plastics production.

- Reduced greenhouse gas emissions throughout the life cycle compared to petroleum-derived plastics, promoting more sustainable industrial production.

- Better recovery and recycling options compared to petroleum



Don't degrade naturally and are commonly blended with normal plastic, but sold as "green alternatives"
Tipically compostable in an industrial facility, but not necessarily home compostable or benign in nature
BIOBASED
Biobased PE, PP, PET
PLA, PHA, Cellulose
NON-BIODEGRADABLE
BIODEGRADABLE
PE, PP, PET
PBAT, PBS, PCL
FOSSIL-BASED
Biodegradable, but still derived from petro-chemicals

plastics, due to the high biodegradability or compostability of bioplastics.

- Opportunities to develop new eco-efficient products and applications based on biological materials, increasing industrial competitiveness.

- Greater job creation potential than biofuels, contributing to economic growth.

In 2019, 45% of global bioplastics production was accounted for by Asia, followed by Europe with 25%, (total = 2.11 million tons) (European Bioplastics, 2019). Main applications of these materials were in the flexible and rigid packaging market, followed by agriculture/horticulture and coatings (European Commission., 2019). Until 2021, the production of bioplastics was more than 1.3 million tons per year (European Commission Directorate-General for Environment, 2011), with a six-fold increase in the period between 2016 and 2021 (European Commission., 2019).

Biomaterials, or bio-based materials, are derived partially or entirely from biomass and they are not made from fossil-derived components. They are obtained through processes and technologies that enable the use of biomass in new fields of application (Genovesi & Pellizzari, 2017).
They are renewable, biodegradable and/or compostable materials. They allow the use of low-energy production methods and the application of alternative waste management strategies, such as biodegradation, and this characteristic makes them potential candidates to replace petroleum-based plastics (Verma & Fortunati, 2019). In addition, they follow the principles of the circular economy, considering at the design stage all the environmental impacts they may have during their life cycle, production and disposal.

Specifically, bioplastic, as defined by European Bioplastics, is a biobased polymer derived from organic biomass sources that can be biodegradable or bio-based, or both. It can be derived from biomass and not be biodegradable, such as bio-PE, bio-PP, or bio-PET; it can be derived from non-renewable raw materials and it can be yet biodegradable such as PBAT, PCL, PBS; or it can be derived from biomass and it can be biodegradable such as PLA, PHA, or starch-based plastics. Today there is a wide range of polymers available made from different types of natural products, such as sugar cane, potato or corn starch, cellulose, straw, and cotton. Currently two of the most important bioplastics in the market are PLA and Mater-bi®, the derivative of starch, vegetable oils or combination of both (also known as starch blends, like Mater-bi® bags) (Venâncio et al., 2022).

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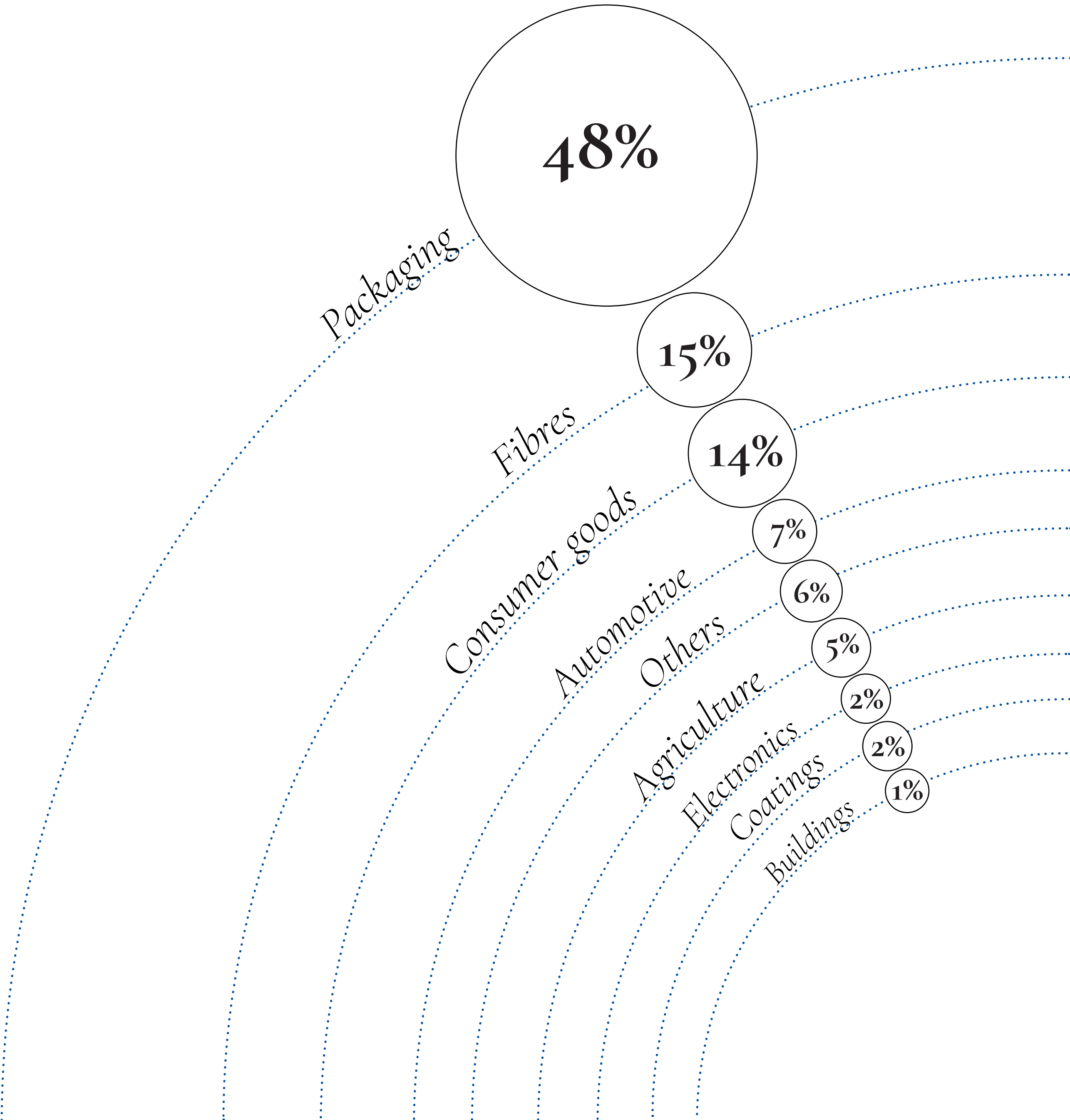
Source: European Bioplastics, nova-Institute (2022)

Global production capacities of bioplastics in 2022



↘ Advantages of bioplastics

Biobased plastics play a significant role in reducing dependence on limited fossil resources and, as a result, can make a significant contribution to the European Union in meeting its greenhouse gas emission reduction targets.
Bioplastics have several advantages over petroleum plastics: unlike petroleum-derived plastics, those derived from renewable biological sources such as plants, bacterial and algal sources can be degraded by microorganisms in the soil, such as fungi or bacteria, without releasing any pollutants. In addition, the well-being of the environment is often maintained by using renewable sources during the production process of these materials: they contain no chemicals and are therefore not considered toxic.
In terms of sustainability, they are easier to recycle, require less production energy, and are renewable and environmentally friendly (Thiruchelvi et al., 2021b). The production of such plastics reduces dependence on nonrenewable fossil resources, enabling a decrease in greenhouse gas emissions associated with the extraction, transportation, and processing of such materials. In addition, the use of renewable sources for plastics production helps mitigate the negative environmental impacts of fossil fuel production, including the extraction of raw materials and the emission of air pollutants. More over, the biodegradability feature offers an additional option for product disposal, enabling a significant reduction in waste volume. Biodegradable plastics hold considerable potential to promote "closing the loop" and increase resource efficiency. Depending on their end-of-life, this can

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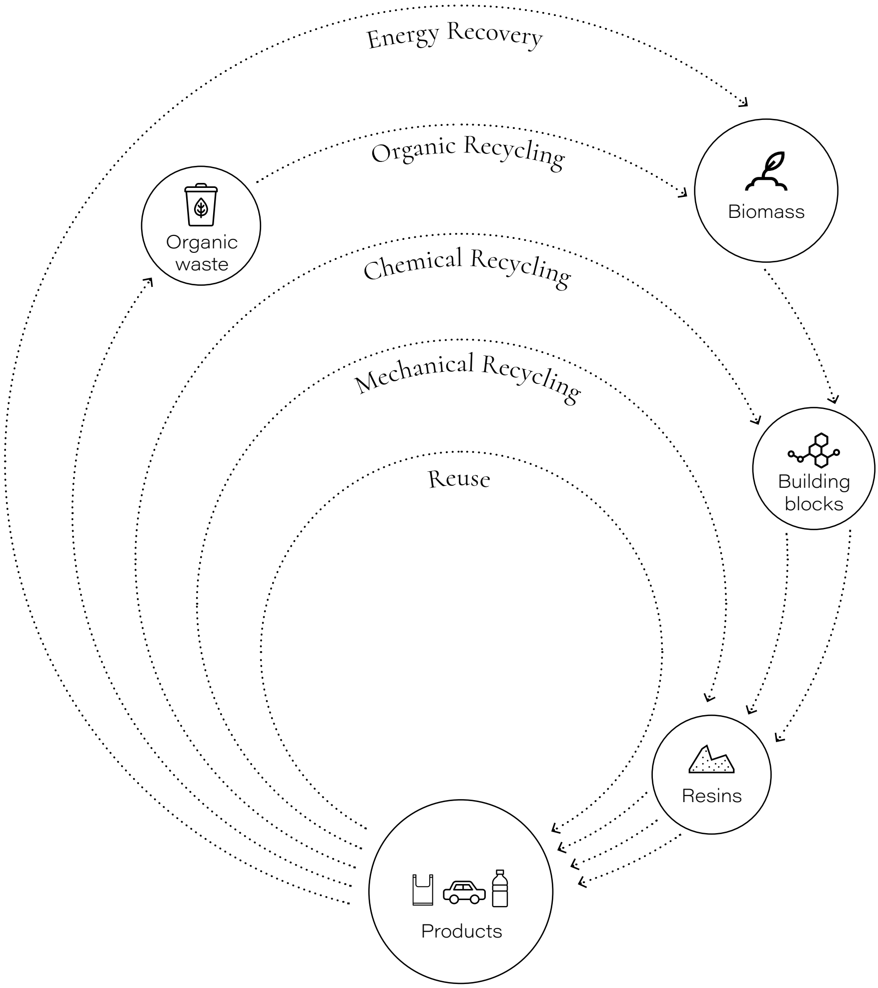
Source: Thiruchelvi, R., Das, A., & Sikdar, E. (2021b). Bioplastics as better alternative to petro plastic. Materials Today: Proceedings, 37, 1634–1639. https://doi.org/10.1016/j.matpr.2020.07.176



The waste hierarchy in the EU prioritizes **reuse** over recycling and emphasizes the importance of considering reuse as the first option. Biobased plastics present numerous opportunities for the creation of reusable products, aligning with this hierarchy.

Mechanical recycling recovers waste biobased plastics using mechanical methods, without changing their chemical composition. This approach enables the production of reusable resins.

Chemical recycling 's aim is to convert waste biobased plastics into valuable feedstock that can be used to create secondary raw materials of equal quality to virgin materials.

Organic recycling involves industrial composting and anaerobic digestion. Compostable plastics help divert organic waste from landfills and incineration, facilitating the production of high-quality compost.

Energy recovery is an alternative approach for the disposal of biobased and/or biodegradable materials. It involves the controlled incineration of these materials to unlock their energy content, thereby generating renewable energy.

result in the following benefits:

- Use of renewable resources to produce durable biobased products that can be reused, mechanically recycled, or incinerated to generate renewable energy. This approach promotes the circular economy, in which resources are used efficiently and optimized to reduce dependence on virgin raw materials and minimize environmental impacts from the production of new materials.

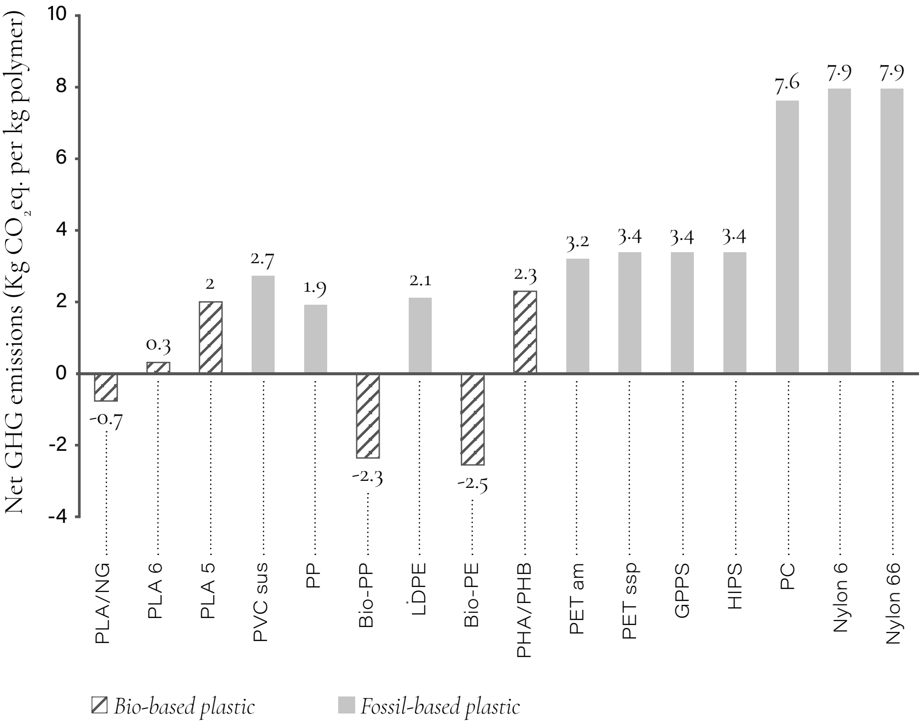
- Use of renewable resources to produce biobased, biodegradable and compostable products that can be subjected to organic recycling, such as industrial composting or anaerobic digestion, at the end of the product's life cycle (subject to appropriate certification). During this process, valuable biomass (humus) is generated, which can be used to grow new plants, thus completing the cycle. This approach takes advantage of the biodegradable properties of plastics to turn them into useful resources, contributing to resource efficiency and waste reduction.

The adoption of biobased biodegradable and compostable plastics, integrated with appropriate waste management systems, can provide numerous environmental benefits. It contributes to the reduction of long-term plastic waste accumulation, encourages the production of renewable energy, and promotes the sustainable use of renewable resources. In addition, the organic recycling of biodegradable plastics and the resulting production of quality humus is an important source of support for soil fertility and the promotion of plant growth.
In terms of climate change, on the other hand, bio-based materials have lower impacts than conventional materials, but greenhouse gas emissions related to land use change, eutrophication, and ozone depletion, which in the case of biomaterials can have significant environmental impacts, must also be considered in the Life Cycle Assessment. During the creation of new biomaterials, it is therefore important to analyze environmental performances and any alterations on the environment (L'utilizzo Dei Biomateriali in Economia Circolare, n.d.).

↘ GHG emissions

Bio-based materials are also considered carbon neutral: their production process is more environmentally friendly, because plants grown to produce the plastic remove as much carbon dioxide from the atmosphere as is released during the production process (European Bioplastics, n.d.). Bioplastics do not produce a net increase in greenhouse gases when they decompose because the plants used to produce the bioplastic have absorbed greenhouse gases as they grow (European Bioplastics, n.d.). In general, fewer greenhouse gas (GHG) emissions are produced, compared to the production of plastics materials, which also meets the much-desired zero-carbon goals, a priority set by many national and international agendas/legislation (Venâncio et al., 2022).
Comparing GHG emissions generated during the production of biodegradable plastics and petroleum-based plastics; the data revealed that the production of bioplastics emitted between 20% and 45% less GHG than petroleum-based plastics (PE and PET were considered in this case) (Piemonte, 2011).
In general, GHG emissions tend to be higher for fossil-based polymers, while those associated with bio-based polymers have smaller negative and positive values. It is important to note, however, that the estimates shown in the figure do not include the entire life cycle (cradle to grave) and therefore do not include impacts associated with the use, recycling, and disposal phases.

Renewably sourced plastics can therefore reduce carbon dioxide emissions and



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Source: OECD based on various: Jamshidian et al., 2010; Smith, 2010; Tullo, 2010; Gerngross, 1999; Harding et al., 2007; and Kurdikar et al., 2001). The green bars indicate biopolymers; the blue petro-based polymers.

potentially act as a carbon sink during their life cycle. Plant resources used to make bio-based plastics capture carbon dioxide from the atmosphere as they grow, and this carbon is then harnessed to make the polymer. The carbon footprint of PE, for example, was found to be -2.2 CO_2e per kilogram of bio-based PE produced compared to 1.8 CO_2e per kilogram of fossil-based PE produced (World Economic Forum, 2016).

The potential for complete degradation under natural end-of-life conditions is one of the main reasons why bioplastics are very attractive . A high degree of biodegradability is, in fact, one of the criteria in the definition of a bioplastic, and is described in the European standard EN 13432, which is linked to the European Directive on Packaging and Packaging Waste (94/62/EC) (Venâncio et al., 2022). These criteria require the plastic to disintegrate within 12 weeks and be completely biodegraded within 6 months, which corresponds to a 90% (or more) conversion of the plastic material to carbon dioxide. However, such high degrees of degradability appear to be achieved only under optimal industrial or laboratory conditions (e.g., pH, temperature or humidity) (Emadian et al., 2017).

The literature states that the rate of degradability depends on the environment in which the material degrades, depending on the abiotic and biotic characteristics of each location, but also on the type of bioplastic, the base material, and its characteristics such as thickness, stiffness (Ruggero et al., 2021), and the structure. Regarding degradation, the entire process of bioplastics requires the assistance of water and oxygen, as with starch-based polymers. By absorbing water from the environment, bioplastics swell when they are buried in the soil, the breakdown of the plastic into fragments is thus caused, which can be easily decomposed by microorganisms (Licciardello & Piergiovanni, 2020). Finally, in soils containing degraded biopolymers, a greater abundance of microorganisms has been presented than in bare soil (Ma & Ma, 2016), this will have a positive impact on plant growth and soil quality, as they facilitate the decomposition of organic matter and nitrogen mineralization in the soil (de Vries et al., 2006).

It should be emphasized that many degradability studies are essential and still ongoing so as to establish the characteristics to be able to achieve total degradation of materials even and especially under realistic conditions (Chamas et al., 2020).

↘ Bioplastic's problems

Furthermore, it becomes clear that joint efforts between industry and materials science research must be a priority to prevent the substantial accumulation (and potential effects) of plastics in the environment. Bio-based bioplastics are derived from agricultural raw materials such as sugarcane, corn, or potatoes. These raw materials are cultivated in monoculture systems using highly industrialized agriculture methods, often involving the use of pesticides. Unfortunately, this intensive agricultural approach has significant consequences for both the environment and human health. While these bioplastics are marketed as "green" alternatives, the processes involved in their production still have substantial environmental impacts. The agricultural raw materials undergo conversion into chemical components, which are then utilized in production processes similar to those used for conventional plastics, typically in large-scale industrial facilities.

As of 2017, biobased plastics accounted for merely 1% of the total plastic production capacity (Lauwigi, 2019). Furthermore, a mere 0.02% of global agricultural land is currently allocated for the cultivation of plants used in the production of bioplastics. However, it is expected that this percentage will experience rapid growth in the coming years, thereby increasing the strain on existing cultivated areas. Consequently, it is crucial to recognize that expanding agricultural cultivation for the purpose of producing environmentally friendly plastics is not a viable solution.

The cost associated with the production of biobased polymers holds substantial significance in the context of their market viability. The production costs exhibit considerable variation depending on the chosen base material. For instance, the utilization of bacteria and yeast in the production of polyhydroxyalkanoates (PHAs) incurs elevated expenses due to the fermentation process, which relies on external factors such as electricity. Conversely, plant-based bioplastics appear to possess greater environmental friendliness, as plant systems harness various natural resources like sunlight and atmospheric carbon dioxide (Raza et al., 2018). However, apart from production costs, there exist significant limitations concerning the large-scale application of biobased polymers. Furthermore, the comparatively low mechanical strength of these polymers necessitates the exploration of blends, often involving conventional plastics (de Matos Costa et al., 2020). These approaches demand meticulous equilibrium to avert cost escalation and/or augmented carbon emissions.
Additionally, considering that the end users of these products are consumers, the final cost undeniably impacts the decision-making process when opting for environmentally friendly products (Soares et al., 2021).

Biodegradable plastics are specifically designed to undergo degradation by microorganisms under specific conditions. These plastics find application in various products, such as compostable rubbish bags, food packaging such as yoghurt containers, take-away coffee cups and fast food trays.
The compostability of these items is certified by an international label.
Unfortunately, the reality differs significantly from the intended concept. According to the test criteria of the label, the plastic should be 90% degraded after 12 weeks at 60 degrees Celsius (Lauwigi, 2019). However, most composting plants only allow waste to decompose for four weeks, as extending this period is not economically feasible. As a result, only water, carbon dioxide and mineral additives remain at the end of the process, without the humus-forming material. Furthermore, the heat generated during the process cannot be used for subsequent recycling, necessitating further energy generation for the production of future plastic products. Technically speaking, this process does not involve actual composting, but rather simple waste disposal.
In practice, a significant proportion of European biodegradable plastics currently end up in incinerators. A common argument used to support the adoption of biobased and biodegradable plastics is that, considering their entire life cycle, they have a lower climate impact than conventionally produced plastics. However, this claim is undermined by the negative effects of conventional cultivation for the production of biobased plastics, such as severe acidification and over-fertilisation of soil and water. Furthermore, life cycle assessments of these plastics do not take into account direct and indirect changes in land use or the potential impacts of the use of genetically modified crops. The consequences for biodiversity in regions engaged in the production of crops for 'biobased plastics' have not been adequately studied to date.

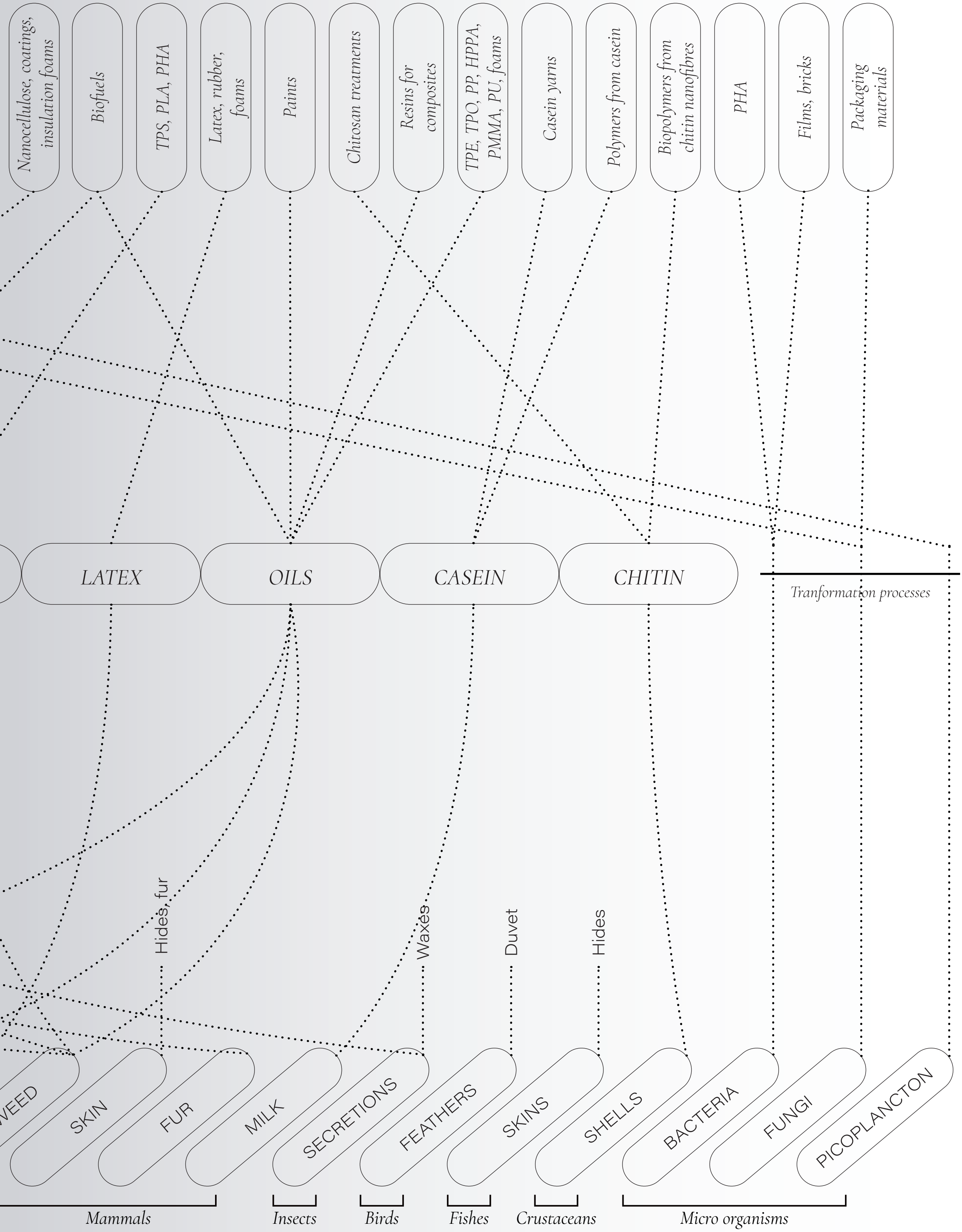
↓
Following pages
Source: Genovesi, E., Pellizzari, A. (2017). Neomateriali nell'economia circolare.

Biodegradable: material which can naturally break down and decompose over time by microorganisms such as bacteria or fungi into simpler substances like water, carbon dioxide, and biomass. However, the speed and conditions of biodegradation may vary depending on the material and the environment in which it is disposed.

Compostable: amaterial which, in addition to being biodegradable, can be transformed into compost through a controlled composting process. Composting converts organic matter into a nutrient-rich material called compost, which can be used as fertilizer for the soil. Compostable materials typically require specific conditions, such as the right combination of moisture, temperature, and oxygen, to fully degrade.

Recyclable: a material that can be recovered and transformed into a new product or material through recycling. This process involves collecting, separating, and treating used materials to make them suitable for use as raw materials in the production of new products. However, the recyclability of a material depends on the availability of appropriate recycling infrastructure and the ability to efficiently separate and treat the material.

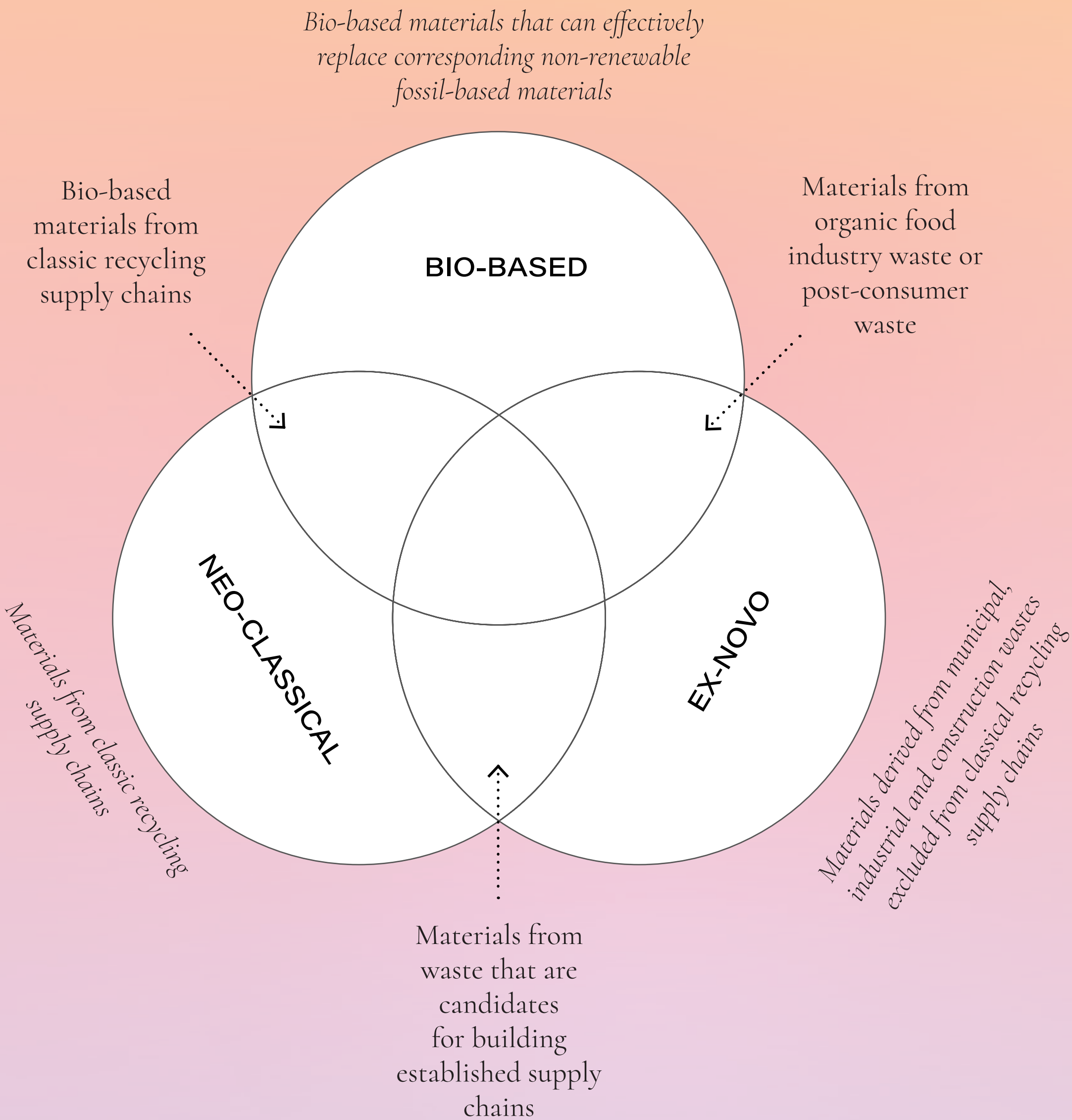
Chipboard, plywood, MDF
Composite fibres
WPC, other biopolymers
Filler for plastics and WPC
Fillers for plastics and concrete
Mat and fabrics for composites
Traditional paper
Bamboo, rice and algae paper
Insulation, padding, coatings
Cotton, linen, hemp, wool, silk, jute
Viscose, cellulose yarns
bioPE, bioPET, PHA, PHB
Coatings
Celluloid, cellophane, others
Chips, sawdust
LIGNIN
FIBRES
CELLULOSE
SUGARS
STARCHES
Timber, planks
Reeds, planks, sheets
TREES
WOOD
BAMBOO
HEMP
HERBAL PLANTS
MALVACEAE
CEREALS
TUBERS
SUGAR CANE, BEET
OILSEED PLANTS
LATEX PLANTS
Plants
Seaweed


Nanocellulose, coatings, insulation foams
Biofuels
TPS, PLA, PHA
Latex, rubber, foams
Paints
Chitosan treatments
Resins for composites
TPE, TPO, PP, HPPA, PMMA, PU, foams
Casein yarns
Polymers from casein
Biopolymers from chitin nanofibres
PHA
Films, bricks
Packaging materials
LATEX
OILS
CASEIN
CHITIN
Tranformation processes
Hides, fur
Waxes
Duvet
Hides
WEED
SKIN
FUR
MILK
SECRETIONS
FEATHERS
SKINS
SHELLS
BACTERIA
FUNGI
PICOPLANCTON
Mammals
Insects
Birds
Fishes
Crustaceans
Micro organisms

↘ Neomaterials

Materials occupy a key role within the production cycle, so a rethinking of their compositions and production processes as well has been deemed necessary with the support of new technologies, creativity and design. Since the 1960s the focus has been on the reuse of raw materials, in the 1980s the focus was mostly on achieving production efficiency, while today, thanks to the systems approach, the material is seen as a single element of the production and consumption process, which must be redesigned from the beginning (Pellizzari & Genovesi, 2021).

Thus, so-called neo-materials are born, produced through the use of renewable sources, with high regenerative power and transformed according to resource conservation perspective. Neomaterials thus identify the category to which bio-based materials, ex novo materials, and neo-classical materials belong.


Bio-based materials that can effectively replace corresponding non-renewable fossil-based materials
Bio-based materials from classic recycling supply chains
BIO-BASED
Materials from organic food industry waste or post-consumer waste
NEO-CLASSICAL
EX-NOVO
Materials from classic recycling supply chains
Materials derived from municipal, industrial and construction wastes excluded from classical recycling supply chains
Materials from waste that are candidates for building established supply chains

Bio-based

BIO-BASED are materials of plant or biological origin consisting of renewable components, these are biopolymers or materials obtained from the cultivation of fungi and mycelium or elements derived from tall trees such as wood and cellulose, the basic component of paper, bamboo, cotton plant, hemp and flax, but also local and domestic plants, such as different grains. Just as in the animal world we can talk about wool, silk, horn, bone, hides etc.
They are defined by the Ellen McArthur Foundation as those raw materials that can return to the earth once their life cycle is over. They also have a nearly neutral carbon footprint because during their lifetime they absorb an amount of CO_2 equal to that released into the atmosphere at the end of their life (European Bioplastics, n.d.).

Ex-novo

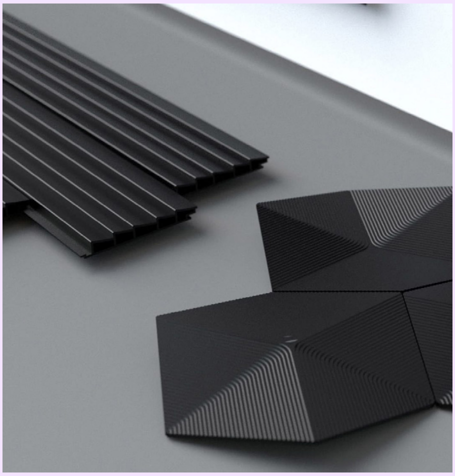
On the opposite, EX-NOVO materials are all those materials derived from industrial processing waste. What used to be considered waste is re-inserted into processing chains and considered as new virgin raw material.

Neo-classical

Finally, NEO-CLASSICAL materials are those materials belonging to already established recycling supply chains. The raw material then results from an already discarded material that has, however, undergone a recycling process, such as recycled plastic.

Of course, differentiation is not always so simple and sometimes it is difficult to characterize a material within one of the three categories, there are in fact some "hybrid" materials belonging to the intersection of one category with the other.

Made by air
Material consisting of 90% atmospheric CO_2
Made of air
2016



Artichair
Shell chair made of thistle and resin natural
Spyros Kizis
2013

Sweatshirt made of PET from recycled bottle
UNIQLO
2020

“IN NATURE THERE IS
NO CONCEPT OF **WASTE**.
EVERYTHING IS FOOD
FOR SOMETHING ELSE- A
LEAF THAT FALLS FROM A
TREE FEEDS THE FOREST.
INSTEAD OF SIMPLY TRYING
TO DO LESS HARM, WE
SHOULD AIM TO DO **GOOD**.
BY RETURNING VALUABLE
NUTRIENTS TO THE SOIL
AND OTHER ECOSYSTEMS, WE
CAN **ENHANCE** OUR NATURAL
RESOURCES.”

Ellen Mccarthur Foundation

_ CIRCULAR ECONOMY AND SYSTEMIC APPROACH

↘ A sustainable approach

Research has focused on bioplastics as a potential direction toward sustainable products with reduced environmental impact (Talan et al., 2022) , which currently account for about 1% of the more than 390 million tons of plastic produced annually (European Bioplastics, 2019).
In particular, today's society needs biobased materials in which renewable resources and waste streams are used as new resources, the most appropriate approach is therefore circular economy.
While recent studies have highlighted the insufficiency of our current resource management practices (Circle Economy, 2022) and the unsustainability of linear growth models on a finite planet (Elhacham et al., 2020), the concept of a circular economy (CE) has emphasized the crucial significance of materials in facilitating an ecological transition.
According to the Ellen MacArthur Foundation, the circular economy is "restorative and regenerative and aims to maintain products, components and materials at their maximum utility and value at all times." With this definition in mind, bioplastics fit into this new economic concept as they help move away from the linear economy characterized by "make, use, dispose", which is not in line with resource restriction posed on society today, in favor of a more circular model based on "make, use, reuse, recycle" (Benetto et al., 2018). The circular economy is therefore an effective response to address this complex problem of pollution, interconnected then to problems of global warming, water quality, limited energy

→ *Source: European Bioplastics, nova-Institute (2022)*

Distribution of the global bioplastics production in 2022

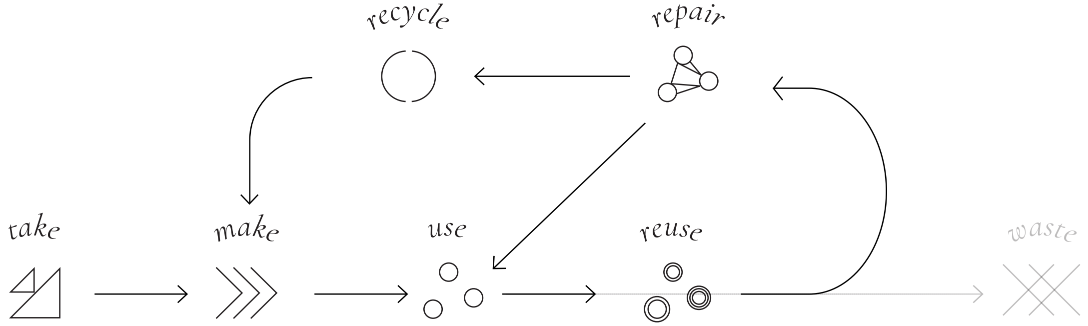
supplies and environmental conservation. Walter Stahel defines the concept of the circular economy as a rethinking within the traditional economy, seeking to recast and restructure it with the intention of making it more efficient. Stahel also defines it differently efficient and at the same time sufficient, sustainable, innovative and performing.

Circular economy benefits are not only in economic terms but also ecological and social, aiming to achieve a system in which we do not talk about waste but about resources to be reused in circular way in production cycles (Stahel, 2019). In fact, this sustainable model reduces the use of natural resources and the growth of waste, thereby also reducing carbon emissions into the atmosphere. More generally, the circular (or systemic) approach differs from the linear economy in that it seeks to rethink the linearity of the "extract-produce-sell-consume-dispose" process, in circular terms, envisaging a shift towards creating value from waste, based on the 3Rs of the circular economy: reduce, reuse and recycle (Bonaccorso & Baños Ruiz, 2019).

The two economic models are not to be seen in opposition but are to be rethought, to make the production phase complementary to the use and especially the reuse of things and resources, reducing waste and seeking to retain the value of products for as long as possible (Scarpellini et al., 2019), increasing waste recovery and eventually creating industrial symbiosis between complementary production chains (Elllen McArthur Foundation, 2016). In the linear model, moreover, materials and componenets are generally thrown away as waste after use (Walzberg et al., 2021) while, according to the principles of the circular economy, these are continuously recycled and reused according to a strategy of reducing, reusing and refurbishing waste, having as its ultimate goal to solve the problem given by a high demand for raw materials against resource scarcity. Therefore, the linear economy is no longer suitable as our environment is reaching its limit to cope with our waste disposal.
In contrast to the pre-industrial era, when the circular economy was a necessity, based on the lack of resources, today we talk about a circular economy of abundance, which, for that very reason, requires an "extra motivation" that knows how to push people to want something that one is not inclined to feel is appropriate. The circular economy also represents not only an attempt to solve the downstream waste problem, but to consider the upstream issue, thus considering production methods but also designing the end of life of a product; in fact, most environmental issues should be addressed in the decisions made at the design stage (Thackara, 2005).

This is implemented through systemic design, which in fact studies production processes, with the aim of transforming the outputs of one process into inputs, as resources for a second activity, creating closed loops of products, product parts, and materials within the boundaries of environmental protection and


take
make
use
waste


recycle
repair
take
make
use
reuse
waste

socioeconomic benefits. The aim is therefore to tend to zero emissions, reduce the amount of waste and the environmental impact of production, following the principles of nature.
The assumption of the circular economy is to follow a certain hierarchy in which the priority is to prevent waste generation at the product design stage, minimise the consumption of materials and energy during production and use processes, avoid the use of substances that are potentially dangerous for the consumer and the environment, and subsequently to change the way products are manufactured and after their use to give them "another life" as a result of repair or re-use (Dziuba et al., 2021). Waste thus is no longer considered just a burden to be disposed of but becomes an asset to be sold, so, as mentioned earlier, it is important to take care of all elements and all stages of the production process and not just the final product. Therefore, we can say that systemic design is inspired by design concepts of nature, which do not support the concept of waste (Pauli, 2015).
As a result, production systems become connected and dependent on each other, like a network, to form a system, where each element is indispensable to the well-being of the others and of the system itself. Moreover, the systems approach is closely based on the territory, because it activates a network of relationships among local productive activities, creating new design opportunities (Bistagnino, 2011). According to the Nova-Institut publication, "The Circular Bioeconomy - Concepts, Opportunities and Limitations" (2018) the circular economy is not complete without the bioeconomy and vice versa. The bioeconomy is based on the idea of implementing biological principles and processes in all sectors of the economy and replacing fossil-based raw materials with biobased resources and principles (Dietz et al., 2018).
Moreover, according to an OECD report, "The Bioeconomy to 2030: designing a policy agenda," the bioeconomy would have the capacity to provide a positive impetus to the industrial revolution through, for example, research in the field of renewable raw materials that can innovate the raw materials, energy production sectors to ensure environmental, economic and social sustainability. Replacing plastics with biopolymers is therefore in line with the assumptions of circular economy, allowing the reduction of substances hazardous for the consumer and the environment.

However, there are still many problems regarding biomaterial application, and there is actually a long way to go to completely solve all arising problems. Some of these are for example: the hygroscopic nature of the new materials, which leads them to absorb water, reducing their structural integrity, possible problems with existing equipment, initial higher costs for technologies if compared to traditional polymers, and performance problems related to limitations regarding some characteristics (e.g. mechanical, thermal) (Dang et al., 2022b).

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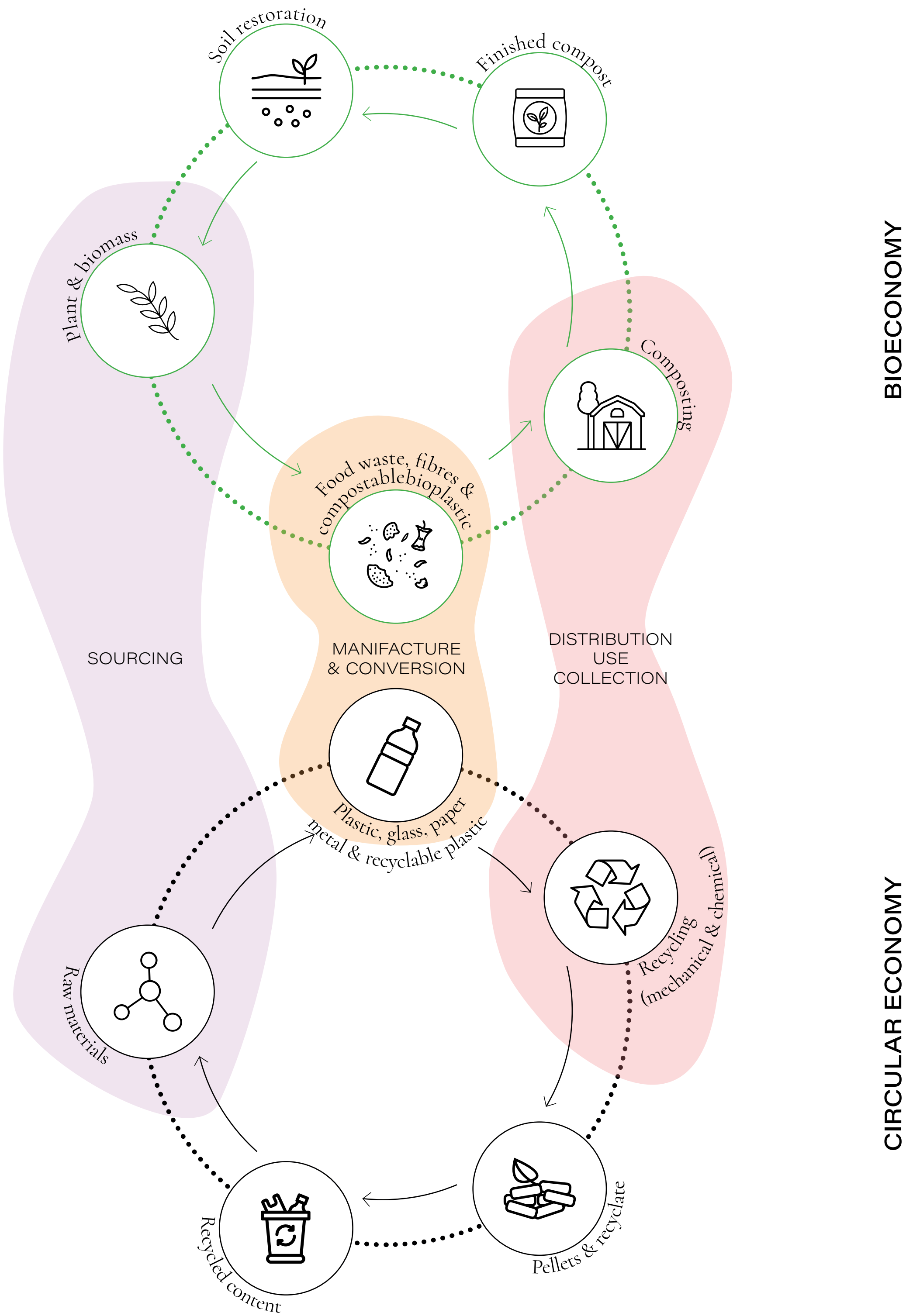
Source: https://sustainablepackaging.org/bioeconomy-and-circular-economy/


Soil restoration
Finished compost
Plant & biomass
Composting
Food waste, fibres & compostablebioplastic
SOURCING
MANIFACTURE
& CONVERSION
DISTRIBUTION
USE
COLLECTION
Plastic, glass, paper
metal & recyclable plastic
Recycling
(mechanical & chemical)
Raw materials
Pellets & recyclate
Recycled content
BIOECONOMY
CIRCULAR ECONOMY

“**DO-IT-YOURSELF** MATERIALS ARE CREATED THROUGH INDIVIDUAL OR COLLECTIVE **SELF-PRODUCTION EXPERIENCES**, OFTEN BY TECHNIQUES AND PROCESSES OF THE DESIGNER’S OWN INVENTION, AS A RESULT OF A PROCESS OF **TINKERING** WITH MATERIALS. THEY CAN BE NEW MATERIALS WITH CREATIVE USE OF OTHER SUBSTANCES AS MATERIAL INGREDIENTS, OR THEY CAN BE MODIFIED OR FURTHER DEVELOPED VERSIONS OF EXISTING MATERIALS.”

Rognoli, V., Bianchini, M., Maffei, S., Karana, E. (2015). DIY Materials. The Journal of Materials and Design, 86: 692-702. (S)

_ DIY MATERIALS

↘ Circular materials: an introduction

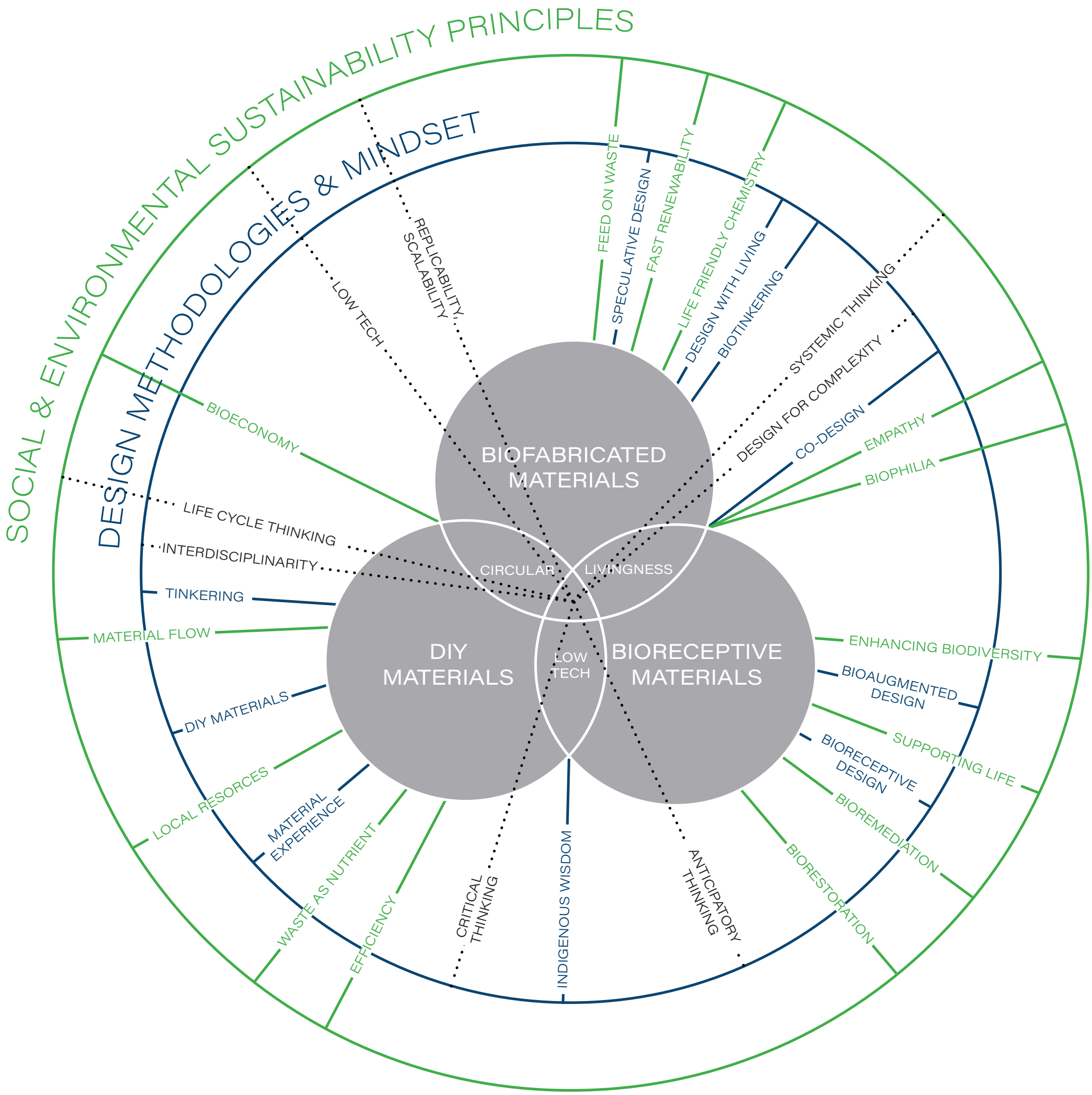
Over the past decade, there has been a significant increase in interest in the material aspect of our lifestyles and economies, a phenomenon that has also been seen in the field of design through a growing orientation towards the importance of materials.
Within the context of circular materials innovation, it is therefore appropriate to specify the different types of materials that can be made:

- Do-It-Yourself Materials are those materials that can be created or manipulated by individuals or small manufacturers using accessible tools and techniques. Such materials often encourage experimentation and customisation, allowing designers and makers to have more control over the properties and characteristics of the material itself.

- Biofabricated materials are synthesized or grown using biological processes, often involving living organisms or bioengineering techniques. They can possess specific properties or functionalities and are produced sustainably. Examples include bioengineered textiles, lab-grown leathers, and biodegradable plastics.

- Bio-receptive materials are designed to interact and integrate

→
Source: Pollini, B., & Jiménez Rodriguez, J. (2022). Teaching sustainability through materials: bridging circular materials and bio-design for new design curricula. In Education for Sustainability approaching SDG 4 and target 4.7 (pp. 125–151). Universidad Pontificia Bolivariana.


SOCIAL & ENVIRONMENTAL SUSTAINABILITY PRINCIPLES
DESIGN METHODOLOGIES & MINDSET
BIOFABRICATED MATERIALS
DIY MATERIALS
BIORECEPTIVE MATERIALS
CIRCULAR
LIVINGNESS
LOW TECH
FEED ON WASTE
SPECULATIVE DESIGN
FAST RENEWABILITY
LIFE FRIENDLY CHEMISTRY
DESIGN WITH LIVING
BIOTINKERING
SYSTEMIC THINKING
DESIGN FOR COMPLEXITY
CO-DESIGN
EMPATHY
BIOPHILIA
ENHANCING BIODIVERSITY
BIOAUGMENTED DESIGN
SUPPORTING LIFE
BIORECEPTIVE DESIGN
BIOREMEDIATION
BIORESTORATION
ANTICIPATORY THINKING
INDIGENOUS WISDOM
CRITICAL THINKING
EFFICIENCY
WASTE AS NUTRIENT
MATERIAL EXPERIENCE
LOCAL RESORCES
DIY MATERIALS
MATERIAL FLOW
TINKERING
INTERDISCIPLINARITY
LIFE CYCLE THINKING
BIOECONOMY
LOW TECH
REPLICABILITY SCALABILITY

with living organisms or natural processes. They are specially developed in order to support or enhance ecological systems, such as by promoting plant growth, facilitating wildlife habitat or improving environmental sustainability. Bio-receptive materials are frequently used in applications such as green roofs, vertical gardens or ecological restoration projects.

Although all three concepts share an innovative approach to materials, they differ in their focus and objectives. Do-it-yourself materials focus on customised manufacturing, biofabricated materials leverage biological processes for the creation of materials, and bio-receptive materials aim at improvement and harmonisation with living systems.

↘ Self-made materials

DIY materials are seen as "Radical Matter" reimagined for a more sustainable future that use a new and holistic approach on their life cycle (Franklin & Till, 2019).
Do-It-Yourself (DIY) materials design is a phenomenon that contributes to the circular economy by harnessing household waste and organic binders. This phenomenon is expanding beyond products to include materials from which finished products are made (Brownell, 2015). DIY materials are of great interest for empowering communities and increasing self-sufficiency. They make it possible to experiment with local resources, develop transformation processes and design creative solutions according to the needs of the moment (Clèries et al., 2021).

The DIY (Do-It-Yourself) movement started with product design and then moved towards material design. This movement applies the concepts of reducing, recycling, and reusing materials when the useful life of the product ends. Do-it-yourself materials generate new experiences, promote sustainability and facilitate self-production. It is an active way of reacting to mass production and promoting knowledge development through action.
On the other hand, they reflect local identity as they are processed with raw materials, techniques and resources abundantly available in the territories where they are produced, reducing costs, encouraging recycling and strengthening ties with the community of origin. Indeed, the DIY movement follows the statement

Side and below
Eggshell and Flour biomaterial
© Ricchiuto Eloïse

"think globally, produce locally" (Gershenfeld, 2012). Self-production refers to a way of controlling production processes through experimentation and tinkering: creating a material in a "non-professional workshop" and transforming the material into a product in the same workshop. The importance of this approach in materials education has been widely recognised as it enables the development of intuitive solutions.
This type of materials responds to a trend that promote material design practice at the user level. They are usually the result of experimentation with individual or community self-production (Rognoli & Ayala Garcia, 2019). The emergence of do-it-yourself materials forces designers to prioritise the understanding of sources, material flow and the expressive and sensory potential of new materials derived from waste, thus facilitating their use in design applications. This production approach has brought a new dimension to the relationship between designers, production processes, and materials and combines craftsmanship and personal fabrication (Kuznetsov & Paulos, 2010). These are all those materials that deviate from industrial processes and they can be self-produced safely at home. They can be completely new materials or modified versions of existing materials (Rognoli et al., 2015). Their production processes and tools are usually low-tech and accessible, while their aesthetic characteristics can be associated with a very handcrafted and imperfect appearance, attributable to the uniqueness of performance that defines DIY processes.

Concerning the aesthetic dimension, DIY materials have imperfect aesthetic qualities that depend by the designer's handiwork and craftsmanship. These imperfections traces of humanity and at the same time they represent an added value of originality and customization. While on an emotional level DIY materials can generate "surprise" among those who come in contact with the materials itself (Rognoli et al., 2015).
Do-it-yourself material design and waste reuse come together in an experience of self-production of novel materials, toward new functionalities with an awareness of need to help generating product life cycles suitable for circular economy concepts (Wastling et al., 2018). In this sense, the material is not used once and then discarded, but enhanced through recycling or reuse. These emerging materials offer an opportunity to bring about positive social, environmental, economic and even political changes (Karana et al., 2018) thanks to many opportunities and benefits that the application of the circular economy concept can bring to a local's economy (Oncioiu et al., 2018).
For a do-it-yourself generation of materials, in which the raw material is based on waste recycling, all those units classified as waste are included, either in design or at the time of use, which become an appreciated source of resources. Their origin is very different, so it requires prior classification to be properly used in the generation of a new do-it-yourself material.
This is a new alternative to the traditional selection of materials from industry, as it gives designers autonomy from conception to self-production. In this way,

Above and side
Foamy Biplastic
© Sanskriti

designers embark on a new disciplinary and working path, creating meaningful experiences of singular materials, becoming a reference in innovation to generate their designs from a renewed material perspective.

Self-produced materials using waste contribute to the need to generate environmental awareness; and provide benefits due to the lower impact on the expense of producing highly technical materials, reducing the demand for energy to produce, as well as the emissions caused by the production and use of materials.

In the creation of DIY materials, design skills are influenced through "learning by doing" and "learning by interacting" processes.
Designers, consistent with the emergence of do-it-yourself materials, need to develop skills regarding waste recycling and the use of unconventional materials for self-production, while developing the skills to manage them. Designers usually develop appropriate skills through social innovation or the commercial level, hone their practical skills with production machines and tools and to develop a practice of tinkering with raw materials (and ingredients). This opens up new opportunities in the field of designers' work, giving rise to a potential impact on the discipline's professional performance from a sustainable perspective focused on new initiatives.
Lastly, DIY materials self-producers have a huge potential for failure. In fact, it is a trial-and-error process, mimicking the natural process of natural selection, where there are no negative effects, in economic or environmental terms, if the protocol does not work (Drucker, 2002).

Laboratory at the Polytechnic of Turin
image of the author

↘ Circular Material Designers as a solution

Designers experiment, test, retest and adjust products and production processes, drawing pleasure and inspiration from the "learning by doing" inherent in hands-on experimentation. Self-makers act as new artisans, but they do not deny all the recent and important technological developments that have influenced the world of materials.

A circular material designer can be defined as "a Designer trained to detect unused materials from technical or natural flows and transform them into circular materials by using their design aptitudes" (Rognoli & Parisi, 2021).
This profile has the potential to increase community sovereignty as well as create circular materials which can be used to generate circular self-made and local solutions. Circular material designers will produce new circular materials and develop their transformation processes, available for communities, which could be used to create solutions that address public concerns. Adopting the circular design approach means that the designer aligns his or her design with the principles of the circular economy, whereby: waste and pollution are designed out so as to be considered a resource, products and materials are repaired and regenerated so as to keep them in use, and natural systems are studied and regenerated.

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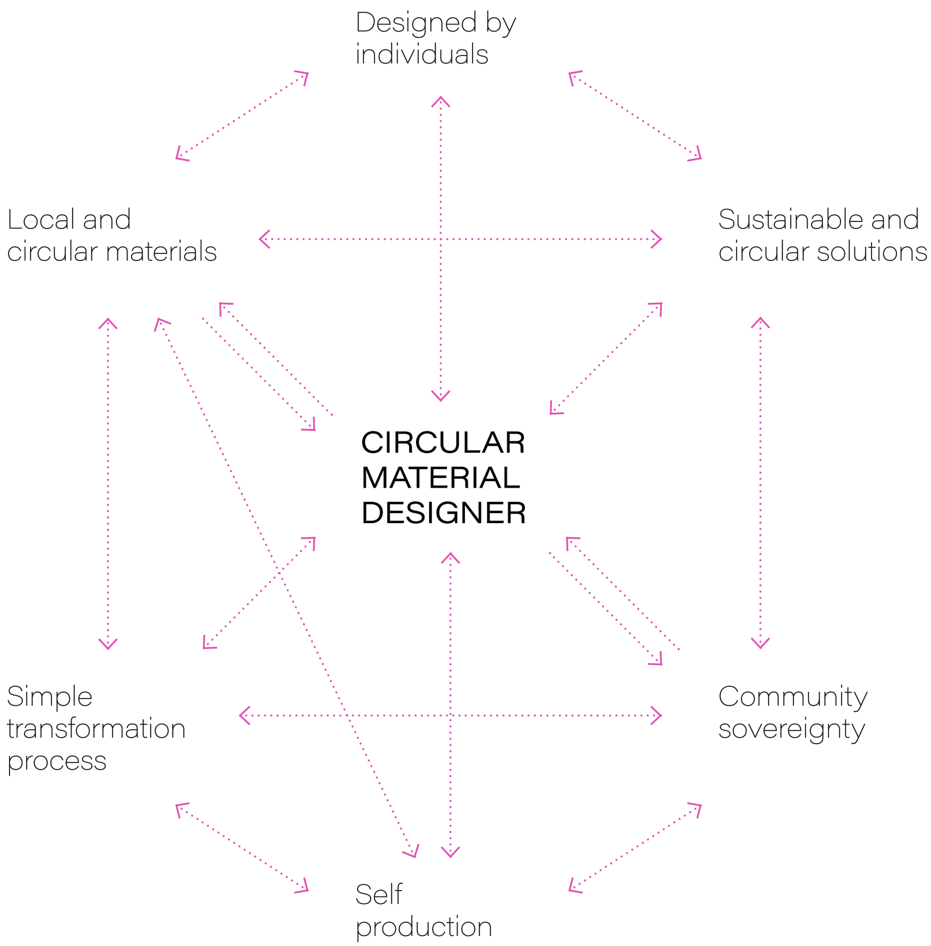
Source: MaDe project, co-funded by Creative Europe Programme of The European Union


Designed by individuals
Local and circular materials
Sustainable and circular solutions
CIRCULAR MATERIAL DESIGNER
Simple transformation process
Community sovereignty
Self production

↘ DIY materials classification: the five kingdoms

For the division of the kingdoms of self-produced materials, the starting resource, the species of matter involved at the beginning of the tinkering process that then leads to material invention, is taken into consideration. Specifically, five groups (Kingdom Vegetable, Kingdom Animale, Kingdom Lapideum, Kingdom Recuperavit and Kingdom Mutantis) were identified, each with its specific characteristics and properties (Ayala-Garcia et al., 2017).

In this thesis, elements belonging mostly to the plant world but also to the animal world have been used in a small part, based on scientific literature and the retrieval of several case studies.

Vegetable Kingdom

The Vegetable Kingdom is composed of do-it-yourself materials from plants or fungi. Materials belonging to this realm differ from the others because they are derived from agricultural processes. Designers who create materials belonging to this category collaborate with biologists or farmers, for example.

Animal Kingdom

The Animal Kingdom refers to all of those materials derived from animals and bacteria. They can be developed either by collaborating with living organisms or by using parts of the animals, like hair or bones.

Lapideum Kingdom

The Lapideum Kingdom includes do-it-yourself products created from minerals: stones, ceramics, sand, cement, etc. Another characteristic of this kingdom is its strong connection with handicrafts, perhaps because these types of materials have a long tradition in our culture.

Recuperavit Kingdom

The Recuperavit Kingdom includes all resources that society considers waste, but which have the potential to be transformed into valuable resources. They often come from plastics, from metal. Sometimes they are the waste products of industrial production.

Mutantis Kingdom

The Mutantis Kingdom consists of those materials obtained through technological hybridization processes in which the interactive aspect and mutant nature are brought to the forefront.

Formafantasma

Autarchy

Rotterdam, 2010

Vegetable Kingdom

Autarchy is a project from the studio Formafantasma based in the Netherlands. They developed a natural material in collaboration with a Baker. It is composed of flour, agricultural excess, and natural limestone. Also the color palette of the material comes from vegetables, spices and some roots that provide their natural dyes.
Autarchy was presented as an installation, which aims to express the statement of the possibility to elaborate products without producing any waste.

Billie Van Katwijk

Ventri

Amsterdam, 2010

Animale Kingdom

Ventri is a project that uses an everyday by-product of the meat industry: cow stomach. Ventri shows how something that is considered waste in many countries is given a new and higher value through the action of design. The studio worked alongside a tannery to develop a tanning process that would make the stomachs hygienic and safe to reuse. The project shows beauty in hidden and unexpected places, discovering new materials through a different look at what is already there.

Lex Pott

Transience x Transnatural

Rotterdam, 2015

Lapideum Kingdom

Over time, under the influence of oxygen and water, dark spots appear on the mirrors, the result of a slow process of oxidation of the silver layer. The project aims to show the beauty of this transition of silver, otherwise considered a degradation. Mirrors reveal the different states of oxidation. Sulfur is used to create an accelerated oxidation process. Depending on the time in which the silver reacts with the sulfur, different shades of color can be obtained, from gold to brown, from purple to blue. The states of the oxidation process are then represented in a geometric drawing.

Sebastian Aumer

Eggo

Germany, 2014

Recuperavit Kingdom

The "eggo!" stool uses recycled eggshell pieces. The furniture is completely compostable as it is made of casein, vinegar and starch. The egg shells were collected from local bakeries, otherwise they would have been considered a waste product. The product can be colored in multiple ways and has been accompanied by an extensive amount of experimentation and research, using at least 1,000 eggs per stool and baking them in a large oven for two hours to achieve a high enough bond in the material.

Jólan van der Wiel

Gravity Stool

Netherlands, 2012

Mutantis Kingdom

Jólan van der Wiel manipulated the natural phenomenon of gravity by harnessing its own power: magnetism. The positioning of the magnetic fields in the machine, opposing each other, largely determined the final shape of the Gravity Stool. It was the combination of the magnetic machine with the plastic material, developed specifically for this purpose, that allowed van der Wiel to start a small, but efficient, assembly line. The shapes and products are characterized by organic and whimsical profiles, typical of nature itself.

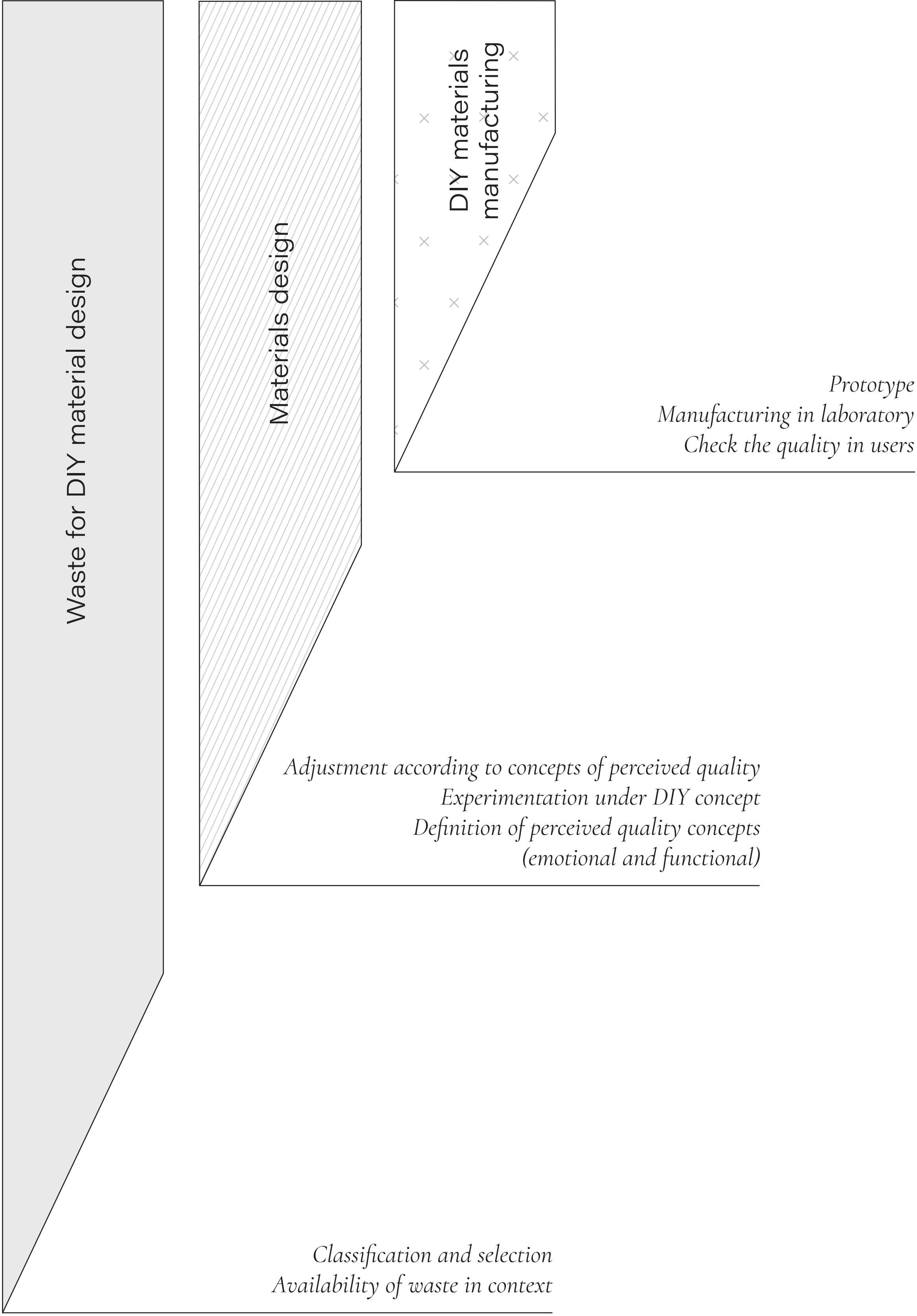
↘ DIY approach

The selection process of DIY-Materials lies somewhere between "natural" and "artificial". On the one hand, there is randomness, especially of the first experiments; on the other hand, there is intentionality in the initial choice of raw materials with which to experiment and the selection of precise characteristics to achieve. In DIY-Materials research, the designer implements variations on the starting ingredients, toward one of the best possible solutions (Rognoli et al., 2015).

During the experimental phase, material development is based on choices according to the data collected. The first data concern a rough assessment of the quality of the obtained samples: regularity of shape (with edges of the desired shape, relatively constant thicknesses, no detachment of fragments), solidity of the sample (such as to allow simple mechanical operations of cutting/refinishing/bending), durability over time (without mold formation and with uniform drying on the surfaces). Through a categorization of the collected data, the designer will go on to more or less modify the starting recipe, narrowing it down to good solutions.

The invention process can thus be defined as an advancement process, based on repetition of recipes and considering the error as important as the positive result, because both are data that will be collected and analyzed for later stages of material testing. Variation is thus the mechanism for the pursuit of perfection.

→
Source: Alarcón, J., Palma, M., Navarrete, L., Hernández, G., & Llorens, A. (2019). Educating on circular economy and DIY materials: How to introduce these concepts in primary school students? 10083–10088. https://doi.org/10.21125/edulearn.2019.2523


DIY materials manufacturing
Prototype
Manufacturing in laboratory
Check the quality in users
Materials design
Adjustment according to concepts of perceived quality
Experimentation under DIY concept
Definition of perceived quality concepts
(emotional and functional)
Waste for DIY material design
Classification and selection
Availability of waste in context

The narrative of the invention process often becomes more important than the invention itself, and error can often lead to the discovery of new results and materials not expected at the beginning of experimentation. It is important, therefore, to evaluate all the results obtained.

One process that contributes to the operational knowledge of the material and its evaluation is "material tinkering," which consists of a series of operational steps of evolution from an initial recipe and procedure to a possible discovery of new materials. It aims to extract data, to understand the properties of the material, its restrictions and recognize its potential. The process assists in obtaining knowledge about materials through experiential learning (Louridas, 1999). "Material tinkering," based on an evolutionary process of "trial and error," can be described with a Darwinian metaphor of survival of the material best suited for use. This kind of knowledge offers insights into the possible development of the material, making suggestions about the products that can be obtained and thus contributing to invention.

Laboratory activity
image of the author

_ PO RIVER: THE SCENARIO

↘ The largest river in Italy

The Po is the Italian largest river in terms of the development of its 652 km course and average annual flow rate of 1500 mc/sec. It rises on the peak of the Monviso mountain, at Pian del Re, about 2000 mt of altitude. It is characterized by a very large catchment area, including almost the entire Mediterranean side of the Alps and a portion of the northern Apennines and its flow is rich throughout the year. It flows for 35 kilometers downhill, with 1700 mt of elevation gain in the Po Valley, then it flows into the Saluzzese plain, and thereafter it flows largely into the largest Italian plain, the Po Valley. At the end, it flows into the Adriatic Sea, with a river delta beginning about 50 kilometers from the Adriatic coast, constituting an ecosystem of great importance and a natural heritage of worldwide relevance (Piemonte Parchi, 2003).

Two main zones can be identified in the plain: the high plain, where the pebbly soil filters water deeply, and the low plain, with finer and less permeable soil. Landscapes in these two belts are also extremely varied. The upper part is more densely populated, and thanks to various factors such as favourable climate and the passage of communication routes, the first settlements, agriculture and early industries using water to generate hydroelectric energy developed. Today, the high plain presents a highly humanized landscape, where agriculture has been replaced by a succession of factories and industrial warehouses, as well as roads, highways, railways and more or less extended population centers, making it one of the most infrastructure-dense areas on the Continent (Piemonte Parchi, 2003). On the other hand, the lowlands are characterized by a very high fertility index, still used mainly for some specialized crops such as rice.

Only in modern times man's perception of the river changed. Water was also used for power generation and water supply for the growing population, not just for agriculture. Streams were channelized and water used and returned, often without adequate purification. Only after some disastrous events such as collapses and floods due to a lack of maintenance of the river, after the middle of the last century, did human-river relations begin to change. Sensitivity to the environment began to develop in institutions and civil society, and in Italy, as in the rest of the world, the establishment of natural parks and protected areas was initiated, including the Po River Park in Piedmont, where the river runs 235 kilometers, one third of its total course. Cities crossed by the watercourse, particularly Turin, have revalued its banks, along which pedestrian and bicycle routes have been laid out, thanks to a different way of seeing and experiencing the river.

Today, the Po appears to be a "perished" river, mainly due to excessive human pressure and a development model that is not compatible with the river ecosystem. Although for those who live around the Po the problems are mainly related to flooding, for the river it is mainly the lean periods that generate criticality, as could be seen in the recent dry summers, in which the Po's flow rate reached historic lows. Once it arrives in the urbanized area of Turin, the Po definitely changes in appearance from the previous alpine section and the portion through the Po Valley, where it takes on the characteristics of a lowland river: slow and with wide bends.

Aosta Valley
Piedmont
Po
Torino
Pian del Re
Piedmont
Liguria
Italy
France

PO RIVER

1st *river in Italy*

652 *km*
lenght

71.000 *km²*
river catchment area

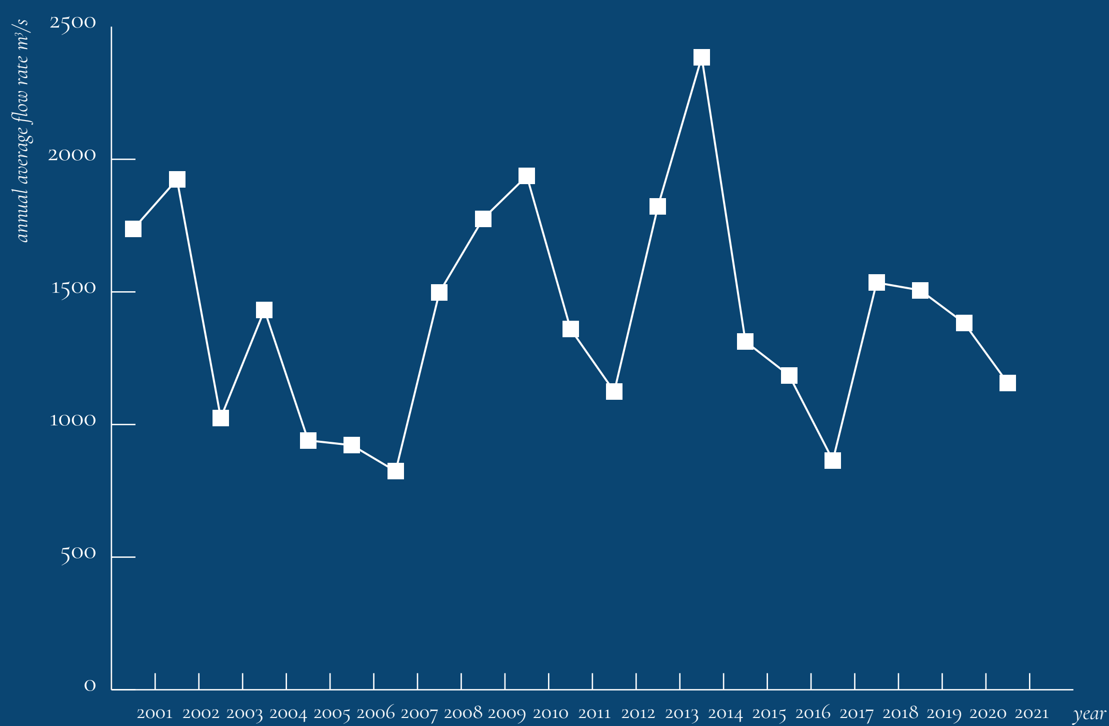
5th *river in Europe*

river with the highest flow rate at the mouth, whether minimum (270 m³/s) *or maximum* (1.540 m³/s)

altitude source 2.022 *m a.s.l.*

crossed provinces 13 *of which 3 provincial capitals:*

- *Torino*
- *Piacenza*
- *Cremona*



↘ Po River in Turin

In the city, the river is constrained by the hand of man and natural elements are replaced by human interventions, construction above all. Indeed, we find works for the safety of the riverbanks, enjoyment of the banks, creation of energy and potabilization of the water (Piemonte Parchi, 2003).
There are many public parks along the banks, also inside the protected area, which strongly connote the city river: Valentino Park, Millefonti Park, Michelotti Park and Colletta Park.
The river in the city is experienced assiduously: walkways, bicycle paths, boarding points and other activities and enterprises on the riverbanks are a tangible sign that the Po River is now a great resource for the city. All these activities obviously replace the more natural features that characterized the previous parts of the river's course, but even so, there are some areas that host large communities of ducks, such as the Meisino Park, or an important colony of herons between Turin and San Mauro, in the area of Isolone di Bertolla.

Murazzi, Turin.
© Film Commission Torino Piemonte

_ PO RIVER ECOSYSTEM

↘ Po River vegetation

Different environments that characterize the Po River Park have distinctive vegetation, mainly due to the existing ecological conditions, which are largely influenced by the river.

Sandbars represent a constantly changing ecological situation, as they are governed by the annual flow patterns of the river. During the lean period of the Po (summer and winter), the islands can be colonized by annual graminaceous plants (such as *Vulpia myuros* or *Polygonum lapathifolium*) characteristic of the warmer areas of the plain and by perennial stoloniferous plants (such as *Saxifraga stolonifera*) that manage to remain attached to the soil even during floods of the river.
The banks of the Po are populated with trees such as White Willow (*Salix alba*) and the Scented Willow (*Populus alba*) that contribute to the consolidation of banks put at risk by spring floods.
The oxbow lakes, marshy areas originating from a section of river abandoned by the watercourse, are the areas where the river during floods deposits large amounts of organic matter and nutrient salts. There is low flow rate in these areas, so plants have developed the ability to root on the bottom by means of large roots and rhizomes.
The reedbed consists of herbaceous plants that root on the seabed immediately near the bank where Mazzasorda (*Thypha sp.*), which hosts an undergrowth of Water Fern (*Azolla caroliniana*), and associated Mazzasorda major (*Thypha latifolia*), which

is larger in size and has cerulean green leaves, dominate. Widespread is Marsh Reed (*Phragmites australis*) whose stems provide nesting support for many birds closely associated with this environment.
Behind the reedbed stretches a belt consisting of Willows; in particular the Cinereous Willow (*Salix cinerea*) grows there.
Following willow groves, we find tree stands. The most characteristic plant is the Black Alder (*Alnus glutinosa*), then, as mentioned, we find the White Willow (*Salix alba*) and White Poplar (*Populus alba*). Among the shrubs we find May Pallon (*Viburnum opulus*), while the herbaceous layer is mostly colonized by sedges, such as Carice spondicola (*Carex elata*) and Sharp Sedge (*Carex acutiformis*).

The canals that flow into the Po River are home to a particular type of aquatic vegetation adapted to live in waters with pronounced current, rooting on the ground, and mostly entirely submerged such as those of the genus Potamogeton (*Brasche*) and the Aquatic Ranunculus (*Ranunculus fluitans* and *Ranunculus trichophyllus*). Among the species that inhabit these environments are also tiny plants reduced to the size of a few millimeters: water lentils (*Lemna sp.*, *Spirodela sp.*, *Wolffia sp.*), they drift along the surface of the water.
In gerbids, on the other hand, water is practically absent. In this situation, hygrophilous tree species manage to survive due to deep rooting. Carex, including Carice lustra (*Carex liparocarpos*), are also widespread, thanks to their slender and very long rhizomes. Liliaceae such as blue Muscari (*Muscari botryoides*) and spring onion (*Muscari comosa*). Wild asparagus (*Asparagus sp.*) is also common.

Po river, Turin.
image of the author

As for fluvial vegetation, Arpa Piemonte technicians are always engaged in monitoring at variable frequency depending on the seasonal vegetation development, which determines which species and with what density they develop according to the sectors investigated.

Aquatic plant growth in Turin sees the presence mainly of:

- *Callitriche*: a genus of submerged aquatic plants that prefer stagnant or low-flowing waters, such as those that characterize the urban stretch of the Po River, forming characteristic clumps on the water surface where their apexes emerge. These are naturally developing plants belonging to the local (native) flora;

- *Myriophyllum spicatum*: not to be confused with Myriophyllum aquaticum, is instead a native, oxygenating, submerged, fast-growing, brown/reddish plant. It is well anchored to the bottom by roots and grows by forming dense groups of plants. In summer it forms small reddish inflorescences at the water surface;

- *Potamogeton*: a genus of perennial plants that produce from rhizomes, stems or stolons of winter shoots and grow rapidly at this time of year. Also present are some algal species including Hydrodictyon reticulatum.

The highest densities of the stands are found at the edges of the river, where the depth is shallower and they are less affected by the water flow, and in the middle, where they are barely visible but firmly attached to the substrate that makes up the riverbed due to the greater depth of the water (ARPA, 2021).

Group:
Spermatophytina

Family:
Hydrocharitaceae

Genus:
Elodea

Elodea Nuttallii

Area of origin
North America (USA and Canada)

Biological form
rooting hydrophyte

Growth form
herbaceous perennial

Flowering

J F M A M J J A S O N D

Appearance

Freshwater plant rooting in the soil, only the flowers protruding out of the water. It forms dense, often submerged mats.

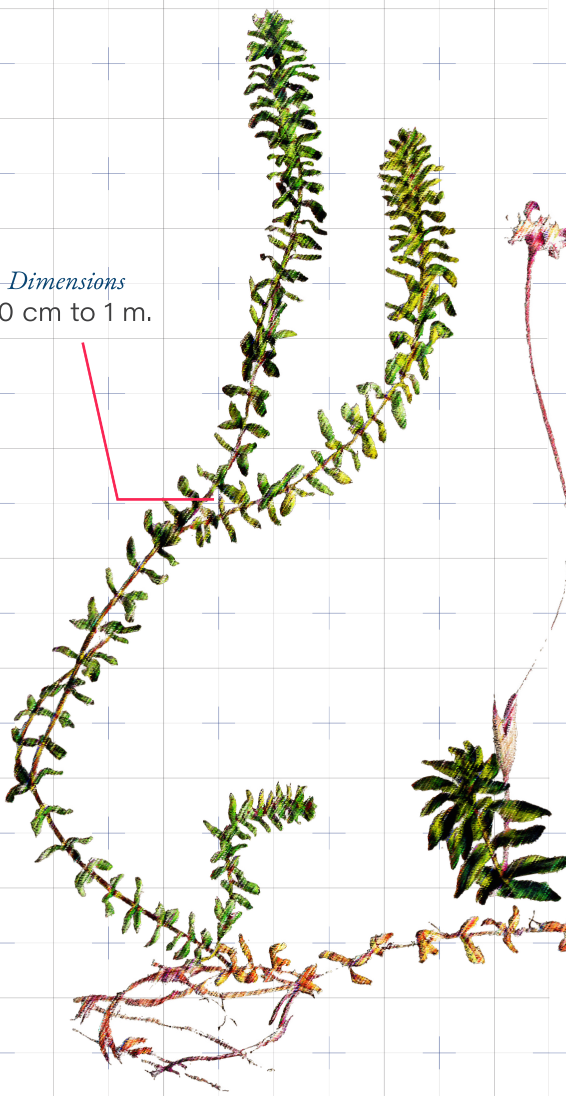
Leaf appearance

small, linear to narrowly lanceolate often curved and bent at the margins. Pale green in colour, at the top of the stem they are arranged in whorls of 3 or 4.

Invasiveness

Rapid growth, vegetative reproduction through fragments easily dispersed by waterfowl and the current.

Dimensions
30 cm to 1 m.



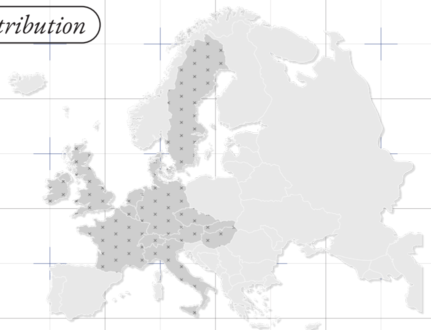
Mode of propagation

by vegetative methods and rarely by seed dispersal.

Habitat

It grows in running waters, ponds, lake bottoms, lowland rivers with calm, warm, shallow waters with a pH between 7 and 9, rich in nutrients, from sea level to about 600 m.

Distribution



Group:
Spermatophytina

Family:
Haloragaceae

Genus:
Myriophyllum

Myriophyllum aquaticum

Area of origin
South America

Biological form
rooting hydrophyte

Growth form
annual growth

Flowering

J	F	M	A	M	J	J	A	S	O	N	D
			■	■	■	■	■	■	■		

Appearance

aquatic herbaceous plant rooted to the seabed, consisting of stems submerged and emerging stems, forming dense coverings on the water surface.

Leaf appearance

light green pinnate leaves 2-4 cm long with 4-15 linear divisions 4-8 mm long; leaves grouped in whorls of 5-6 inserted at one point (node) on the stem.

Invasiveness

Very high capacity for vegetative reproduction through detachment of fragments following disturbances or wind and wave motion. Increased during the summer period when the climate is warmer.

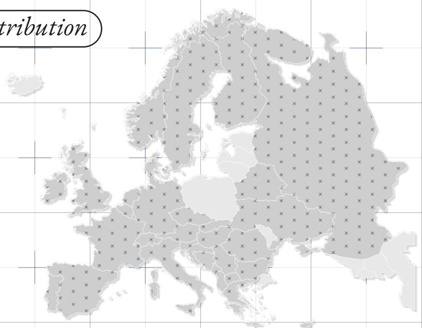
Mode of propagation

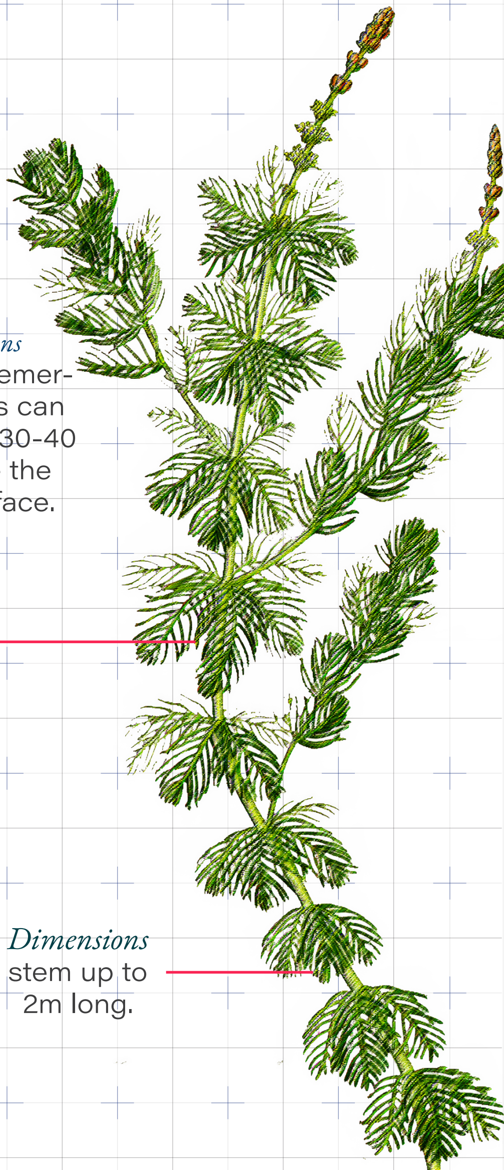
vegetative.

Habitat

It grows in still or slowly flowing shallow eutrophic waters (< 1.5 m). Very plastic species, able to withstand variations in current velocity, depth and nutrient concentration.

Distribution





Dimensions
stems and emerging leaves can grow up to 30-40 cm above the water surface.

Dimensions
stem up to 2m long.

Group:
Spermatophytina

Family:
Araceae

Genus:
Lemna

Lemna minor

Area of origin
Cosmopolitan

Biological form
angiosperm

Growth form
herbaceous perennial

Flowering

J	F	M	A	M	J	J	A	S	O	N	D
□	□	□	■	■	■	■	■	■	■	□	□

Appearance

Very small aquatic plant, consists of a single very small leaf, oval or rounded, floating on water.

Leaf appearance

small, measuring on average 2-3 mm in length, from which a single small, thread-like root, approximately 8 mm long, floats in the water.

Dimensions
up to 2-4 mm wide
3 cm high (including root).

Invasiveness

Very high speed of vegetative multiplication. The spread of the plant is due to the extension of the plant with very small stoloniferous buds.

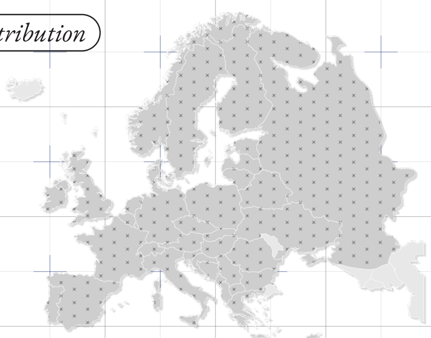
Mode of propagation

by budding.

Habitat

It grows floating on the water surface of stagnant rivers and lakes. It populates, sometimes in an infesting manner, freshwater ponds up to an altitude of 1800 m. It often covers the surface of springs.

Distribution



↘ Effects of global change on freshwater biota

The latest report on climate change in Italy shows a confirmation of the criticality of the global situation, as 2020 is placed at the peak of the annual average temperature series over land, with an anomaly of +1.44°C compared to the period 1961-1990 (Ispra, 2021). Climate change can have strong direct and indirect effects on freshwater biota (Bates et al., 2008). Direct effects include:

- Increase in extreme flood events, caused by the increase in intense rainfall events that are highly localized in space and time resulting in increased probability of flooding;

- Increase in extreme low-flow events, as a result of increased temperatures and the number of consecutive non-rainy days;

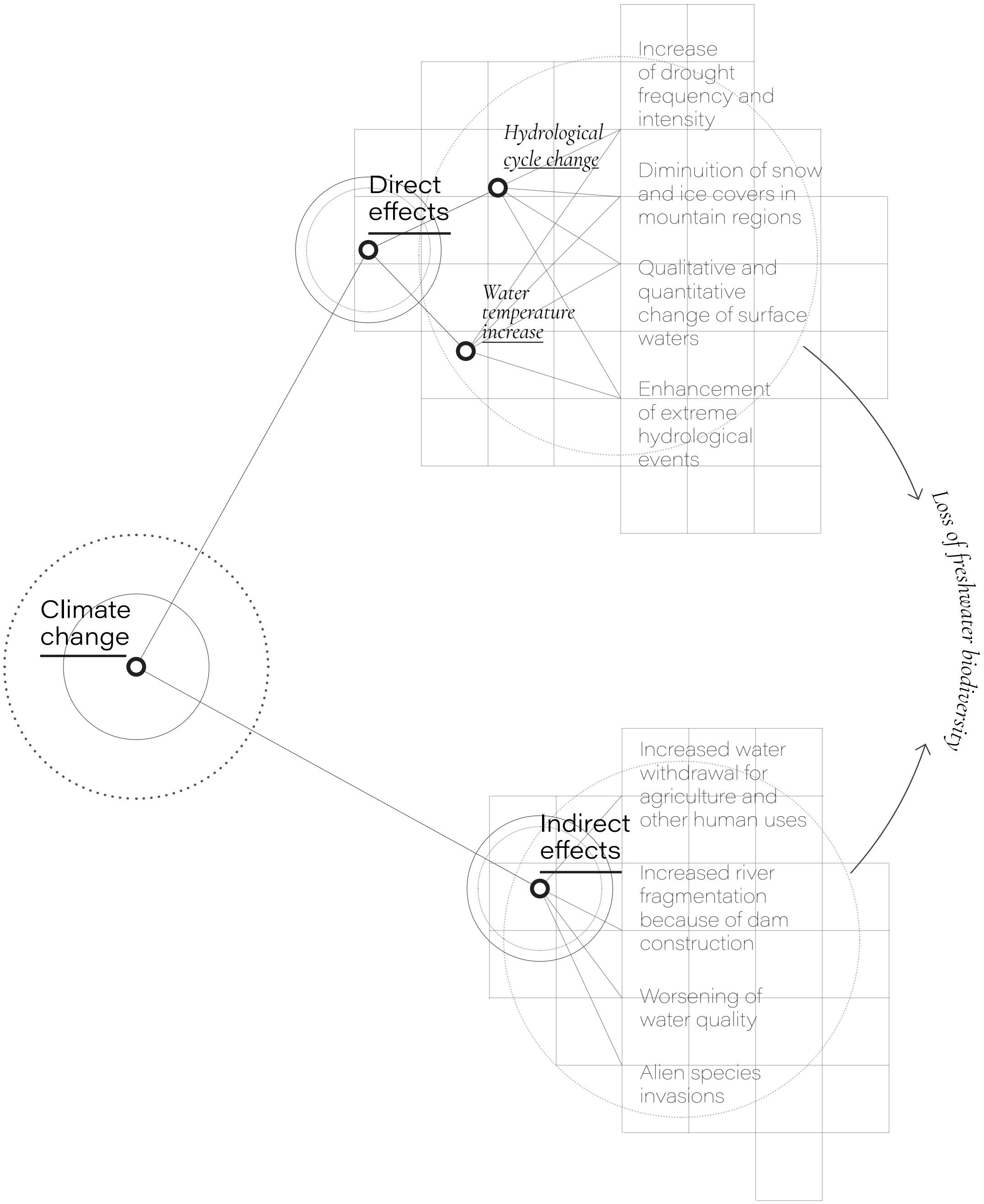
- Increased water temperature.

While, some indirect effects are:

- Landscape transformation and alteration of river morphology; enhanced agricultural irrigation needs;

- increased dam construction resulting in river fragmentation;

→
Source: Fenoglio, S., Bo, T., Cucco, M., Mercalli, L., & Malacarne, G. (2010). Effects of global climate change on freshwater biota: A review with special emphasis on the Italian situation. Italian Journal of Zoology, 77(4), 374–383.


Climate change
Direct effects
Hydrological cycle change
Water temperature increase
Increase of drought frequency and intensity
Diminuition of snow and ice covers in mountain regions
Qualitative and quantitative change of surface waters
Enhancement of extreme hydrological events
Indirect effects
Increased water withdrawal for agriculture and other human uses
Increased river fragmentation because of dam construction
Worsening of water quality
Alien species invasions
Loss of freshwater biodiversity

- deterioration of water quality, due to reduced dilution of pollutants, as a result of an increase in extreme drought events;

- invasion of alien species, due to an increase in water temperature. For some species, an extension of suitable habitat will be possible while others will be challenged to the point of extinction.

This rapid climate change will dramatically affect the biodiversity of vast regions, with changes in the occurrence and distribution of many species, a decrease in taxonomic richness, and the disappearance of entire ecosystems (Svenning et al., 2009). In particular, water temperature has important effects on the life of freshwater organisms and aquatic vegetation, both directly and indirectly (e.g., because the solubility of oxygen in water decreases with increasing temperature). Many studies speculate that there is a direct relationship between climate change and biological invasions (Sittaro et al., 2023). Global warming allows some species to expand their distribution and leads to the survival and dispersal of tropical and subtropical species, especially those capable of changing their seasonal cycles (Fenoglio et al., 2010). In addition, global climate change disrupts community structure and increases the loss of native species and biodiversity. Biological invasions of plant species into natural ecosystems are increasingly considered a major threat to ecosystem functions. In addition to the loss of biological diversity, IPSs cause health and economic damages of great magnitude (Early et al., 2016).

The river ecosystem is particularly vulnerable to invasion by exotic species. River are complex ecosystems consisting of a succession of habitats that vary from upstream to downstream, and the aquatic and terrestrial plant and animal species that are part of this environment have great adaptive capability. Invasive alien species, being extremely competitive, are favoured in colonizing these habitats. Also having a rapid growth rate and high reproductive efficiency they manage to develop dense formations by competing with the natives for resources, space and light until the native species disappear completely. Rivers then, with the current, contribute to the expansion of allochthonous species by transporting the seeds and plant parts, while the artificial transformation interventions of waterways promote the establishment of invasive organisms (ARPAT, 2022).

The Po River running dry in Turin.
© Ansa

↘ "Alien algae"

"Alien algae" is how Elodea nuttallii is defined, an algae that in the first half of 2022 invaded the Po River, especially in Turin. The "tropicalization of climate" has manifested its influence particularly visibly in Italy's most important waterway, which for centuries has fed the productive sector of the Po Valley.
It is an invasive, perennial rooting hydrophyte species native to stagnant to flowing freshwaters of North America. Its leaf shape makes it recognizable: linear or linear-lanceolate with a narrowly acute apex (Simpson, 1988). It has fast growth and strong spreading ability due to its exclusively vegetative propagation mode (Walters et al., 1980) and high phenotypic plasticity (Agrawal, 2001). Due to the large and dense monospecific populations it creates, Elodea is defined as a species capable of transforming ecosystem (Buccheri et al., 2019).

Rising temperatures and a prolonged absence of rainfall have made the waters of the Po River exceptionally calm, warm, and significantly shallow. The salt wedge has risen several kilometers, making the river saltier and therefore unsuitable for agriculture. The increase in salinity is closely linked with the proliferation of invasive plant species, which generally prefer warm, shallow waters (Brundu, 2015), and the Po, under these conditions, is a perfect ecosystem for the spread of exotic pest species.
This happened in the stretch of river that runs through the city of Turin: here the presence of the so-called "Alien Seaweed" has been reported, which is on the

Black List - Management List of the Piedmont Region. Specifically in the list of exotic species that are already present in the territory in a widespread manner and "for which containment measures and eradication interventions can be applied in circumscribed areas." It is also identified at the European level as a plant to be combated with active management, as it is dominant over native plant communities (Regione Piemonte, 2022).
The proliferation of the alga has taken on characters of a true invasion, capable of destroying the river ecosystem, and consequently action to remove the said aquatic vegetation was deemed necessary.

Elodea, a native of North America, was introduced to Europe as aquarium algae in the early 1900s, is widespread in much of Europe, particularly in Italy it probably arrived in the 1970s, and began a full-fledged "invasion" beginning in the 2000s. Until 2000 it was found only in lakes in northern Italy (first recorded in 1989 in Lake Idro), but in following decades it expanded to canals and rivers (Buldrini et al., 2022).
Indeed, biological invasions are one of the great challenges facing ecosystems today against a backdrop of global climate change and increasing human pressure, responsible for altering aquatic habitats and atrophying waters as consequences of human activities (Wärner et al., 2011). This is particularly true for freshwater ecosystems, which are among the most threatened on Earth and the most affected by biological invasions (Bolpagni et al., 2020).
It is classified as an adventitious species, that is, as a plant capable of reproducing only in a very restricted range and usually disappears after a certain period.

In July 2022, however, a real alarm was triggered in Turin. The extreme weather conditions, pollution and salinity level of the Po River have facilitated the profileration of the alga to the point of becoming harmful to the ecosystem. In fact, reproduction occurs in the easiest and most invasive way possible: each fragment of Elodea, broken by the currents, can take root and give rise to a new plant.
Therefore, a "coordinated natural removal intervention" was necessary to eradicate the weeds that, constituting dense beds of vegetation, obstruct drainage channels and impede navigation, slow down water movement, decrease luminosity and consume a lot of oxygen, risking the suffocation of native species, both plants and animals.
In agreement with the City of Turin, the removal was done manually, thanks to institutions, volunteers and citizens, by grubbing, as the strong reproduction capacity makes it dangerous to carry out mechanical mowing or, even worse, chopping operations that could result in a high spread of the plant downstream (Ente di gestione delle Aree Protette del Po piemontese, 2022). However, the eradication operation is an experimental and non-resolving intervention, driven by the emergency of the period, which means that the problem may recur in the warm season as we see increasingly rapid temperature rise (ENEA, 2022).

Elodea Nuttallii.
© Flowgrow

Already in 2016, eradication actions were carried out due to the presence of Myriophyllum aquaticum in the Po River waters. This is an exotic species of South American origin, mainly used for aquarium set-ups, is highly invasive and causes significant impacts on the biodiversity of aquatic ecosystems. It is also reported as a species that obstructs water flow, consequently leading to damage to cultures, and making navigation difficult (Ortiz et al., 2019).
Like Elodea nuttallii, it requires manual intervention, as mechanized mowing would result in the spread and multiplication of this species.
It is also in the Black List of plant invasive exotic species of the Piedmont Region, and for this reason it is subject to new continuous eradication interventions, control and monitoring activities along the stretch of the city of Turin (Regione Piemonte, 2017).
Aquatic vegetation removal activities resulted in a large mass of organic waste that, until now, was then disposed in specially designated areas so as to avoid dispersion to surrounding areas. Disposal at incinerators represents the safest mode of destruction of material resulting from slashing, mowing and eradication. However, at present the number of such facilities in Piedmont is limited, so the use of this mode of disposal in the region may prove complicated and costly (Giunta Regionale, 2017).

The goal of the project is therefore to reintroduce this biomass into a production cycle by implementing the systems approach and acting locally.

Above and side
Elodea Nuttallii eradication in Po River, Turin.
© Manuela Gatti, Rai.

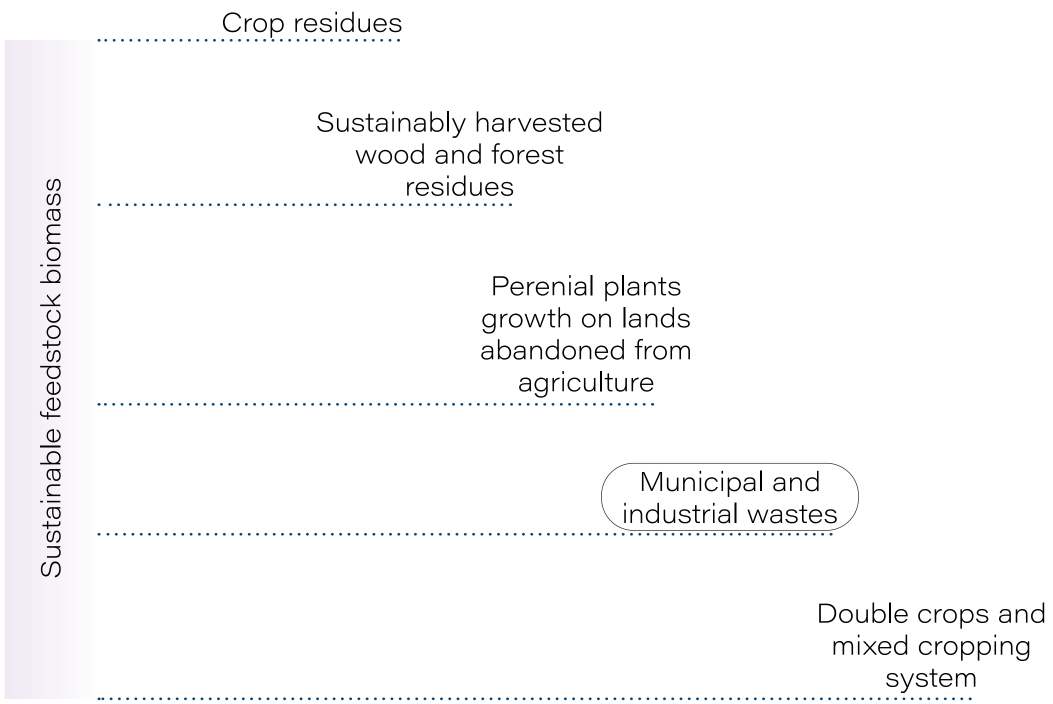
_ BIOPLASTICS AND AQUATIC VEGETATION

↘ Use of algal biomass

Biomass is considered a renewable resource only if its rate of consumption does not exceed the rate of restocking. A viable strategy for making bioplastics, is to select sources that have fast growth, are easy to exploit, and do not disturb agricultural activities; this is called a sustainable biomass supply strategy.
The raw materials most in use today for creating bioplastics are corn, potatoes, vegetable oils, wood, food waste, and cornstarch (Lim et al., 2021a). The main types of bioplastics nowadays are starched-based, followed by polylactic acid (PLA), poly-3-hydroxybutyrate (PHB), polyamide 11 (PA 11), and organic polyethylene (PE) (Shah et al., 2020).

Algal biomass also turns out to be a good candidate as a raw material for making bioplastics. They have many benefits as raw materials compared to other feedstocks. For example, reducing GHG percentage from the environment, planted in seawater instead of land, abundant and high yield. Moreover, since some seaweeds are edible, they can be utilized in food packaging industries (Zhang et al., 2019).
They also possess a low percentage of lignin but are rich in long-chain hydrocarbons; therefore, high-purity cellulose can be extracted economically (Zanchetta et al., 2021). Finally, they can grow in polluted conditions, in the presence of CO_2-rich gases or in wastewater containing nitrogen and phosphorus (Zerrouki & Henni, 2019). They can use CO_2 to carry out photosynthesis and their by-product is clean air, oxygen. For this reason, algal biomass can be considered carbon neutral with

→ *Visualization of the sustainable biomass feedstock concept where feedstock neither compete with food crops nor directly or indirectly cause land-clearing.*

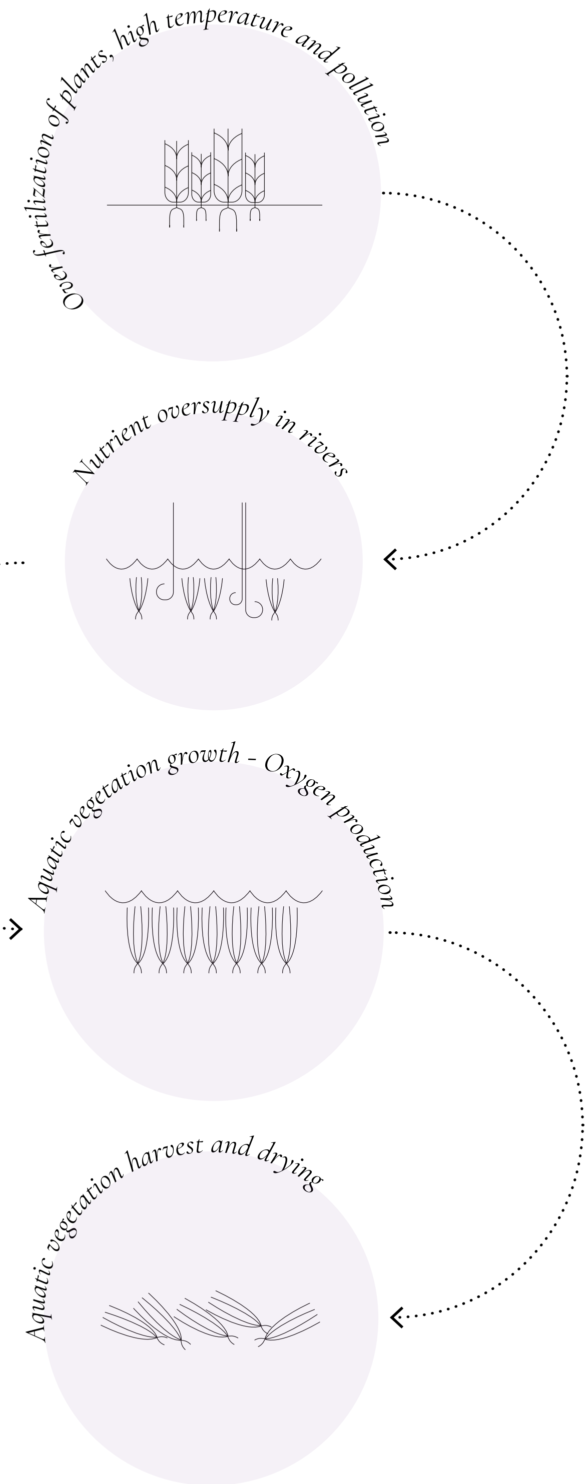

Crop residues
Sustainably harvested wood and forest residues
Perenial plants growth on lands abandoned from agriculture
Municipal and industrial wastes
Double crops and mixed cropping system
Sustainable feedstock biomass

an high photosynthetic efficiency.

It is pointed out in the literature that macroalgae such as seaweed have greater potential than sources from plants or bacteria. They are considered a good candidate for bioplastics because of their high biomass, cost-effectiveness, ease of cultivation in the natural environment without requiring arable land, can grow in a wide range of environments and can be harvested throughout the year (Rajendran et al., 2012). They have very high growth rate value, can double in volume in one day, and are, to date, an unexploited resource. Seaweeds are productive with higher growth rates than land crops. For example, Kappaphycus alvarezii has a maximum daily growth rate of 2.29 ± 0.11% day-1 and 4.55 ± 0.34 g DW m-2 day-1 productivity after 40 days in a tailored tank (Phang et al., 2017). The growth rate of fluvial aquatic vegetation has similar characteristics, they have a very high growth rate.

Additionally, seaweed bioplastics will not degrade into microplastics like conventional plastics that are hard to collect, and they can biodegrade in the soil in only four to six weeks (Hira et al., 2018). Algae is still little used in the plastics industry, but it is a good, toxic-free, environmentally friendly and inexpensive bioplastic, believed to be of good quality in terms of tensile strength and chemical resistance. Finally, numerous substances can be extracted from algae, such as polysaccharides that are used as the main ingredient or as additives in the creation of bioplastics, as well as proteins and lipids (Lim et al., 2021b). Polysaccharides have often been extensively studied in terms of their characteristics, in particular phycocolloids are high molecular weight polysaccharides consisting of simple sugars that are able to form viscous dispersions and gels when dissolved in water (Abdul Khalil et al., 2017). They are derived from brown algae and are used in the food industry, for example in the production of ice cream, as they prevent the formation of ice crystals even at low temperatures.
Seaweeds are highly valued for their phycocolloid content. The main phycocolloids of seaweeds are three: agar, carrageenan, and alginates. They're used in many applications including plastic making as they exhibit interesting film-forming properties and have negligible lignig content (Lim et al., 2021c).

→
Visualisation of the growth process and collection of fluvial aquatic vegetation.


Over fertilization of plants, high temperature and pollution
Nutrient oversupply in rivers
Aquatic vegetation growth - Oxygen production
Aquatic vegetation harvest and drying

Agar-agar

Agar agar is a valuable compound extracted from red seaweeds, with Gelidium being the main species contributing to about 35% of the world's production (Barsanti & Gualtieri, 2014). Lower quality agar is typically derived from Gracilaria and Hypnea species. Agar agar is a polysaccharide consisting of agarose (70%) and agaropectin (30%), extracted from macroalgae membranes (Sahin, 2021). Agarose acts as the gelling fraction and is a neutral polysaccharide, while agaropectin is a non-gelling fraction. This characteristic allows agar agar to exhibit gel or liquid properties, transitioning between states with heating or cooling. It finds common applications in culture media preparation in laboratories, molecular biology, and food processing as a vegan substitute for gelatin (Graham et al., 2009).

Alginate

Alginates are salts of alginic acid, a polysaccharide consisting of β-mannuronic and α-guluronic acid monomers, and constitute the cell walls of brown algae, of which they account for 20-60% (on average 40%) of their dry weight (Rashedy et al., 2021). They can be found in almost all types of algae but are usually extracted from Kelp and Wrack algae. They possess gelling, viscosity-modifying, and stabilizing properties and are widely used as thickeners and stabilizers of emulsions (Tabriz et al., 2015). They are also often made into fibers and used in the textile industry or as wound dressings; they are also used in printing, cosmetics, and even in ice cream production (Barsanti & Gualtieri, 2014).

Carrageenan

Carrageenan is an affordable, biocompatible, and biodegradable sulfated polysaccharide derived from red algae. It is utilized in the production of bio-based films with strong tensile strength and low water vapor permeability (Sedayu et al., 2019). It has three variants: kappa (rigid and brittle), iota (flexible), and lambda (does not form gels). In bioplastics' production, carrageenan is often combined with cassava starch and glycerol, in order to enhance moisture resistance, reduce brittleness, and improve the tensile properties of the polymer. The introduction of carrageenan into the compound results in a proportional decrease in tensile strength and elongation. Carrageenan and glycerol exhibit good compatibility, forming strong hydrogen bonds when mixed together (Suryanto et al., 2019).Carrageenan finds widespread application as a binder in the manufacturing of cosmetics, drugs, and toothpastes (Barsanti & Gualtieri, 2014).

↘ Case studies: harnessing natural materials as a sustainable base

As for river vegetation, we do not find much evidence in the literature, but they mostly have the same characteristics as marine vegetation.

Therefore, aquatic vegetation is of great interest as potential feedstocks for various applications, including environmental sustainability, wastewater treatment, biofuel production, and the manufacture of high value bioproducts (Ahmad et al., 2022). Algal biomass can be used to produce composites that are biodegradable and have strong mechanical properties. Since they do not require freshwater, land, and pesticide to grow, they are considered the clear winner, in comparison to other biomaterials.

Below some interesting case studies for the purpose of project development.

SEACell

Smartfiber

Germany

SEACELL is a patented environmentally friendly fiber that has endless applications in textiles. The fibers are suitable for a wide range of uses in sports and leisure fabrics, from underwear and loungewear to soft furnishings and it can be combined with any other fiber.

The basis of the process is the Lyocell/Viscose manufacturing process, which uses cellulose (wood pulp), dissolved in solvent and converted into fibers.

There are no harmful substances in the production process, it occours without chemical reaction, the solvent is non-toxic and can be recycled efficiently. Seaweed are added to the mixture of dissolved cellulose in powder form. The solution is then spun into fibers, polymerized in water and then processed into staple fibers.

All process liquids and water are recycled and reused, and all fibers and waste are completely biodegradable.

Algae foam

Bloom

Mississippi

Algae foam is a flexible foam made from wasted algae. Algae are a vital component of nutrient management in aquatic ecosystems, however, when temperatures rise, algae thrive, choking aquatic life.
Bloom's company turns algae into biofoam, combined with an EVA compound. Algae biomass is rich in protein and has natural thermoplastic qualities. This allows it to mimic the properties of traditional flexible foams when properly processed.

AlgiKnit

Keel.labs

North Carolina

It is a biodegradable fibre that is strong and elastic enough to be knitted into a fabric. It is also suitable for use in 3D printing processes and obtains its colour from natural pigments. At the end of its life cycle, this algae fabric can serve as compost or animal feed. It also reduces the carbon footprint of the clothing industry because no harmful fibre particles are lost during washing, as is the case with polyester.

To produce the yarn, the research team extracts a substance called alginate from the algae, which is then combined with other renewable biopolymers for further processing. For transformation into filament, the biopolymer mixture undergoes an extrusion process in a salt bath that polymerises the organic yarn.

In addition, to minimise waste, all products are knitted to shape. This technique enables AlgiKnit to produce products with little or no waste.

Algae T-shirt

Vollebak

United Kingdom

The technical clothing company Vollebak has designed a T-shirt made from wood pulp and algae, which biodegrades in 12 weeks in compost or buried. The algae are grown in bioreactors, simply placed in water and then provided with light and carbon dioxide to grow. The T-shirt is made from wood pulp from sustainably managed forests. Eucalyptus, beech and spruce are cut and pulped before being made into fibre, then into yarn and finally into fabric.
Seaweed is used to produce a printable ink. The water is passed from the bioreactor through a filter, separating the algae. The seaweed paste is dried in the sun to create a fine powder, which in turn is mixed with a water-based binder to make seaweed ink.

Bio film

Studio Tang

Sweden

Schikan Joline & Gwózdz Barbara explored the biodegradable materials' world. Their work aims to explore the potential of seaweed in architectural context. Apart from investigating macroalgae, the work also includes studies on microalgae and seagrasses. The project's approach on the material investigations is mainly from an aesthetic point of view and the durability of the material.
The main ingredients used are agar, alginate and carrageenan combined with water and glycerin and other ingredients such as spirulina or algal biomass. These are then combined in different proportions to achieve different results and thus biofilms with different aesthetic and structural characteristics.
The material sample evaluations are based on estimations and personal opinions.

Packaging

Margarita Talep

Chile

Chile-based designer Margarita Talep decided to develop an environmentally friendly packaging to replace plastic. The material is made only of natural substances, including the dyes used for colouring, extracted from the skin of fruit and vegetables such as blueberries, purple cabbage, beets and carrots. The basic mixture consists of a polymer, a plasticiser and an additive; the quantities of each ingredient vary depending on the desired consistency of the final product.

In this case the main ingredient is agar, extracted from red algae by boiling. The mixture is boiled at about 80 degrees Celsius, and then transferred into a mould. When the liquid drops to a temperature below 20 degrees Celsius, it takes on a gel-like consistency. This is then left to dry in a well-ventilated room at a constant temperature until it becomes similar to paper or thin plastic.

Cladophora

Studio Malu

Germany

This project collects fibrous algae from the lakes of Berlin and uses their different qualities to produce textiles. Due to its wool-like appearance, Cladophora can be turned into a translucent nonwoven fabric or a yarn for surface production. When of lower quality, it can be turned into a biodegradable bioplastic that could, in the future, replace PVC for mackintoshes or bags. Fabric - quality 1: Cladophora still attached to the rocks comes in long fibres and soft fibres. This quality can be easily spun to produce textiles. Non-woven fabric - quality 2: the short but soft fibres of Cladophora can be made into non-woven fabrics. Bioplastic - quality 3: the already partially decomposed Cladophora is of low quality. The fibres rely on a binder to be transformed into a surface.

Zero Waste

Austeja Platukyte
Lithuania

"Zero waste" is an algae-based packaging made following the zero-waste philosophy. The project is the result of an experimental practice aimed at finding a substitute for synthetic plastic using only natural resources that would then form a new cycle in nature. This new algae-based material holds its shape perfectly, is waterproof and protects the product from damage.

Composed of only two natural ingredients, this material is completely organic and compostable. Once the product is consumed, the packaging can simply be composted or used as fertiliser. Even if this packaging is discarded as waste, thanks to natural processes and micro-organisms it will return to nature, forming new layers of chalk, and will not cause any harm to the environment or other life forms.

Terroir

Jonas Edvard and Nikolaj Steenfatt

Denmark

The Terroir project was created by Danish designers Jonas Edvard and Nikolaj Steenfatt. By combining seaweed and paper, Edvard and Steenfatt have created a strong and durable material, a warm and tactile surface with the softness of cork and the lightness of paper, which can be used for products and furniture. The colour of the material is determined by different species of seaweed, ranging from dark brown to light green.
The algae are harvested along the beaches of Denmark, which stretch over 8,000 km. After being dried, the seaweed is ground into a powder and cooked until it becomes glue, exploiting the viscous and adhesive effect of alginate. By using locally sourced materials, the two designers hope to contribute to a local and sustainable economy.

Leap

Beyond Leather

Denmark

Beyond Leather, a Copenhagen-based company, has created a plant-based leather alternative called Leap. The product is made by mixing apple scraps with natural rubber and applying them to a textile backing made of cotton and wood fibre before finishing it with a protective coating, creating a three-layer structure that can be dismantled at the end of its life cycle. Leap's durability is currently guaranteed by a protective plastic coating, which is embossed to give texture and also contains the pigments that give the leather alternative its colour. The three-layer structure allows for easy disassembly once the product reaches the end of its life cycle.

Beyond Leather hopes to make the material fully biobased and biodegradable by 2024. According to company estimates, the apple-based version of Beyond Leather emits 85% less CO2 in its production than conventional leather, as well as requiring 1% less water.

Seacrete

Studio Tang

Sweden

The big disadvantage of cement is its huge carbon footprint. About 8% of all global emissions come from the cement industry. During the production process, when limestone and clay are heated, about 600 kilograms of CO_2 are released into the atmosphere for every ton of cement produced.
All these data demonstrate the need for a more sustainable building material with similar qualities that can compete with cement. That is why Schikan Joline and Gwózdz Barbara have begun to study how to create new type of concrete. They developed an example of bricks composed the crushed oyster shells mixed with a solution of alginate and algal biomass.

En Route

Brigitte Kock
and Irene Roca Moracia
United Kingdom

“En Route” is a sustainable bioconcrete.
Designer Brigitte Kock and architect Irene Roca Moracia collaborate to create an innovative new material that adds monetary value to the removal of invasive biological species.
In the UK, both Japanese seaweed and the American crayfish have been the focus of extensive removal efforts. The two designers have used the by-products of this removal effort to create a range of new bio-concrete tiles. The material is composed of a mixture of wood ash and powdered crayfish shells. The final colour and textures depend on the curing time and chemical reactions of the aggregates with the binder and water.
Their biocement is their personal interpretation of what they could achieve by following the ancient Roman methods of concrete production. The duo sees the product as a new luxury material for interiors that can replace concrete.

↘ Footwear and flip flops pollution

Very often we hear about plastic waste in the oceans, but we often fail to consider how everyday objects affect this huge plastic pollution problem. One of the causes stems from our feet, and more specifically from what we wear: flip-flops.
The Japanese call them *zoris*. They're *thongs* in Australia. *Tsinelas* in the Philippines and *chinelos* in Brazil. Archaeologists have even discovered an Ancient Egyptian pair made from leather, dating from approximately 3,500 years ago (Yasukawa & Page, 2017).
"Over three billion people can only afford that type of shoe," says Erin Smith of Ocean Sole, a conservation group and recycling collective. "They hang on to them, they fix them, they duct tape them, mend them and then usually discard them." The average lifespan of a flip flop is two years, she adds.

Flip-flops are ubiquitous around the world, inexpensive and millions of them are discarded

Footwear waste, San Lorenzo (IM). image of the author

every day. Additionally, they're made of synthetic rubber and therefore not biodegradable. For this reason, tons of them are washing up on the East African Coast.
A significant quantity of the pollution which appears on East Africa's beaches come from discarded flip flops – approximately 90 tons a year, says Ocean Sole (Ocean Sole, n.d.).

They're not only an eyesore, but a direct health hazard to human and marine life, and with no hope of biodegrading. When discarded, they don't go away, they stay forever in landfills or make their way into the ocean. They contaminate the environment by emitting chemicals into the soil and many of them are made of some plastic compounds that can not be incinerated because of air pollution and health concerns.
In general, experts say that the global footwear industry will be worth more than 95 billion dollars by 2025. Every year, more than 20 billion shoes are manufactured. The manufacturing process releases large amounts of carbon dioxide. It is responsible for 1.4% of GHG emissions in the world. A pair of sneakers generates 30 pounds of CO_2 emissions, keeping a 100-watt light bulb on for a week (di Napoli, 2022).
A possibility is to produce green alternatives such as flip flops, or more generally soles, that are biodegradable, from natural resources. Since the escalating consumption of footwear tends to accumulate the synthetic polymers as waste disposal in our environment, it is imperative to develop the footwear components with biodegradable properties (Bernardini et al., 2015). In this way, whenever they end up, they will not damage the environment.
Below are some case studies of the use of sustainable materials in the footwear industry.

Above and side
Footwear waste, San Lorenzo (IM).
image of the author

Ghost Sneaker

Orba shoes

New Zealand

The shoes are crafted from carefully chosen materials, ensuring biodegradability and compliance with relevant ISO standards for casual footwear. The Orba sole incorporates natural compounds like titanium dioxide and zinc, commonly found in sunscreens. These compounds enhance color retention and UV resistance, effectively delaying the sole's degradation over time. Beeswax, along with traces of pine resin and sulphur, is added as natural preservatives to improve sole performance. These compounds are natural, non-toxic, and environmentally safe, comprising less than 2% of the sole's weight.
To further enhance sustainability, Rice Husk Ash, a by-product of rice production, is utilized as a "Biosilica" in the shoe's construction. Additionally, coconut oil replaces petroleum-based oils, and smoked natural rubber is employed. Smoking acts as a natural preservation method and enhances the rubber's hardness and durability, resulting in improved overall shoe performance.

Boots

Bottega Veneta

Italy

Bottega Veneta has patented an eco-friendly, biodegradable material for footwear production. This material combines sugar cane and coffee to create a unique blend, forming boots that blend elements of boots and clogs. These boots are fully biodegradable due to the use of natural molecules from sugar cane and coffee, replacing synthetic chemicals.
When placed underground or in controlled environments, these boots decompose within approximately one year. Suitable lighting, humidity levels, and the presence of microorganisms contribute to the degradation process. Bottega Veneta's achievement of being the first luxury brand to receive a LEED certificate highlights its commitment to sustainable practices.

Sea Sense

Sea Sense

United Kingdom

Sea Sense flip-flops are crafted using natural rubber, making them not only environmentally friendly but also remarkably gentle, supportive, joint-friendly, and devoid of blistering issues.

This rubber is sourced from Vietnamese forests, where it is responsibly obtained from rubber trees without any need for deforestation. The farmers involved in this process receive fair compensation and work under favorable conditions. Additionally, the rubber is dyed using natural dyes, ensuring a sustainable coloring method. Notably, the production process of Sea Sense flip-flops has been ethically certified by PETA, affirming its adherence to vegan principles.

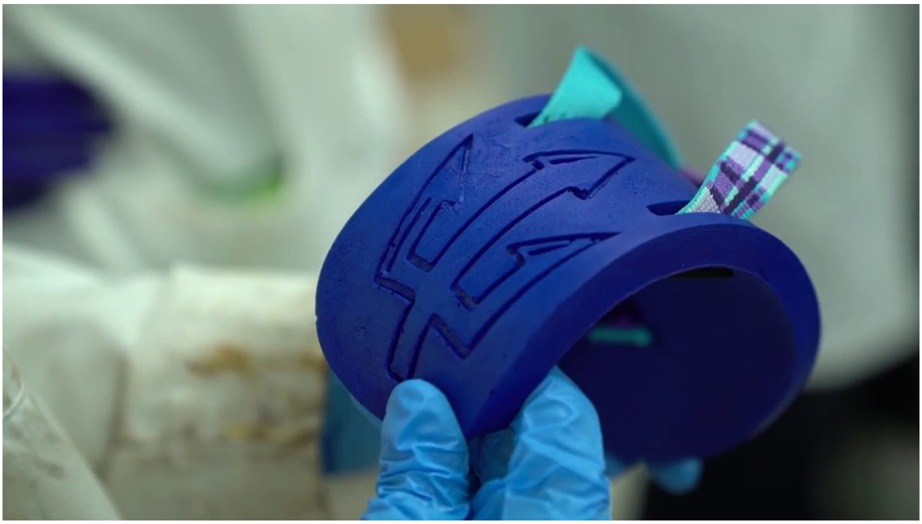
The rubber is then skillfully molded into flip-flops using specialized "cookie-cutter" molds. These plant-based and biodegradable flip-flops exhibit exceptional durability, surpassing the longevity of other plastic-based brands.

Flip flops

UC San Diego & Algenesis

California

Sticking with their chemistry, the team of researchers formulated polyurethane foams, made from algae oil, to meet commercial specifications for midsole shoes and the foot-bed of flip-flops. The results of their study are published in Bioresource Technology Reports and describe the team's successful development of these sustainable, consumer-ready and biodegradable materials.
The research was a collaboration between UC San Diego and startup company Algenesis Materials—a materials science and technology company.



_ EWAP: THE PROJECT

↘ Naming

The name 'EWAP' has a dual meaning. On the one hand, it recalls the acronym 'EVA', which is associated with a common polyethylene-based rubber called Ethyl Vinyl Acetate. EVA is a plastic material known for its many characteristics, including high strength and flexibility. Therefore, it is often used in the footwear industry.
On the other hand, 'EWAP' stands for 'Enhance Wasted Aquatic Plants', expressing the aim of the project in a simple and straightforward manner. This name emphasises the intention to improve the utilisation of wasted aquatic plants, highlighting the aspect of enhancing and optimising natural resources.

↘ The process

The project is centered around the utilization of abundant aquatic invasive vegetation sourced from eradication operations in the Po River in Turin as the primary raw material for production. The main objective is to identify suitable applications for this waste material, integrate it into a production process,

Side
Barbara Gwóźdź, Studio Tang.
image of the author
Below
The Seaweed Archives, Studio Tang.
© Barbara Gwóźdź

and enhance its value, thereby achieving economic, environmental, and social benefits. A "Do It Yourself" (DIY) approach was adopted, utilizing cost-effective and low-tech materials and technologies, eliminating the need for professional machinery during the production phases. The raw material was used in its natural state without undergoing chemical treatments or derivative extraction processes. Moreover, the aquatic vegetation exhibited favorable characteristics for the development of bioplastic materials, and a sustainable biomass supply strategy can be implemented due to its rapid growth, even in polluted environments, independence from soil dependency for growth, and classification as a carbon-neutral substance.

The primary aim of this project is to produce a bioplastic material that can match the properties of conventional plastics/foam typically employed in the production of shoe soles and flip-flops, while also being biodegradable. The process involves experimental designs discovered through a desk research, particularly on the Materiom platform—an open-source online community comprising chemists, designers, and engineers who share their research. Insights from previous studies conducted by Studio Tang were also considered. Although limited information on the utilization of river aquatic vegetation for material creation is available in existing literature, the DIY approach was embraced. By consulting gray literature and examining case studies, three primary protocols were initially identified, leading to the subsequent development of nine recipes with minor variations. The process involves using water as a solvent in which various substances are dissolved. The 9 recipes can be found specifically in the recipe book.

In the course of the research, extensive investigations were conducted into the properties of various ingredients. Among these ingredients, a few constants emerged that remained constant throughout the exploration process. These key constituents include:

- Water, acts as an essential solvent in which other substances are dissolved. It plays a crucial role in creating the desired consistency and facilitating the mixing of the different components. As a universal solvent, water enables the formation of homogeneous mixtures and serves as a medium for the performance of any chemical reactions;

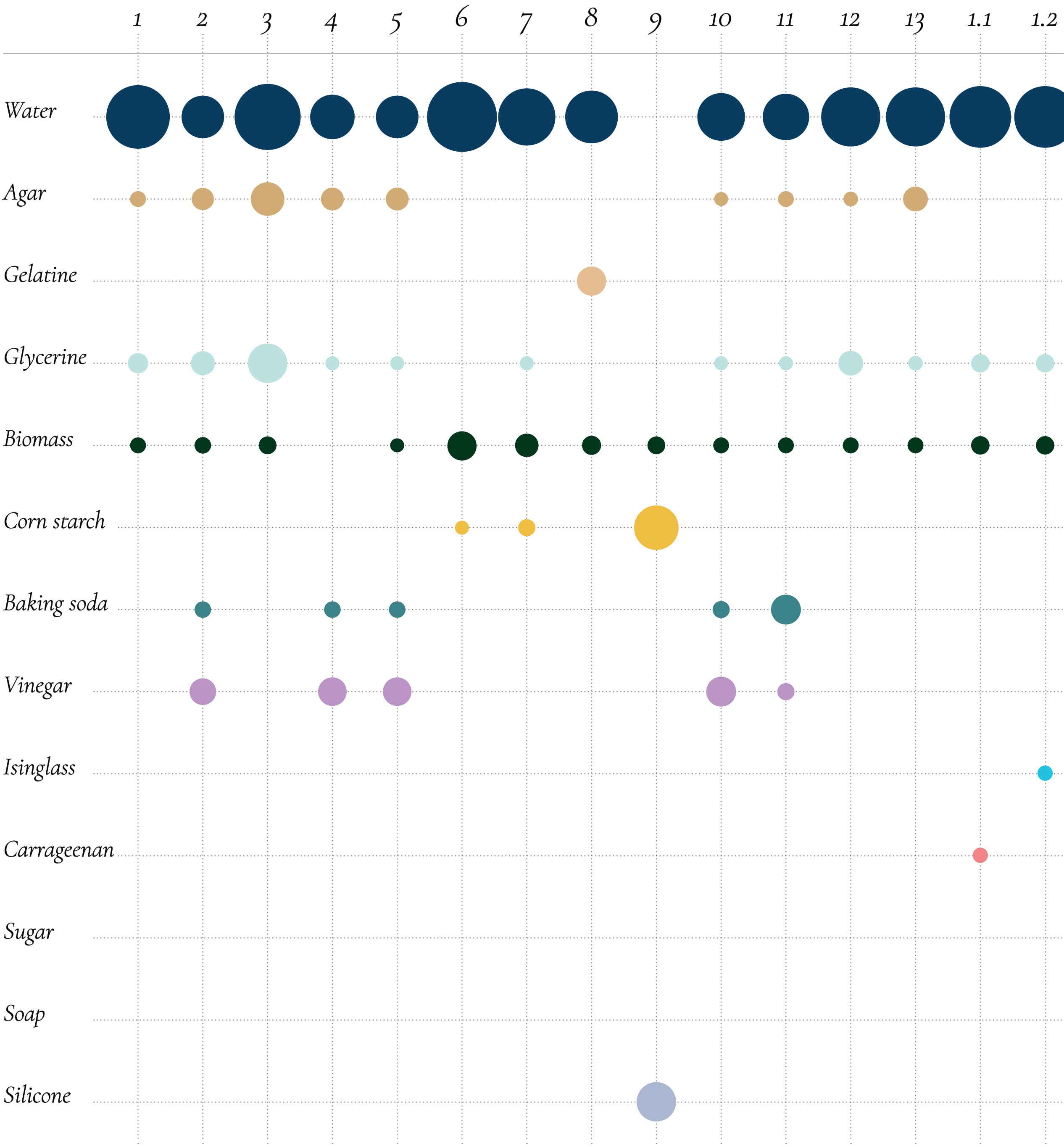
- Vegetable glycerine, is a natural plasticiser that is often incorporated into materials to improve their flexibility, durability and workability. It possesses exceptional plasticising properties, mainly due to its ability to attract and retain water molecules. In addition, vegetable glycerine is non-toxic, biodegradable and derived from renewable sources, making it an environmentally friendly choice;

- Natural gelling agents, such as gelatin, agar, alginate or corn starch are used to give strength and consistency to the resulting material, forming the polymeric component. Gelatin, derived from animal collagen, is a protein material commonly used in the food industry as a gelling and stabilising agent. Agar and alginate, on the other hand, are polysaccharides obtained from red algae and possess gelling, stabilising and thickening properties. These natural gelling agents act as binders, facilitating the cohesion of other substances and contributing to the formation of strong, flexible materials.

Through careful selection and combination of these ingredients, research aimed to develop a comprehensive understanding of their properties and interactions. This knowledge serves as the basis for the creation of innovative bioplastic materials with the desired characteristics, offering potential applications in various fields, including product design.

After an extensive evaluation of 9 initial recipes during the test phase, the identification of the most promising candidates necessitated their subsequent iteration in a wide range of variants. Consequently, 31 distinct samples were manufactured through a trial-and-error process. These samples were subjected to continuous monitoring of their responses and characteristics in a controlled environment that maintained constant temperature and humidity conditions for a period of 20 days. Through a selection process, 10 recipes were then chosen as the most favourable.
Subsequently, the aforementioned set of 10 materials was replicated using an alternative, larger mould to ascertain possible changes in the material. Care was taken to ensure an equal distribution of ingredients to facilitate a full comparison between the replicate samples.

Above and side
First 31 experiments conducted
image of the author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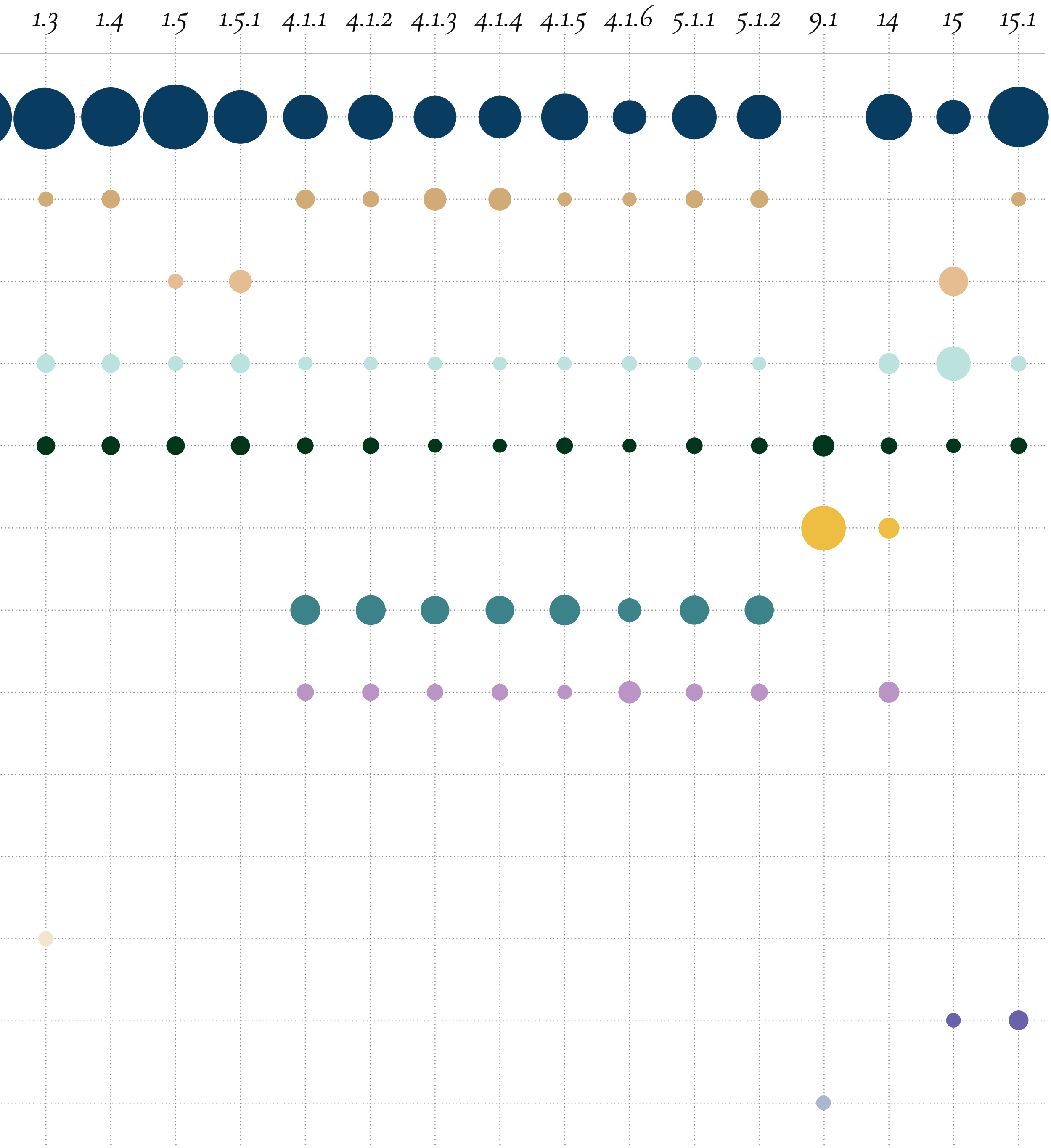
Baking soda
Vinegar
Isinglass
Carrageenan
Sugar
Soap
Silicone


1.3
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4.1.6
5.1.1
5.1.2
9.1
14
15
15.1

↘ Tools and ingredients

In the DIY experiment for the creation of a biobased biodegradable material, we focused on the use of readily available ingredients to make the process accessible to everyone. water was chosen as the main solvent, as it is widely available and safe to use. the addition of plasticisers such as agar, gelatine or cornflour powder was then explored to improve the properties of the resulting material.
To begin with, the ingredients were carefully measured and mixed in appropriate proportions using household tools such as hot plates, cooking pots and various mixing utensils. The intention was to create a simple and accessible process for anyone who wanted to try making the bio-based material.

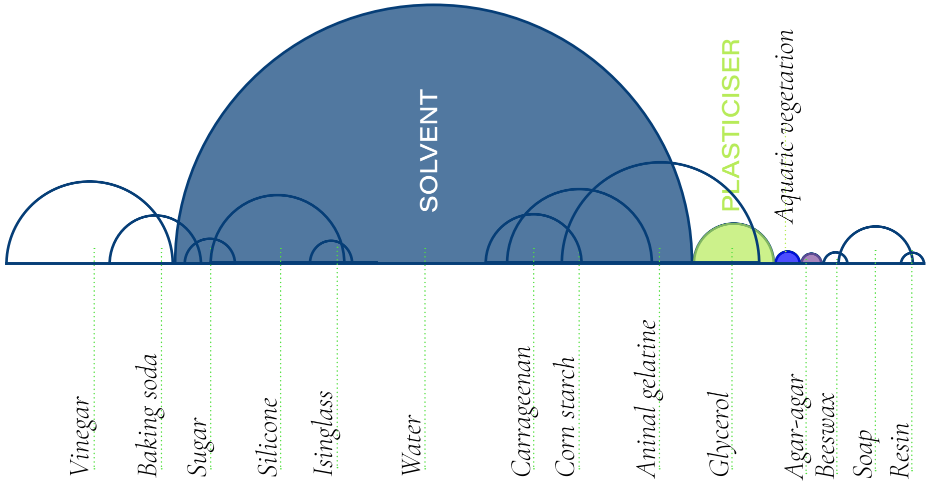
Next, various ingredients were tested to evaluate their effect on the mechanical properties and water resistance of our material. Such as beeswax, resin and sugar to observe possible improvements. care was taken to keep track of the quantities and proportions used so that the impact of each ingredient could be assessed and experiments could be repeated.
After obtaining the desired mixture, we poured the mixture into moulds. To create the moulds, pastry tools and other household utensils were used, which we modified to obtain the desired shapes, ensuring that the moulds were sufficiently strong and easy to use.

Once the material was poured into the moulds, it was allowed to harden and


Beaker
Mould
Frame
Scissors
Ruler
Hotplate
Spatula
Mould
Saucepan
Mould
Measuring spoon
Thermometer
Post-it
Scale


Sugar
Vegetable biomass
Carrageenan
Isinglass
Corn starch
Vinegar
Agar agar
Beeswax
Soap
Baking soda
Animal gelatine
Resin
Glycerine
Water

dry completely. This allowed us to observe the final properties of the bio-based material, such as strength, flexibility and the ability to maintain the desired shape. Throughout the process, the results and observations were noted in order to refine and improve the creation method. The experimentation demonstrated that it is possible to create biobased materials that are biodegradable using resources that are accessible to all. This process opens up new possibilities for innovation and creativity in the field of ecological biobased materials.



↘ Experimental development

The development process of a new biobased material was characterised by the use of the trial-and-error method. Therefore, after an initial phase of literature research and case studies, a test phase was conducted in order to mainly understand the behaviour of the ingredients in certain situations, both in contact with each other and when mixed with other ingredients. In addition, following each testing phase, analyses of the collected data were carried out in order to obtain a detailed understanding of the cause-effect relationships between the ingredients and material properties and thus identify the most suitable ingredients or formulations to achieve the set objectives. Importantly, the process was not without its challenges and obstacles. The trial-and-error approach required multiple iterations, where test results and data analyses guided the refinement of formulations and the selection of the best ingredients. A flexible mindset and continuous learning ability was required to adapt to test results and make significant improvements to the biobased material in development.

Ultimately, the research and development process was characterised by an experimental approach, which provided valuable knowledge on ingredient compatibility and material performance in different situations.

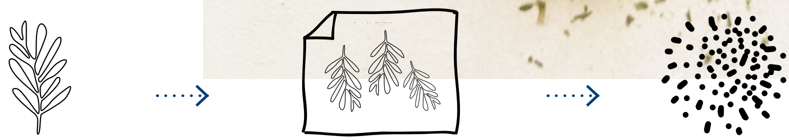

1 filler
3 protocols
#001
#002
#003
31
recipes
tinkering
test
"top"
10
tinkering
test
3 recipes
#001
#012
#015
tinkering
test
#015
base recipe for further development

↘ *First phase: the filler*

The initial phase encompasses the collection and subsequent dehydration of the aquatic vegetation fraction. Once the vegetation is gathered from the river, the fronds are left to naturally desiccate at ambient room temperature, typically ranging between 17-19ºC, for a duration of one week. During this period, moisture content decreases as the fronds gradually lose water, resulting in the desired dehydration.

Following the dehydration process, the fronds undergo a grinding procedure utilizing a professional-grade kitchen blender. The grinding continues until the fronds are transformed into a powdered substance, characterized by fragments ranging in size from 0.01 cm to 0.3 cm. This transformation into a powdered form allows for ease of handling and integration into subsequent stages of the experimental process. It is essential to highlight that this specific dehydration and grinding process is conducted only once, serving as a standardized procedure applied uniformly across all subsequent tests.

The filler image of the author



Collection

Dehydration
17-19°C - 1 week

Grinding
0.01 - 0.3 cm

↘ *Protocol N.001*

For the experimental testing, a nonstick pot is utilized, employing an electric hot plate as the heat source. Each individual ingredient is precisely weighed and subsequently combined within the aforementioned pot.
The overall processes involved can be succinctly summarized into four distinct steps. The initial step, which remains consistent across all recipes, involves the amalgamation of water, glycerine, and a gelatinizing agent, such as agar or gelatine derived from animals. These ingredients are thoroughly mixed to achieve a homogeneous blend, ensuring the uniform distribution of components throughout the mixture. Subsequently, the mixture is subjected to gradual heating on an electric hot plate, steadily reaching and maintaining a temperature range of approximately 85-90°C. This controlled heating process is vital in attaining the desired adhesive consistency, which is a critical factor in the subsequent stages of material formation and shaping.
Once the target temperature range is attained, as determined by measurements using a kitchen thermometer or the onset of bubbling, the vegetable component is introduced into the mixture with, ensuring thorough integration while continuously stirring. This approach prevents undesirable scorching or burning of the ingredients. Upon achieving a well-homogenized composition, the prepared mixture is transferred into silicone molds, which were selected for their advantageous characteristics that facilitate easy removal of the sample once it has undergone the drying process. The duration of the samples' stay in the molds varies depending on the specific recipe, ranging from 10 minutes to an hour. The optimal time for extraction from the molds is determined by the adequate thickening of the material, leaving no residue on the mold's surface. To facilitate complete drying, the samples are placed on a breathable surface composed of a wooden frame and mesh fabric. This arrangement effectively prevents the accumulation of condensation within the silicone molds, which could potentially contribute to mold growth, as observed in initial trial runs. Moreover, the breathable surface ensures consistent and uniform drying conditions, facilitating efficient moisture loss.

Following the aforementioned steps, the final phase of the drying process takes place under ambient room temperature conditions, typically ranging from 20-22°C. The data gathered during the experimental investigation has demonstrated that complete drying occurs within a timeframe spanning approximately the 15th to the 20th day. Throughout this period, the sample gradually undergoes a reduction in volume as it progressively loses all the water content originally present.

During the course of the study, various drying methods were explored, including UV lamp drying and hot thermoforming utilizing electric hot plates. These methods were investigated to assess their effectiveness in achieving optimal drying outcomes. Comprehensive analysis and comparisons were performed to determine

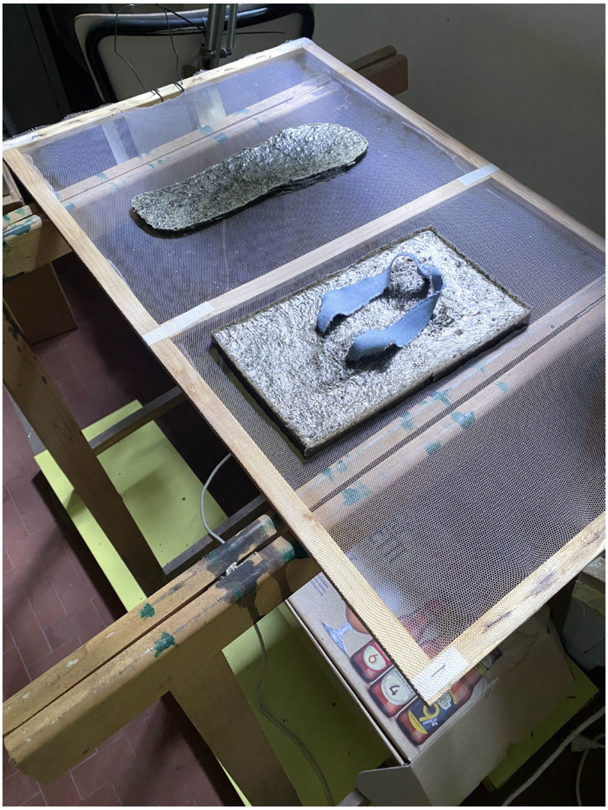
Agar Bioplastic

Protocol N.001

INGREDIENTS
80ml water / 3gr agar / 12ml glycerine / 4gr aquatic vegetation

PROCESS
Mix water, agar agar and glycerine in a saucepan and put it on the hot plate.
Stir until the mixture just below boiling temperature (about 90-95°C).
At this point, add the vegetation.
When the mixture begins to boil, remove it from the flame and continue stirring.
Pour the liquid in the mold.
Let stand for 30-60 minutes until solidified, then remove from the mold and continue drying at room temperature for 1-2 days.

Above and side
Drying methods.
image of the author



the most suitable drying technique for the specific material compositions under investigation. It is important to emphasise that the information provided refers to the basic recipe, while the specific characteristics of the samples vary depending on the precise quantities of each ingredient used in their formulation.

Two other basic protocols were later identified, which differ in the incorporation of additional ingredients during the mixing phase.

↘ *Protocol N.002*

The first recipe introduces vinegar, an acidic component, and bicarbonate of soda, commonly known as baking soda, into a solution composed of water, glycerine and agar. After mixing, a chemical reaction occurs in which the acetic acid (CH_3COOH) in the vinegar reacts with the bicarbonate ($NaHCO_3$), resulting in carbon dioxide (CO_2), water (H_2O) and sodium acetate ($NaC_2H_3O_2$), a salt compound. This reaction induces effervescence and the formation of bubbles within the mixture, resulting in a more porous material.

Foamy Bioplastic

Protocol N.002

INGREDIENTS
33ml water / 11gr agar / 1,3ml glycerine / 4gr aquatic vegetation
16ml vinegar/ 4,5gr baking soda

PROCESS
Mix water, vinegar, agar agar and glycerine in a saucepan and put it on the hot plate.
Stir until the mixture just below boiling temperature (about 90-95°C).
At this point, add the vegetation.
When the mixture begins to boil, add the baking soda and continue stirring. Then remove it from the flame.
Pour the liquid in the mold.
Let stand for 10-30 minutes until solidified, then remove from the mold and continue drying at room temperature for 1-2 days.

↘ *Protocol N.003*

In the second recipe, dish soap, which acts as a surfactant, is incorporated into the base mixture. Through the mechanical action of stirring, a foam is formed due to the entrapment of air within the liquid. As the solution is stirred, the surface of the mixture expands, facilitating the dispersion of air in the liquid. The soap, acting as a surfactant, decreases the surface tension and improves the stability of the foam by increasing the elasticity of the solution.

“Two-tone“ Bioplastic

Protocol N.003

INGREDIENTS
30ml water / 23gr animal gelatine / 30ml glycerine / 3gr aquatic vegetation / 3gr soap

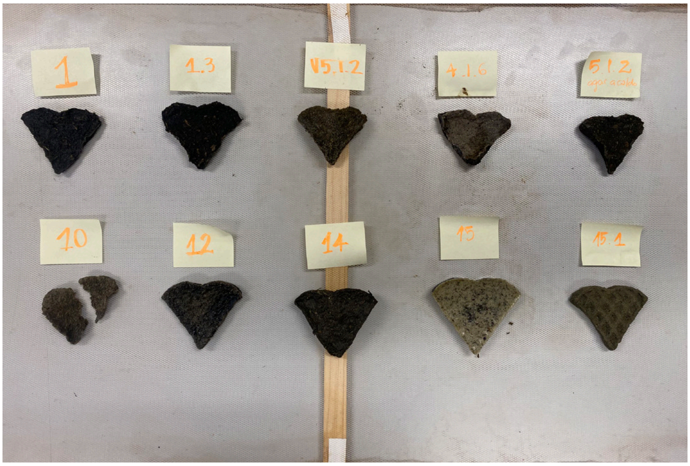
PROCESS
Heat water, gelatine and glycerine to medium temperature.
Stir for a few minutes until the mixture thickens slightly (about 90-95°C).
When the mixture begins to boil, add the vegetable part and continue stirring.
After a minute add also the soap.
Stir about a minute, then remove it from the flame and pour the liquid in the mold.
Let stand for 10-30 minutes until solidified, then remove from the mold and continue drying at room temperature for 2-3 days.

↘ *From 3 protocols to the "top-10" recipes*

Next, the ten materials with the most suitable and rubber-like characteristics were carefully selected. As previously outlined, these materials were then reproduced using a different silicone mould from the one previously used. The new mould was approximately 1 cm high and had a textured bottom, reminiscent of shoe soles or slippers, designed to prevent slipping. In particular, the following recipes were selected (named with numbers in ascending order, as indicated in the separate recipe book):

- 1
- 1.3
- 5.1.2
- 4.1.6
- 5.1.2 (using re-heated agar)
- 10
- 12
- 14
- 15
- 15.1

After a drying period of about 20 days, a comprehensive evaluation of various characteristics was conducted, including the tensile and compressive strength, the shrinkage factor of the individual material, as well as the elasticity and hardness properties.



Side and below
"Top-ten" recipes.
images of the author

↘ *The 3 "podium-winning" recipes*

Based on these analyses, three recipes, Recipe 1, Recipe 12 and Recipe 15, were identified as the most noteworthy. Recipe 1 and Recipe 12 have in common the incorporation of agar as a plasticiser in their composition, but differ mainly in the amount of glycerine used. Recipe 12 uses twice as much glycerine as recipe 1, resulting in increased plasticity, tensile strength and reduced volumetric shrinkage during the drying process (39% compared to 58% in recipe 1). In addition, these two materials have a coarser surface texture than those formulated with animal gelatin.

As for material number 15, it incorporates animal gelatin as a plasticiser and has soap added to its composition. After drying, this material demonstrates exceptional resistance to both tension and compression, with a minimum volume reduction of only 15%. In particular, the introduction of soap gives the material a distinct characteristic: dual colouring. The material has a darker green hue, where most of the aquatic vegetation is deposited, while the surface shows a lighter green colour with a frothier consistency. This phenomenon can be attributed to the formation of air bubbles during the preparation of the compound.

In summary, the evaluation of these properties led to the identification of the three recipes mentioned above, each of which offers unique attributes and performance characteristics.

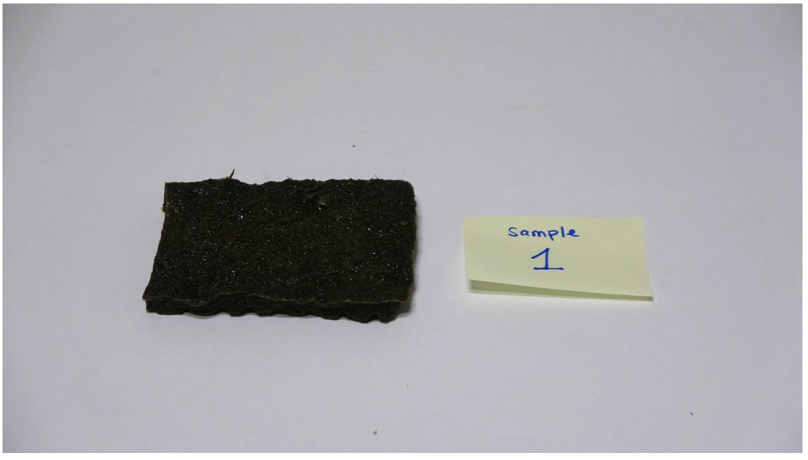
: "Top-three" recipes
image of the author

Agar Bioplastic

Recipe N.001

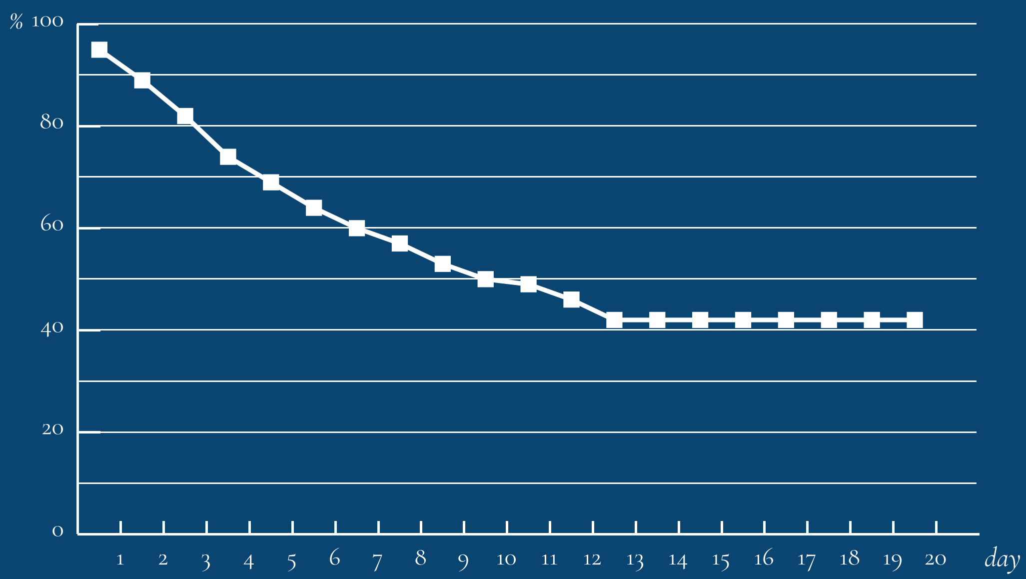
INGREDIENTS
240ml water / 9gr agar / 36ml glycerine /
12gr aquatic vegetation

PROCESS
Mix water, agar agar and glycerine in a saucepan and put it on the hot plate.
Stir until the mixture just below boiling temperature (about 90-95°C).
At this point, add the vegetation.
When the mixture begins to boil, remove it from the flame and continue stirring.
Pour the liquid in the mold.
Let stand for 30-60 minutes until solidified, then remove from the mold and continue drying at room temperature for 1-2 days.



Material Tinkering sheet

Volume reduction



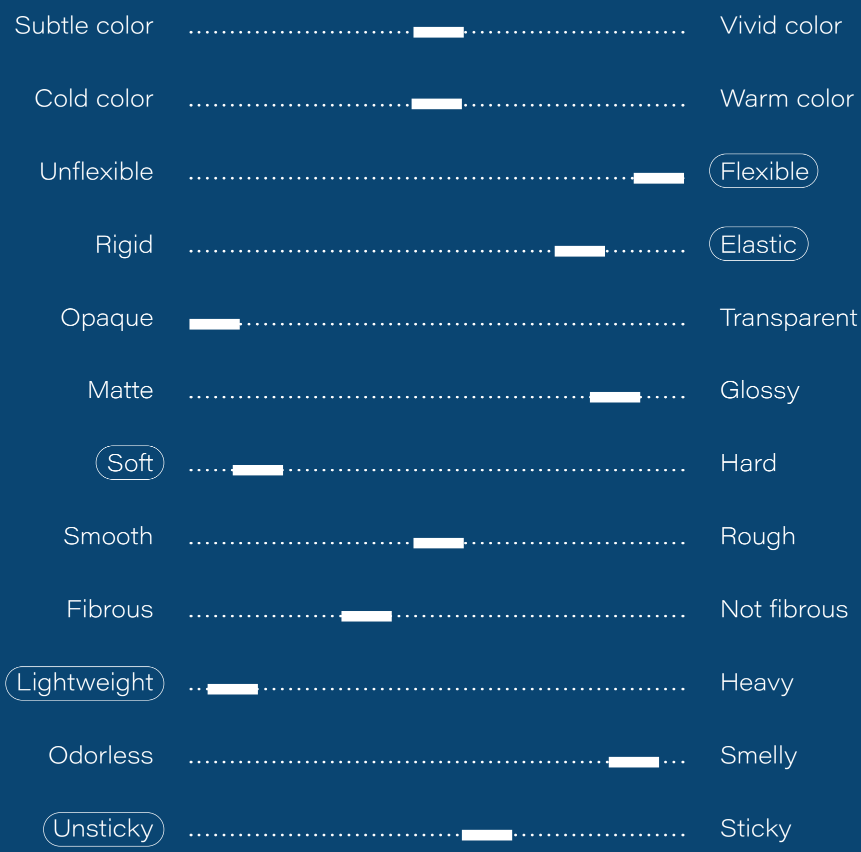
Agar Bioplastic

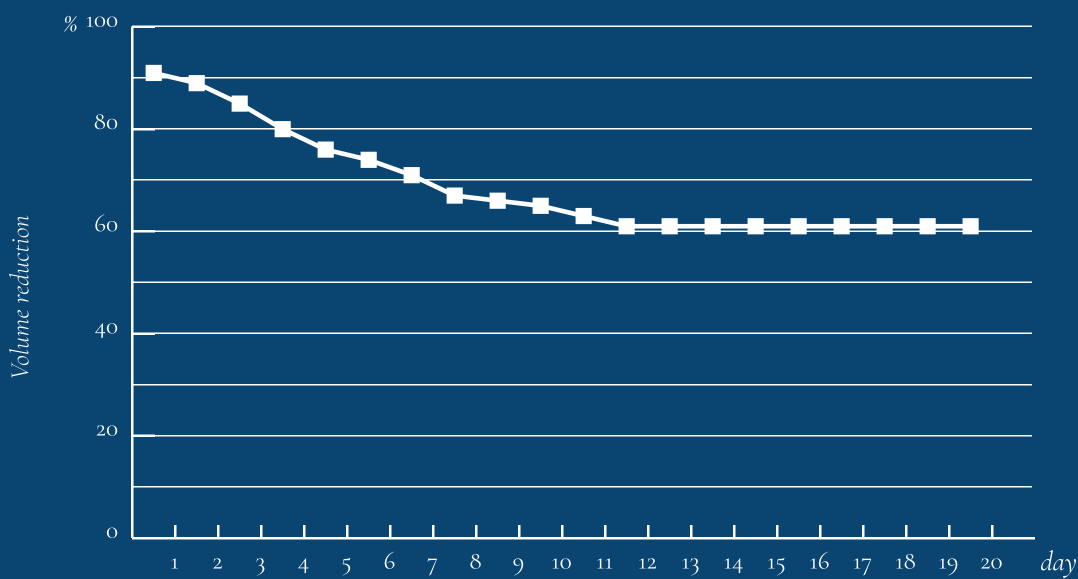
Recipe N.012

INGREDIENTS
240ml water / 8gr agar / 64ml glycerine /
12gr aquatic vegetation

PROCESS
Mix water, agar agar and glycerine in a saucepan and put it on the hot plate.
Stir until the mixture just below boiling temperature (about 90-95°C).
At this point, add the vegetation.
When the mixture begins to boil, remove it from the flame and continue stirring.
Pour the liquid in the mold.
Let stand for 30-60 minutes until solidified, then remove from the mold and continue drying at room temperature for 1-2 days.

Material Tinkering sheet





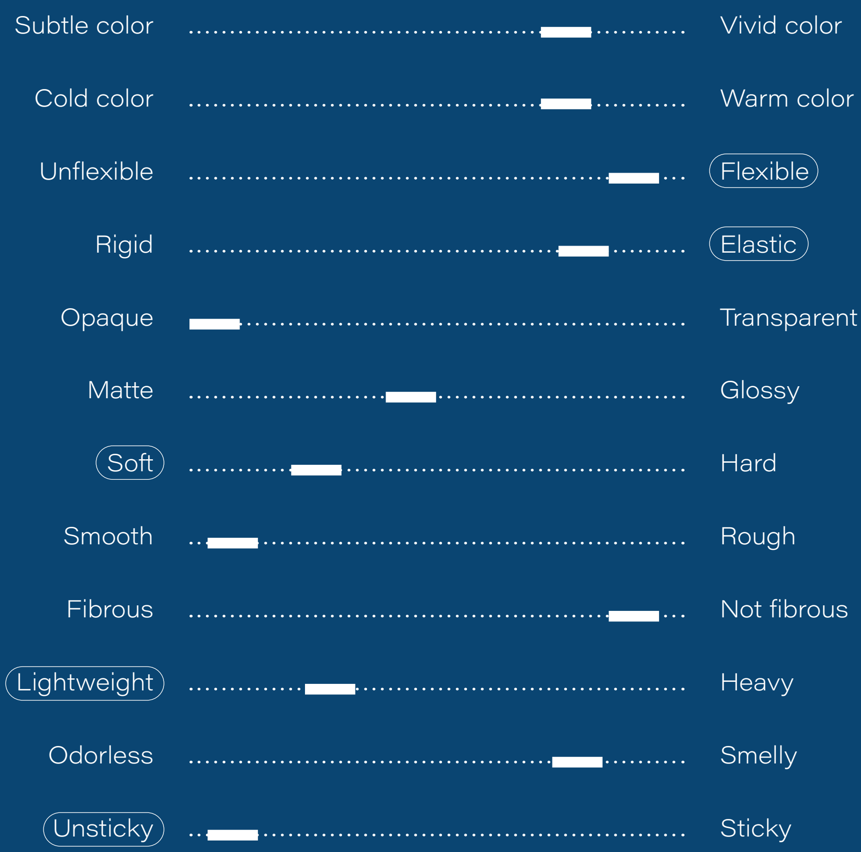
Gelatine Bioplastic

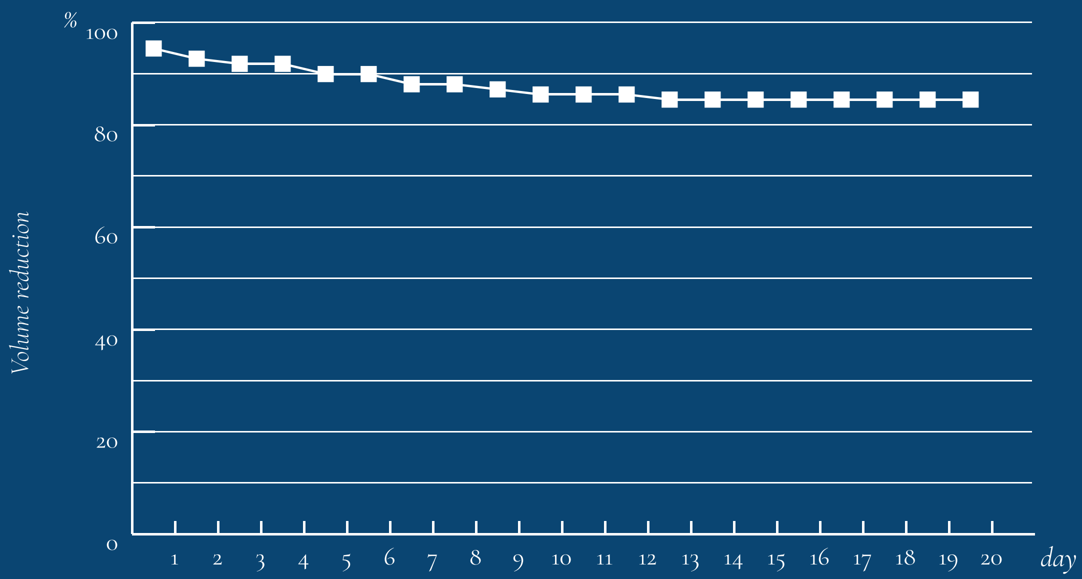
Recipe N.015

INGREDIENTS
100ml water / 50gr animal gelatine / 82ml glycerine / 10gr aquatic vegetation / 10ml soap

PROCESS
Heat water, gelatine and glycerine to medium temperature.
Stir for a few minutes until the mixture thickens slightly (about 90-95°C).
When the mixture begins to boil, add the vegetable part and continue stirring.
After a minute add also the soap.
Stir about a minute, then remove it from the flame and pour the liquid in the mold.
Let stand for 10-30 minutes until solidified, then remove from the mold and continue drying at room temperature for 2-3 days.

Material Tinkering sheet

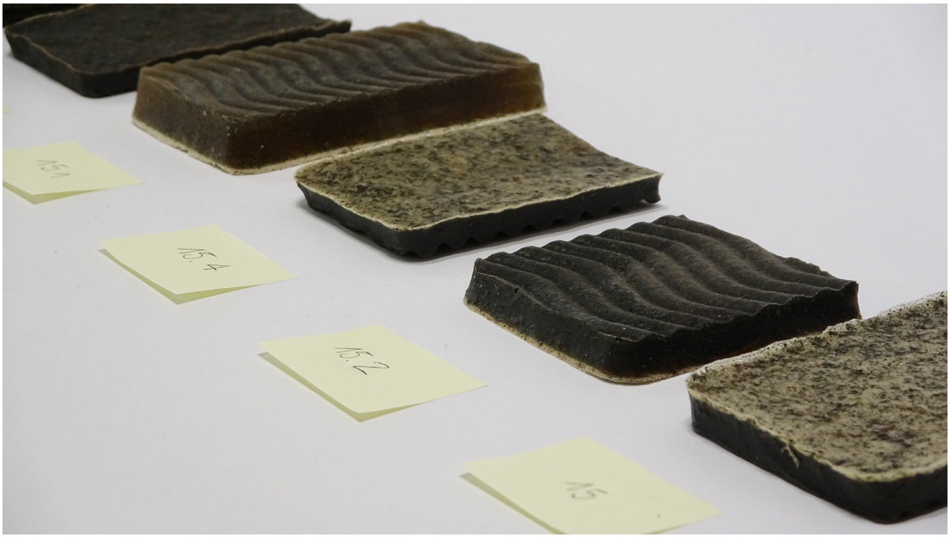




↘ *The final*

Among the three recipes tested (Recipes 1, 12, and 15), Recipe 15 has emerged as the most promising option due to its utilization of animal gelatin, which results in a lesser reduction in volume. Consequently, Recipe 15 has been selected as the foundation for further recipe development.
The comparative evaluation revealed that Recipe 15, incorporating animal gelatin as a key ingredient, exhibits a reduced tendency for volume reduction during the drying process. This characteristic is of significant value, as it allows for the preservation of the material's original dimensions to a greater extent. In contrast, Recipes 1 and 12, employing agar agar, resulted in more substantial volume decreases, which may pose challenges for consistent and controlled production methods.

After numerous tests during the Materials Experimentation phase, the most promising recipes identified were 15.3 and 15.4. These recipes proved to be superior in terms of tensile strength and volumetric reduction compared to the others. It was found that materials made from animal gelatine are more suitable than those made from agar agar, as they shrink less during the drying process. In addition, from an economic point of view, animal gelatine is cheaper than agar agar.

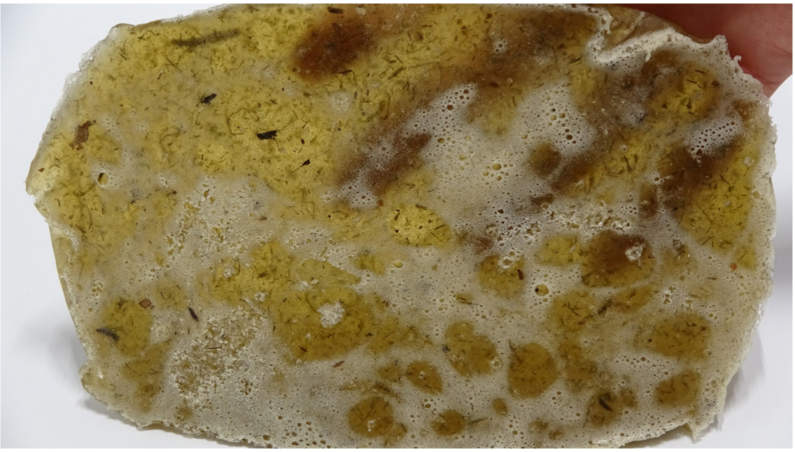


Experiments on recipe number 15
image of the author

↘ *Improvement tests*

Subsequently, recipe 16 was developed by combining the two previously mentioned recipes, which became the basis for subsequent modifications and tests. Recipe 16 has an adequate proportion of gelatin and glycerine to ensure good material strength and flexibility, but shows poor water resistance.
In order to improve resistance to water immersion, beeswax and pine resin were introduced in two separate recipes, but did not provide sufficient results. After much research and consultation with experts in the field, it was concluded that no natural element, used through the DIY method, could make the material completely hydrophobic. Therefore, to achieve greater water resistance, it would be necessary to resort to chemical elements that would compromise its completely natural nature and its biodegradability in the environment. Despite this, the material obtained would still remain largely natural (around 90%) and would be a replacement for fossil-based plastic, contributing to sustainability by avoiding the use of petrol.

Improvement tests
image of the author



↘ Further development

One possible strategy to increase the level of hydrophobicity of a material is through its chemical cross-linking. This process involves the creation of a three-dimensional network of chemical bonds between the molecules within the mixture, forming a structural lattice.
Cross-linking is commonly used in polymers to improve their strength, stability and mechanical properties, as well as the material's hydrophobicity. The resulting three-dimensional structure is solid and compact, reducing or preventing water absorption and giving the material hydrophobic or water-repellent characteristics.
To achieve cross-linking, a multifunctional monomer, such as polyethylene glycol diacrylate, was used together with a radical initiator, such as benzoyl peroxide. This combination made it possible to initiate a cross-linking polymerisation process. This reaction offers numerous advantages, including the possibility of adjusting the degree of cross-linking by varying the quantities of the two components used. To implement cross-linking, it is sufficient to add these components to the biomaterial mixture and then subject it to a temperature of around 60/70°C to initiate the chemical reaction.
A further development perspective for the material concerns the use of biomass from aquatic marine vegetation, using vegetation found on beaches. Preliminary tests have been conducted to assess the feasibility of using the same material formulation, replacing the filler of river origin with marine filler. It would be interesting to further study the behaviour of the different biomasses within the

Bioplastic with marine vegetation
image of the author

material and to understand their relative advantages or disadvantages. Initial evaluations seem to indicate that materials containing marine filler show less volumetric reduction during the drying process, which is promising.
In conclusion, the use of marine biomass could further expand the possibilities of material development, enabling the exploration of new characteristics and applications.

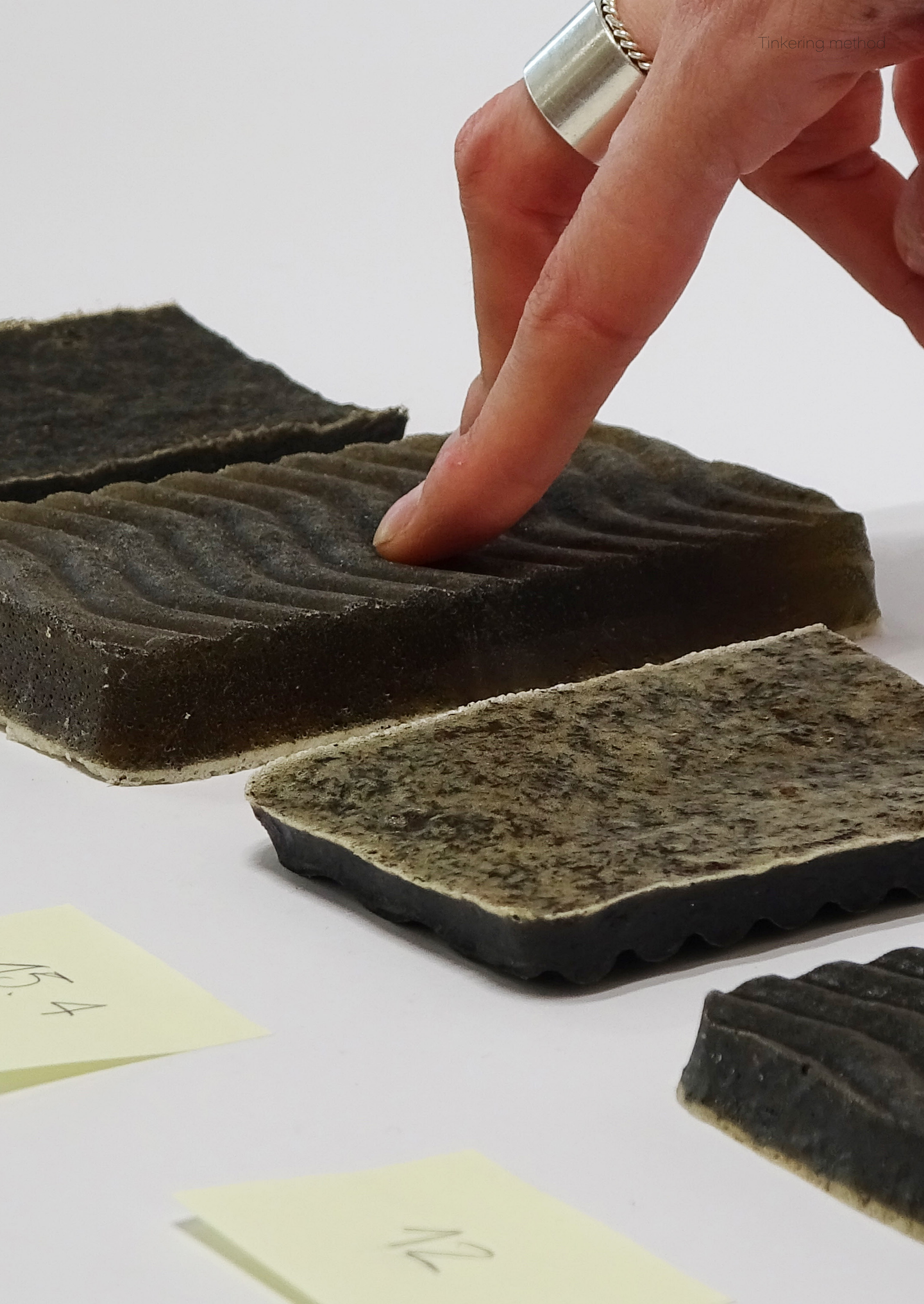
In light of the bio-based material's characteristics of flexibility and consistency obtained through appropriate proportions of the ingredients, a possible variant for use in the creation of yoga or gym mats was identified. Furthermore, its application in the creation of safety tiles for workout environments was evaluated. However, before proceeding with practical implementation, further tests will be necessary to assess the material's stability and durability, considering that these objects require good resistance over time. The possibility of using the bio-based material for such purposes represents an interesting field of application that deserves further investigation. To this end, a student from the Department of Environmental Engineering at the Politecnico di Torino will conduct a more in-depth investigation in the coming months. However, it is worth noting that this time the use of marine aquatic vegetation as an ingredient will be explored, bringing an additional dimension to the application of the material. This investigation will further investigate the feasibility and suitability of the bio-based material for the creation of yoga or gymnastics mats, as well as for the creation of safety tiles. Further tests will be conducted to assess the stability, durability and specific properties required for such long-lasting objects. This study represents an important step forward in the evaluation of the potential and applications of the developed bio-based material. The involvement of the Environmental Engineering Department of the Polytechnic of Turin will ensure a rigorous scientific and technical approach in the exploration of the possibilities offered by the combination of biobased material and marine aquatic vegetation.

Gym mat mockup
image of the author

↘ Tinkering method

The knowledge of materials is a fundamental topic for designers. Understanding the technical properties, sensory qualities, production processes and treatments of materials allows for selecting the most suitable material for each project. An effective method for learning such skills in a pratical and experiental way is Material Tinkering.

The term "Tinkering" refers to the activity of manipulating and hacking physical materials through an interaction characterized by creativity and collaboration based on Learn by Doing method. This approach is considered innovative internationally in the field of STEM (Science Technology Engineering Mathematics) and HCI (Human-Computer interaction) (Bevan et al., 2015; Zimmerman et al., 2007). Tinkering



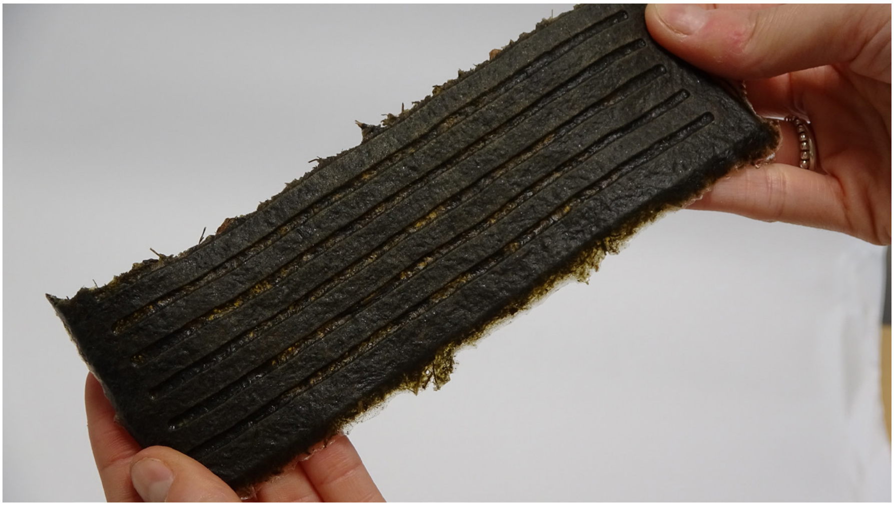
represents, therefore, a form of infAormal, playful and creative learning that stimulates the attitude to problem-solving through experimentation and learning based on error and pratical application, interacting directly with different materials, components and tools (Cermak-Sassenrath & Møllenbach, 2014).

As for the fiels of Material Design, the acquisition of knowledge about materials and processes constitutes a fundamental step in the training and practice of Material Designers. The purpose of Material Tinkering is to acquire data and knowledge through a pratical approach, considering both the technical properties and expressive, sensory, and experiential qualities of materials, thus recognizing their empirical properties but also their constraints and indentifying their potential (Karana et al., 2014).
Material Tinkering, applied to Material Design, is the art of creatively manipulating material for the purposes of discovery and learning, using an empirical approach based on experimentation and trial-and-error, sometimes revealing unpredictable and unique results. This methodology is characterized by total freedom for the sole exploration of materials, aimed at acquiring knowledge and generating hypotheses, as well as creating tangible material drafts. In fact, the physical results of the materials obtained through Material Tinkering are only experimental and incomplete, devoid of a specific purpose or integrated application. They are identified as "material drafts," or proposals for underdeveloped materials ready for further development or to be used as a source of inspiration.

Using this methodology, material designers have the opportunity to manipulate and experiment with materials, producing innovative samples with often unique characteristics. In this process, it is essential that the designer is open to interpreting the feedback that comes from material manipulation. Experiential learning, therefore, promotes the acquisition of knowledge and the development of procedural understanding. Indeed, Tinkering constitutes a powerful tool for material designers, who can thus expand their lexicon of experiences and build their aesthetic preferences (Parisi et al., 2017).
In the Material-Driven Design (MDD) method, a new methodology for exploring and designing materials that focuses on the notion of Material Experience, designing the experience that users will have with a certain type of material (Giaccardi & Karana, 2015), Material Tinkering is applied in the so-called "Tinkering with material" phase. The purpose is to understand the material through its direct manipulation, to further develop materials.

In addition to Tinkering with materials, there is also Tinkering for materials. The latter requires the declared intention on the part of the designer to investigate beyond the material drafts considered promising through Tinkering with materials, and to provide further development of them, as a project objective. The final result of the experimentation process is the so-called demonstrator materials, which become the demonstration of what the designer has in mind to

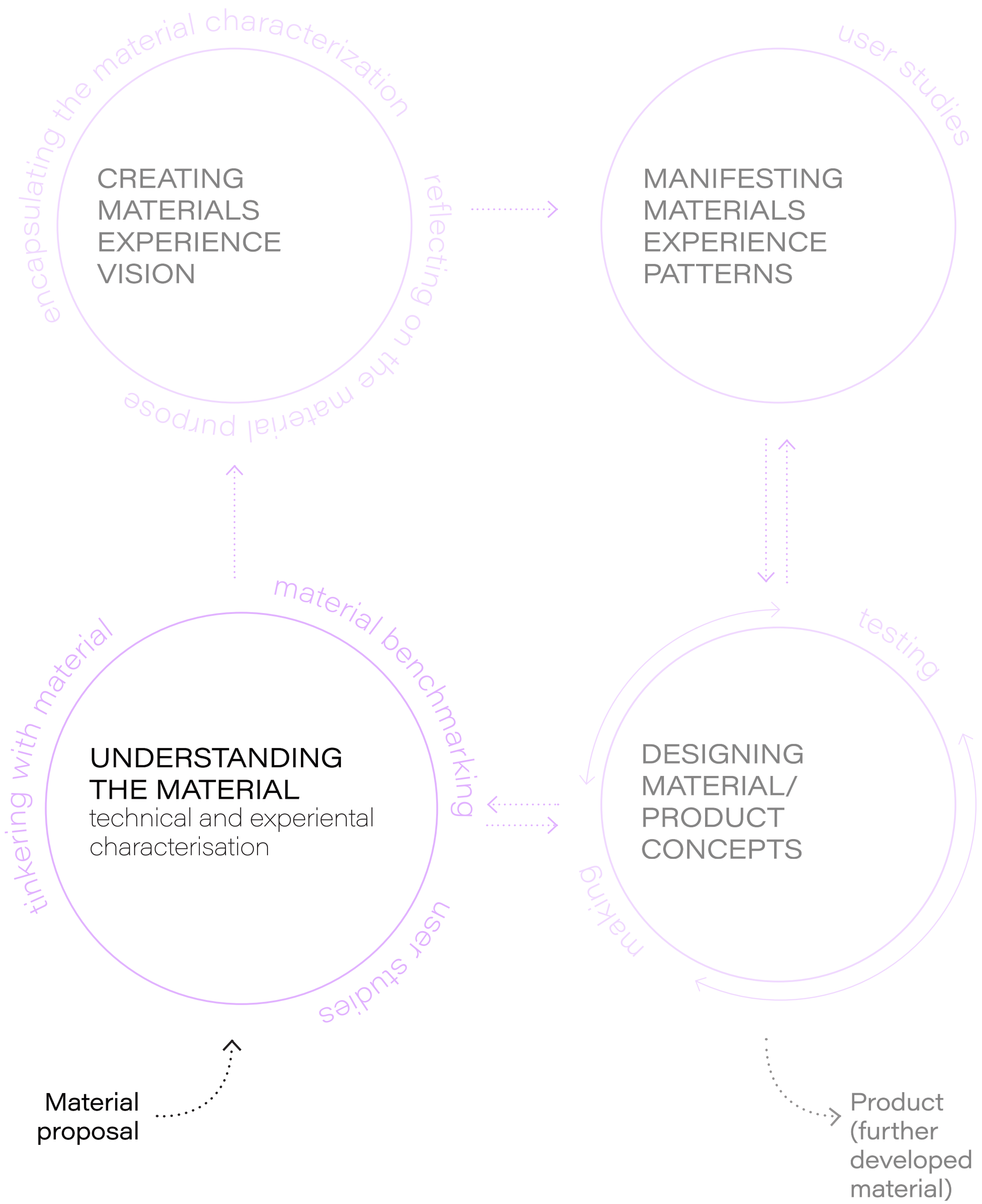
Below
Tinkering tests
image of the author



design, in terms of innovation of materials and processes. In contrast to Tinkering with materials, which only produces material drafts as a physical output.
This method and these direct experiments are often used by designers who want to develop low-cost, low-tech self-produced materials, also known as DIY materials, where designers can control the entire production process independently (Ayala-Garcia & Rognoli, 2019).
This practice implies an unconventional design paradigm. Typically, in standard industrial practice, engineers develop new materials, and only later do designers make these materials meaningful for users by experimenting with their sensory and expressive characteristics and seeking an application for them. Instead, with the adoption of an exploratory approach to DIY materials, designers initially conceive meaningful experiences with the materials, and only later do engineers work to make the design idea feasible and fully functional (Parisi et al., 2017).
The result obtained through the adoption of this methodology will consist of a series of sample materials, including drafts and demonstrators, characterized by different qualities and properties. Such materials will be accompanied by specifications regarding the formula, process, tools used, quantities, and final properties, thus configuring a sort of "recipe book," including photos, videos, and drawings (Rognoli & Parisi, 2021).
In conclusion, it is possible to affirm that Tinkering represents a discipline situated at the intersection of instinct and science, emotions and perseverance. In the case of Tinkering for materials, this discipline assumes an approach more inclined towards science, since the designer aims to program a precise end, moving from an open exploration to a more rigorous and scientific approach, especially regarding the realization of experiments. The ultimate goal of Tinkering remains the improvement of materials.

A connection can be noticed between Tinkering and the practice of crafting, intended as a manual creation process. This connection is in line with a growing trend in the design sector, defined as Craft 2.0, in which designers draw inspiration from the techniques, skills, and knowledge of traditional craftsmanship and adopt a self-produced, practical, and experimental approach (Micelli, 2016).
Material Tinkering could therefore be defined as a nostalgic return to traditional practices, but in reality, it represents precisely the opposite. In fact, it can be considered as an evolution towards the future and innovation, using craftsmanship as a source of inspiration and creativity to improve and qualify design. This practice can be considered as a creative engine for innovation and future development, improving and qualifying the culture of materials used in design (Rognoli & Parisi, 2021).

→
Source: Material Driven design. A method to design for material experiences. https://materialsexperiencelab.com/index.php/material-driven-design-method-mdd/


encapsulating the material characterization
reflecting on the material purpose
CREATING MATERIALS EXPERIENCE VISION
user studies
MANIFESTING MATERIALS EXPERIENCE PATTERNS
tinkering with material
material benchmarking
UNDERSTANDING THE MATERIAL
technical and experiental characterisation
user studies
testing
making
DESIGNING MATERIAL/ PRODUCT CONCEPTS
Material proposal
Product (further developed material)

↘ Application of Material Tinkering method

In this project, the Material Tinkering method was used to progressively identify the most suitable materials and their recipes to create a rubber-like material. A series of Tinkering activities were conducted to gain knowledge about the materials produced and their preparation, with the aim of obtaining materials suitable for further testing and development.
Initially, basic recipes, characterised by different amounts and types of ingredients, were manipulated to identify those with the desired physical properties, such as high tensile strength, tear strength and elasticity. Consequently, unsuitable materials were excluded, while others were used as samples for the development of better materials. Iterative modifications were made to production processes, drying techniques, moulding techniques, types and percentages of ingredients, as well as time and temperature parameters, in order to achieve the desired results.
Other properties, such as colour, surface type and finish, were also evaluated and characterised. Subsequently, once a group of materials with optimal physical properties had been identified, further tests were conducted to assess resistance to water, fire and cleaning chemicals. Each activity provided valuable information to understand the nature of the material and was based on knowledge gained during previous Tinkering activities.
All observations were recorded on special characterisation sheets, developed based on a model used in the pilot course 'Tinkering with Do It Yourself (DIY) Materials' at the Politecnico di Milano in 2015, and inspired by Elvin Karana's

→ *Example of Material Tinkering sheet.*

Tinkering sheet

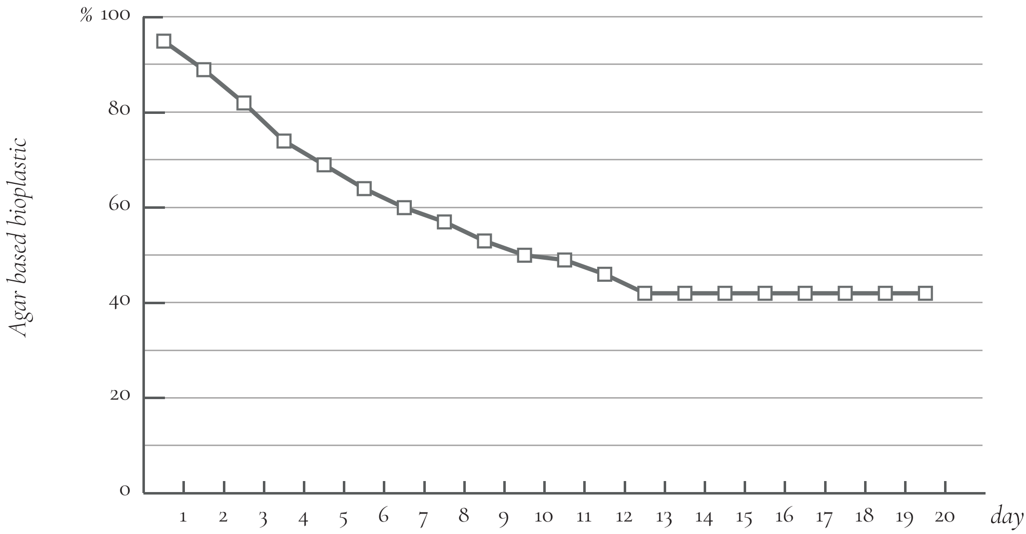
Subtle color	Vivid color
Cold color	Warm color
Unflexible	Flexible
Rigid	Elastic
Opaque	Transparent
Matte	Glossy
Soft	Hard
Smooth	Rough
Fibrous	Not fibrous
Lightweight	Heavy
Odorless	Smelly
Unsticky	Sticky

'Sensory Evaluation Scales' (Parisi et al., 2017). In that project, each material characterisation sheet consists of a list of 13 properties identified as most effective in determining the characteristics of a material. Each property is represented by three infographics indicating the two opposite levels and the moderate level of each property (e.g. transparency represented as transparent, translucent and opaque) (Karana et al., 2009).
The 13 sensory properties are divided into three main groups: tactile properties (pressure, force, friction and temperature), visual properties (light reflection and colour) and olfactory properties (odour). The model includes descriptive photographs of the material, name, description of the material and its properties, sensory qualities, ingredients and tools used and transformation processes.
For the present project, a sheet containing twelve variables was specially developed to identify the optimal material to meet the requirements set at the beginning of the study.

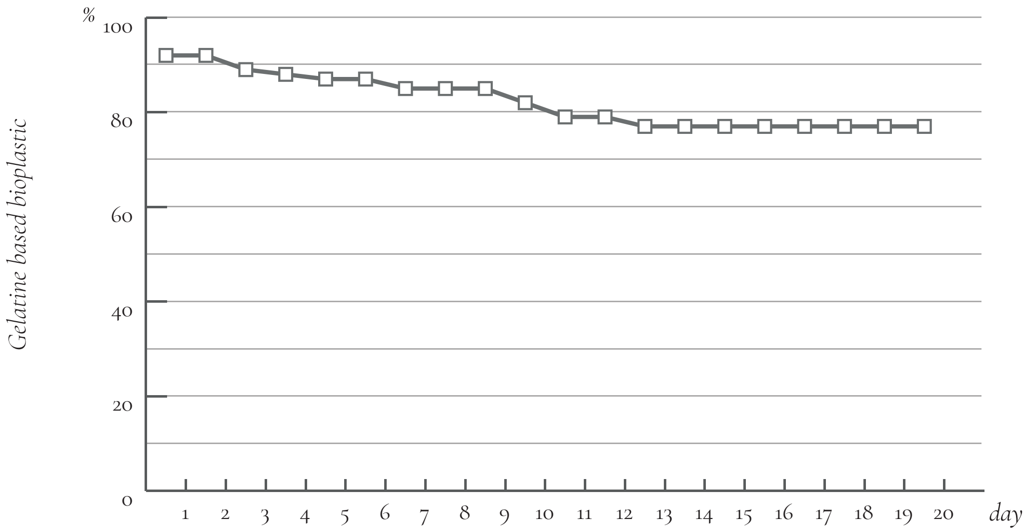
With regard to the determination of the shrinkage coefficient of the material, it was calculated as a percentage for each sample. Specifically, each sample was monitored for a period of approximately 20 days, during which daily measurements of length and width were taken. These measurements were used to calculate the area in square centimetres and compare it to the total mould area in order to determine the percentage of volumetric reduction. The samples that showed the greatest shrinkage were 60 per cent smaller than the initial measurements, while the sample with the least shrinkage shrank by 15%.
The decision to adopt a 20-day monitoring period was taken on the basis of the observation that, after 20 days of drying, the material was 'stabilised'. From around day 14 to day 20, no further changes in the sample measurements are observed.
Tests were then conducted on the water resistance of the different materials, using fractions of the samples obtained after the 20-day drying period. The samples were immersed in containers filled with water for periods of two hours, one hour and thirty minutes in order to assess the effects of water on each sample according to immersion time. The results of the tests showed that none of the samples could withstand one or two hours without being damaged. Some samples showed greater resistance than others after thirty minutes of immersion, however, all samples were irreversibly damaged after 30 minutes.

→
Volume reduction charts of differnt samples.

Sample 1



Sample 15.4



Above and side
Material Tinkering.
images of the author

↘ Discussions

The analysis of the results obtained during the testing and tinkering phase outlines the positive and nagative aspects of the material obtained. It is useful to consider the downsides as well as the upsides, as they can be the starting point for future developments.

↘ *Criticalities*

The plant biomass used in the development of the project derives from collections made in the Po River to tackle the problem of invasive exotic plants. Consequently, the raw material under study consists of a mixture of different types of vegetation, resulting in fragments of different colours, sizes and shapes. Therefore, the final samples will show slight variations between them due to the composition of the raw material. Although this may appear as a disadvantage from an industrial point of view, it can also be regarded as a distinctive feature of the DIY methodology.

One of the main challenges in the transformation process of river biomass concerns the volumetric reduction of the obtained material during the drying phase. All tests conducted involve the use of abundant water as a solvent and, consequently, the loss of water during drying to stabilise the material leads to

Above
Different colour shades.
Side
Volume reduction of the samples.
images of the author

results that are difficult to control with DIY methods. It was tested and confirmed during experimentation that materials tend to decrease in volume by 15% to a maximum of 60% of their initial volume. In particular, materials composed of agar agar were found to be more critical in terms of volume loss (40-60%), whereas the use of animal gelatine allows material samples to be obtained that reduce their volume only slightly (15-25%), thus obtaining materials very similar to those initially cast in the mould. In addition, the addition of liquid soap to the gelatin mixture helps to minimise volume reduction. This aspect is important to take into account when designing products or design applications.
Drying methods can have a significant impact on the final result of samples. Air drying at room temperature is a time-consuming method, but ensures a gradual loss of water and volume. The use of UV lamps accelerates the drying process, allowing stabilised material samples to be obtained in just one day. The lamps available in these tests are too powerful and tend to burn the material, making it too rigid for the purpose of this study. However, this limitation can serve as a starting point for the development of biomaterials that require high stiffness, such as building materials. In conclusion, it can be stated that the presence of water and moisture levels significantly influence production times.
The abundant presence of water also poses problems with the formation of mould. Therefore, it is necessary to work in a controlled environment, promote air circulation, avoid changes in temperature or pressure and constantly monitor the temperature as far as possible. It is important to remove the material from the mould as soon as it can be easily removed and to continue the drying process on a mesh surface, allowing uniform drying without condensation inside the mould. The continuous interaction with air, water, light and microorganisms can affect the progress of experiments and make it more difficult to conduct tests on these materials.

Another problem concerns the material's water resistance. Various methods have been studied to increase the material's resistance to water by adding natural substances, but tests have always shown failure. The material does not resist immersion in water and degrades irreversibly after an interval of 30 minutes.
Increased water resistance can only be achieved by adding chemicals that cross-link the molecular structure of the material, making it more resistant and hydrophobic. It would no longer be an environmentally friendly material, however, as its degradation in the environment would also release chemicals. However, it would still be a predominantly natural material that replaces materials of fossil origin.
A final issue concerns odour. Freshly manufactured samples emit an unpleasant odour that only dissipates during the drying period and only disappears completely one to two months after the sample has been produced.

Side
Mould formation on samples.
Below
Material alterations due to immersion in water.
images of the author

↘ *Advantages*

The main positive aspect of the material is the complete use of plant-derived materials, which is a significant strength of the research. Furthermore, as laboratory tests have shown, it is possible to generate the material without significant energy inputs, in line with the principles of the DIY approach used. Furthermore, it allows for the reintroduction of a material considered as an output of the river ecosystem in the creation of a new production system, according to the principles of systemic design. The initial material has no chemical or physical constraints that prevent its reintegration into production chains.
The artisanal approach inherent in the do-it-yourself methodology used during the experimental research indicates the vast development potential of both materials and processes. Using only commonly available tools such as pots, hotplates and everyday moulds, a wide range of materials with different properties can be developed. Furthermore, all measurements and recipes were properly documented using scientific methods to facilitate the replication of the experiments by other interested parties, thus fostering open-source knowledge. This also leads to the assumption that the material created in the laboratory could become the object of further study, up to and including a hypothetical patenting or engineering of the material.

A significant advantage obtained through this experimentation is the ability to obtain various materials with different levels of consistency and stiffness, always using the same basic recipe and only varying the proportions of the ingredients or introducing new natural ingredients. This indicates the versatility of the material and its potential for multiple applications. Although only one specific application was analysed in this study, preliminary tests suggest that the other materials obtained could find application in various sectors. Furthermore, they possess the ability to conform to any mould shape in which they are contained, as the initial compound is liquid and can adhere perfectly to any type of mould.

The material's behaviour when washed with water and alcohol is another positive aspect. Temporary exposure to cleaning the surface with a cloth does not cause structural damage to the material, which remains compact and cohesive. So does exposure of the material to running water for a limited period of time. Frequent washing could compromise the structure, as well as the temperature of the water, as higher temperatures lead to greater alteration of the material.

Another advantage of the material is its behaviour when exposed to a source of fire, such as a lighter. It does not ignite but melts slowly, becoming sticky, like plastics of fossil origin. Prolonged exposure to high temperatures, however, even without the use of a flame, makes the material a little sticky.

Above
Different shapes of the same material.
images of the author

A characteristic of the material is its anti-slip property, which enables it to provide a surface with increased grip and resistance to sliding. This characteristic offers several benefits in various contexts, including safety, injury prevention, and sports facilities, provides a secure and stable surface.

Finally, data collected from the first biodegradability tests show that the material's characteristics seem to make it suitable for biodegradation. The material dissolves completely in water after only 25 days of immersion. No tests were conducted on the physical and chemical residues of the biodegraded material. However, it has been observed that the natural sedimentation of the compound results in two distinct layers. The plant sediment remains at the bottom, while the water becomes turbid and contains dissolved substances. It would be necessary and interesting to conduct tests to identify the type of residue and analyse whether it contains environmentally harmful substances.

Side
Flexibility of the material.
Below
Material degradation.
images of the author

↘ Design proposal

As already mentioned, the aim of the research was to develop a material with a wide range of potential applications. In particular, the footwear sector was considered due to its well-known environmental impact, both in terms of production processes and the use of materials with a high environmental impact. Furthermore, footwear is not considered a durable good and reaches the end of its useful life relatively quickly, posing disposal problems due to the presence of different materials in a single shoe. Consequently, the research aimed to develop a pre-prototype of a rubber-like material to replace shoe soles, focusing in particular on the feasibility of flip-flops.

Flip flops are part of the "world" of fast fashion, being inexpensive and enabling over 3 billion people to afford a pair, according to Erin Smith of Ocean Sole. Their average lifespan is only a couple of years, after which they are discarded and thrown away. The contradiction lies in the fact that they are made of synthetic rubber, designed to last much longer than two years, and that they eventually leak into the seas and coastlines, especially in African regions. Most of the pollution on beaches, around 90 tonnes per year, comes from discarded slippers. Not only are they unsightly, but they are also a serious problem for human health. They have no chance of biodegrading; at best, they disintegrate into microplastics, invisible to the eye, which are highly harmful both to humans and to the ecosystem and environment.

Below
Sole stamping with mould.
images of the author

The objective is therefore to initiate an experimentation to ascertain the possibility of replacing fossil-based plastics used in shoes with a more environmentally friendly alternative derived from bio-based sources. It is important to note that through the DIY approach, the aim is not to develop a finished product ready for market release, but rather to create a pre-prototype that serves the purpose of assessing future feasibility.

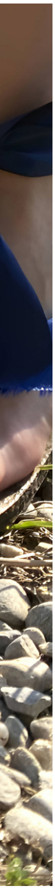
Given the do-it-yourself (DIY) methodology employed in the study, no moulds or specialised machinery were available, necessitating alternative methods. Initially, an attempt was made to create a mould using a mixture of silicone and corn starch by making a mould of a flip-flop. The mixture of silicone and corn starch produces an easily mouldable paste that, once dried, retains the given shape, creating a precise mould. it is then sufficient to impress the flip-flop into the created paste so that it adheres well, and then, after an hour for drying, to remove the object. However, this method proved to be a little too 'home-made' and inaccurate, as obtaining two identical moulds was difficult due to the rapid drying of the silicone, which allows limited time for modelling. In addition, the shrinkage of the material during drying was a complication. It would be necessary to make larger moulds and then, after the drying and shrinkage period, to obtain a slipper of the desired size. Consequently, it was decided to construct a rectangular mould into which the material was poured, allowing it to dry into a rectangular shape that would shrink without affecting the final shape of the flip flops. Only after the material had completely stabilised and dried was it possible to cut the desired shape of the sole.

As for the mould, a rectangular aluminium kitchen container was used, while a plastic sheet, used in confectionery, was placed on the bottom, textured to simulate the non-slip surface of a sole. In addition, the texturisation of the sole can contribute to increasing the stiffness of the material in question. In this case, these features can be considered analogous to ribs, which are structural elements usually integrated into a material in order to increase its rigidity and strength. The resulting effect is achieved through an optimised stress distribution and an increase in the material's cross-sectional area. In fact, a larger cross-sectional area enables the material to resist deformation and external stresses more effectively, reducing the risk of failure or damage.Consequently, sole texurisation represents a mechanism that can help increase the material's stiffness and improve its ability to resist external stresses and deformations.

For the sole shape, standard shoe sizes were followed, while an intermediate size corresponding to 38/39 was chosen for the mockup. In order to achieve optimal cutting precision, various methods were explored. In the end, the most effective method proved to be the creation of a specially designed mould for cutting the material.

Using a jigsaw, the shape of the sole was moulded onto a sheet of wood. Subsequently, this shape was contoured with a 0.6 mm thick sheet of metal. Before proceeding, the sheet was drilled and then fixed to the wooden support using screws. Once the mould construction was completed, it was used to stamp the material. The procedure involves placing the obtained biomaterial on a wooden base and positioning the mould on it. Through the application of pressure, also with the help of a hammer, the sheet in contact with the biomaterial will act as a shear. At the end of the operation, a precise and well-cut sole shape will be obtained. In conclusion, the use of a specially created mould has proven to be the most suitable method for achieving accurate and satisfactory cutting results. This approach makes it possible to produce sole lasts that are consistent with standard shoe sizes and overcome the challenges of processing biomaterials in the footwear industry.

The upper part of the flip-flop was not the focus of this thesis; however, it was planned to add a fabric strap that could be easily removed at the end of the product's life.
In summary, this study addressed the development of a pre-prototype of a rubber-like material to replace shoe soles, with a specific focus on the feasibility of flip-flops. The do-it-yourself approach was used to create the moulds used for testing. Further studies are needed to improve the accuracy and reproducibility of the moulds, as well as to assess the specific properties of the material and the suitability of the final product in terms of sustainability and environmental impact.



↘ Notes to the design proposal

The goal of replacing synthetic rubber with biobased materials in the field of footwear is very ambitious, as shoes are designed to be durable, whereas biobased materials are typically designed to be biodegradable. Furthermore, the DIY method does not allow for specific tests to be carried out to test the durability or strength of the material, as there is no suitable specific machinery available. However, the results obtained with the DIY methodology are very promising and open up interesting future scenarios. By using the biomass of aquatic plants instead of non-renewable resources, it is possible to reduce the dependence on fossil fuels and related greenhouse gas emissions in conventional plastic production.

Through numerous tests, the desired flexibility for a sole has been successfully achieved, and aquatic plant waste is effectively integrated into the material, forming its solid part. Furthermore, it is a material that can be easily processed in any situation and can take the shape of any mould into which it is inserted. In this case, the shrinkage of the material, mentioned earlier in this thesis, does not adversely affect the final product, as a rectangular mould is used. The aspect of biodegradability was also satisfied: the material is able to biodegrade in less than a month when immersed in water.

It should be noted that there are currently few 100% natural biobased materials that can match the properties of fossil-derived plastics. In particular, to improve

their properties, these materials usually undergo chemical polymerisation processes. For example, polylactic acid (PLA) is a bioplastic produced from renewable sources such as maize, sugar cane or potatoes. These materials undergo chemical processes to extract starch, which is then fermented to produce lactic acid and finally polymerised to create PLA.
Even the material developed from aquatic vegetation would still require a polymerisation process to improve its water resistance and flexural properties. With the help of Professor Marco Sangermano of the Department of Chemical Engineering at the Politecnico di Torino, two reagents were identified that would increase and stabilise the material's internal crystalline structure, making it more suitable for design applications. The material would still be considered biobased, being 85-90% natural, offering environmental advantages over traditional petroleum-derived plastics.
In this case, even though it is considered biobased, further in-depth studies on the material are needed, considering its entire life cycle in order to assess its overall environmental impact.

A critical issue encountered during the testing phase lies in the flexibility of the material. In particular, when trying to replicate soles for larger shoe sizes (40 and above), it was observed that maintaining the same level of flexibility, obtained in the first small sample sizes, becomes more difficult. As the shoe size increases, the material tends to become excessively soft. This problem can be addressed by the use of the same chemical reagents mentioned above, which, through the process of cross-linking the material, create a stiffer and stronger internal three-dimensional structure. As a result, an improvement in the material's mechanical properties, including strength, stiffness and thermal stability, will be achieved.
Further in-depth research will be needed to determine the optimal technique for using the material, either through polymerisation or by producing a composite material that combines bio-based and fossil-derived components.

In summary, the research aims to replace synthetic rubber in footwear with biobased materials and it has been proven that the results from the do-it-yourself approach are promising. The use of aquatic plant biomass provides a renewable alternative to fossil-based resources and the material has the desired characteristics of flexibility, integration of waste materials and biodegradability. Although only a few natural biobased materials can currently match the properties of fossil-derived plastics, ongoing research and development in this field offers the potential for further advances in sustainable materials for various applications.
In conclusion, the study yielded encouraging results, indicating the feasibility of replacing synthetic rubber with bio-based alternatives in footwear. It is worth noting that although few natural biobased materials currently equal the properties of fossil-based plastics, ongoing research and development in this field offer the potential for further advances in sustainable materials suitable for various applications.

_ CONCLUSIONS

This study shows promising results in using organic biomass waste collected from the Po River, or any other aquatic vegetation in a river, to create a bio-based material using a do-it-yourself (DIY) approach. Although initial results are encouraging, further improvements are needed to enable efficient full-scale applications. The use of local aquatic plant biomass offers several advantages and is in line with the principles of DIY biobased materials.

A key advantage of using local materials is the reduction of the carbon footprint associated with transport. By minimising the need for long-distance transport, greenhouse gas (GHG) emissions can be reduced, contributing to climate change mitigation. Furthermore, the use of local resources can support the local economy and potentially create new job opportunities, promoting the principles of the circular economy.
Furthermore, the use of aquatic vegetation as raw material does not compete with arable land used for food industry crops. Since aquatic plants do not require soil to grow, their use for the production of biobased materials does not interfere with food production. And finally, it has a very high growth factor, so it will always be easy to obtain raw material in a short time.

These two characteristics suggest that it is also possible to undertake controlled cultivation of sustainable aquatic vegetation, in contrast to this project, in which waste material was used. In this way, the criteria of systemic design are fulfilled, whereby what was considered waste, and therefore output of a system, is valorised and reintegrated me input for a new production system, thus minimising waste. The do-it-yourself approach used allows the properties and characteristics of materials to be explored through a trial-and-error methodology. It serves as a basis for future research and to establish further directions in the field in order to increasingly reduce the dependency on the use of fossil-based plastics. At present, the results obtained have great potential on a conceptual level. Next steps include the engineering of materials to improve the properties of the samples, making them viable alternatives to fossil-derived plastics in various applications beyond the fashion and footwear industry. Certainly, more in-depth experimentation will be needed to more precisely analyse and define the physical, chemical and mechanical properties. In this way, the material could also be entered into a materials library database, where it can be compared with other materials and possibly improved.

In summary, this study highlights the potential of a do-it-yourself approach to transform aquatic vegetation wastes into bio-based materials. The use of local resources reduces greenhouse gas emissions, supports the local economy and avoids competition with arable land for food production.

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