



Filtration System for Solid Surface Waste in Coastal Waters Based on Biomimicry and Circular Economy

Sistema de filtración de residuos sólidos superficiales en aguas costeras basado en la biomímesis y la economía circular

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Abstract: One of the biggest environmental problems in the world is the inadequate disposal of solid waste in the oceans. Therefore, this article aims to demonstrate the importance of biomimicry and the circular economy in the development of a boat with peculiar characteristics of the filtration system existing in the mouth of the Whale Shark, which is capable of filtering surface solid waste in coastal waters, submerged at a depth up to two meters. Therefore, the basis for the research focused on studies published in books, articles, dissertations, websites, magazines relevant to the topic, taking into account the methodological process of product design. Finally, the importance of Biomimicry, Circular Economy and Design as strategic tools to find innovative solutions in order to mitigate environmental problems was verified.

Keywords: *Biomimetics; Circular Economy; Waste; Sustainability.*

Resumen: Uno de los mayores problemas medioambientales del mundo es la inadecuada eliminación de residuos sólidos en los océanos. Por lo tanto, este artículo tiene como objetivo demostrar la importancia de la biomímesis y la economía circular en el desarrollo de un barco con características peculiares del sistema de filtración existente en la boca del tiburón ballena, que es capaz de filtrar los residuos sólidos superficiales en aguas costeras, sumergido a una profundidad de hasta dos metros. Por lo tanto, la base de la investigación se centró en estudios publicados en libros, artículos, disertaciones, sitios web, revistas relevantes para el tema, teniendo en cuenta el proceso metodológico de diseño de productos. Finalmente, se verificó la importancia de la Biomímesis, la Economía Circular y el Diseño como herramientas estratégicas para encontrar soluciones innovadoras con el fin de mitigar los problemas ambientales.

Palabras clave: *Biomimética; Economía Circular; Residuos; Sostenibilidad.*

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INTRODUCTION

Due to the enormous environmental problems marked by the growing demand for products and services, caused by the disorganized initiative of man who believed that natural resources were infinite, the need arose for him to reflect and put into practice actions aimed at mitigating the serious problems affecting the ecosystems of planet earth with sustainable actions.

The UN's *Brundtland* report in 1987 was an important initiative that established the debate on Sustainable Development, which would be meeting the needs of the present without compromising future generations' ability to meet their own needs, i.e. opportunities to access the same global natural resources, within a socio-ethical, economic, political and environmental dimension (MANZINNI and VEZZOLI, 2011).

One of the many environmental problems is the improper disposal of solid waste: on the streets, in sanitary infrastructures, rivers and seas, due to a lack of environmental awareness. The disposal of solid waste in the sea specifically causes problems: economic, environmental impacts and damage to human health, both for those who live near and far from the sea. The lack of environmental awareness of people who put solid waste in inappropriate places, not managing it properly with collection and treatment is one of the causes of the problems of waste in the seas, originating from these land-based sources (TURRA *et al.*, 2020).

Turra *et al.* (2020) state that the sea is beautiful, immense and fascinating. It is *home to* thousands of marine species. It is a source of income for fishermen and a whole economic chain that depends on seafood, as well as boosting tourism. Its contamination affects everyone. Therefore, protecting it and keeping it clean of solid waste is essential for economic development, human health and environmental balance.

According to Manzini (2011), solving or mitigating various problems in contemporary times requires the intervention and action of various types of knowledge. Among them is *design*, which by nature has in its DNA the search to solve problems and improve quality of life. Designers therefore have a social and ethical responsibility to promote creative, innovative and sustainable solutions (PAPANEK, 1997).

In addition, designers must be attentive to the problems faced by society, seeking creative solutions with an eye for innovation, technology and, above all, sustainable development (Kuya, 2023). From this perspective, moving through the field of circular economy knowledge and biomimicry is necessary in order to present values that guide thinking away from the linear and Cartesian patterns still in force today (PEREZ, 2023).

For Perez (2023), the circular economy is based on socio-ecological principles. It presents a cycle similar to that of nature, where there is no waste and the basic principles of reusing, reducing and recycling are fundamental to combating the linear life cycle of products today. It shows its importance through its zeal for natural goods, which are finite, providing strategies so that these goods are not wasted. The circular economy is based on nature, which is economic and cyclical, does not accept waste and makes the most of material and energy resources (BENYUS, 2010).

The circular economy is based on and inspired by the science of nature called biomimicry. Biomimicry consists of imitating or learning from the patterns and techniques of nature, with the aim of solving the various problems or needs of humanity, bringing hope above all (BIOMIMICRY INSTITUTE, 2023).

Benyus (2010) states that biomimicry involves understanding processes, systems and innovations in nature. It is not simply imitating formal aspects, but learning from them. In this sense, the importance of the Circular Economy, Biomimicry and Design as strategic teaching tools to find innovative solutions to reduce or end environmental problems found within today's society has been verified. Therefore, the main objective of this work was to develop an innovative design for a boat that, by analogy with the filtering system in the mouth of a whale shark, is capable of filtering solid waste from the surface in coastal waters, submerged at a depth of up to two meters.

THEORETICAL BACKGROUND

Solid Waste

Solid waste is mistakenly referred to as "garbage" due to a lack of knowledge. According to the National Solid Waste Policy - PNRS (2010), the materials, objects, substances or goods thrown away are generated and originate from human actions and are called solid waste. The PNRS (2010) aims to recycle, reuse and reduce solid waste. These actions are in line with the Circular Economy.

Araújo and Júnior (2018) highlight some positive and negative points and improvements following the implementation of the PNRS in Brazil, as can be seen in Table 01.

TABLE 01: Characteristics of the PNRS.

PNRS - National Solid Waste Policy	Actions
Positive points	Closure of garbage dumps; disposal of waste in sanitary landfills; affirmation of waste pickers as professionals; reverse logistics; reduction of environmental, economic and health impacts caused

	by improper waste disposal; improvement in quality of life.
Negative points	Waste disposed of incorrectly in dumps (weak enforcement of the law); Few municipalities in Brazil have managed to properly dispose of their solid waste, demonstrating that the incentives to achieve this goal have been few or poorly planned.
What can be improved	More incentives for small municipalities, as resources are scarce and it is more difficult to adopt the measures stipulated by the PNRS; Encourage civil society to separate their household waste; Propose environmental education to prevent waste generation and reduce consumption.

SOURCE: Adapted from Araújo and Júnior (2018).

The truth is that countless quantities of solid waste are disposed of inappropriately in the streets, squares, manholes, canals, sewers and streams that inevitably end up in the rivers and oceans of planet Earth. Specifically, solid waste that reaches the sea has a negative impact on the marine environment, affecting tourism, human health and an entire chain that depends economically on resources from the sea. Turra *et al.* (2020) stresses that:

The sea is also used as a source of income for a large section of society, such as the many families that depend on fishing. Waste thrown into the sea damages their fishing gear and reduces the amount of fish they can catch. This affects both the fishermen, who will have no income to support their families, and you, who may have no fish or seafood to eat. In addition, contamination of the seas by garbage and other pollutants can affect this food and put human health at risk. In this way, even those who live far from the sea can be affected.

According to UNEP (2023), the amount of plastic produced in the world is very large. It is estimated that more than 430 million tons are produced annually. Some of these plastics are short-lived, become waste and end up in the oceans, with the possibility of being consumed by humans involuntarily.

A simple candy wrapper thrown down the drain can reach the sea and directly affect all humans and marine life, as exemplified in Figure 01.

FIGURE 01: Solid waste's journey to the sea.



SOURCE: Turra *et al.* (2020).

The protection of the oceans must be based on human rights. Everyone needs and deserves to live in a healthy, clean, safe and sustainable environment, which is legally recommended in 155 countries (UNEP, 2021).

Circular Economy and Design

For Benyus (2010), nature is economic and cyclical, and does not accept waste. Following this same vision and perception, the circular economy is not based on closed linear patterns and questioning, but on procedures in the development of products, which become "waste" (PEREZ, 2023).

The circular economy seeks ideas and concepts based on a systemic perception of life. It seeks to understand people and nature as integrated elements. Therefore, the relationships between nature and

human beings cannot be conceived as independent poles, but rather as interwoven systems, like a web woven into current life and with intensely articulated threads and knots (Fontgalland, 2022). The circular economy understands that natural resources are finite and therefore need to be protected, renewed and reused. Therefore, developing products with an environmental conscience means thinking about the entire product development cycle, from conception to its last possible use. According to Platcheck (2012), this means that any *design* process that meets the criteria of functionality, safety, ergonomics, aesthetics, reliability and technical feasibility must also include the environment as an integral part of the process. This is called Ecodesign!

The fundamental aim of the circular economy is to reuse, recycle and mitigate or eradicate the creation of waste. It thus opposes the current linear model (Santos *et al*, 2018). It is known that not everyone is totally in favor of the circular economy proposal or that it is still an ambivalent topic. There is no consensus among researchers, thinkers and environmentalists. One of the main questions is that in order to reuse or recycle a product, it is necessary to incur other costs, so there is no concern about the socio-environmental impacts of the product's life cycle (KUYA, 2023).

The circular economy is intrinsically linked to eco-design, biomimicry and *Life Cycle Design*. All of these concepts seek to regenerate nature, sustainable products, with circular *design* strategies, through reuse, recycling and increasing the useful life of products, for example. Attitudes that only foster employment and innovation and consequently boost economic growth. Applying the circular economy to every field of knowledge only benefits consumers with more durable and innovative products. In addition to the incalculable benefit for nature and future generations.

Principles of the Circular Economy

For Santos *et al.* (2018), the circular economy is a model that opposes the current model of linear consumption and production. It uses strategies to solve society's current problems. The basic principles are to reduce or eliminate waste production. Reducing, reusing, recycling and regenerating through continuous cycles are key priorities.

It is essential to reduce the amount of material used and its waste, through zero-waste thinking and attitudes, seeking to consume fewer products, which can be replaced by services or interesting innovative alternatives. This reduces the ecological footprint.

Reusing materials, waste and products is a creative, economical, viable, interesting and sustainable alternative if reduction is not possible or sufficient. It is economical because it consumes less energy, promotes the mitigation of consumerism and provides socio-environmental well-being. In addition, it doesn't have to go through the complex system of recycling, which consumes energy, sometimes even

virgin raw materials, and reduces the quality of materials. Therefore, it should be the last tool to be used if options are lacking (PEREZ, 2023).

Recycling has encountered restrictions in the current scenario. Even with the National Solid Waste Policy (PNRS) encouraging and stimulating the recycling process in Brazil, the amount of material actually recycled is very small. Furthermore, in the Brazilian context, there is still a lack of public incentive policies on the part of government authorities, with the aim of widely promoting recycling and making it a national reality.

McDonough and Braungart (2002) defend the concept of *upcycling*, which is the creative reuse of waste, products and their parts without fragmenting them, but gaining new functions different from those initially conceived. This concept is widely used in fashion design, with interventions in clothing, but is already gaining ground in other areas of design, as can be seen in Figure 2 (IDEIA CIRCULAR, 2023).

FIGURE 02: Product design with bicycle parts using the upcycling concept.



SOURCE: bikefurniture.com, (2023).

Sustainable Design, Innovation and Circular Economy

The nature of design is to solve problems with the aim of improving the lives of people and their surroundings. However, for a long time, artifacts were designed, produced, distributed and used without concern for environmental and sustainability aspects, i.e. there was less thought given to making an eco-efficient product from an environmental, socio-ethical and economic perspective (Platcheck, 2012). There is therefore a need for a paradigm shift in design practice. The primary objective is to achieve actions towards circular, regenerative and sustainable design (PEREZ, 2023).

For Papanek (1997), designers have a social and ethical responsibility to promote sustainable and innovative solutions. Designers are pointed out as one of the actors responsible for the negative socio-

environmental impacts resulting from an economy based on market logic and the strong appeal for consumption of products that generate exorbitant profits and waste in their conception and then in their use, stemming from a linear economic model present in contemporary society.

Programmed obsolescence is another technique or trap that design has included in product conception. In other words, the product is born with days scheduled for it to die, so that the consumer has to buy a new product. As a result, more natural resources are used up, energy is wasted, more waste is generated, the soil, air, rivers and seas are polluted, and the population's health is harmed.

In design, it is essential to consider the dimensions of sustainability from the conception, maturation, development and final solution of the product. Solving environmental problems such as pollution and inappropriate disposal of solid waste (PLATCHECK, 2012).

Design strategies aimed at solving and mitigating environmental problems with creativity and innovation in search of a better society with sustainable development, can happen through projects with circular designs (VEZZOLLI *et al.* 2018).

Revoada is a company that takes and reuses discarded tire tubes and umbrella fabrics and transforms them into high-quality products such as wallets, jackets and bags (see Figure 03), providing jobs for waste pickers and rubber workers. To this end, it practices design and the circular economy and, consequently, sustainability, preventing a lot of solid urban waste from remaining on the streets causing pollution and from reaching rivers and oceans (IDEIA CIRCULAR, 2021).

FIGURE 003: PProducts developed by Revoada.



SOURCE: Circular Design, (2021).

Revoada gives materials a new life cycle, with the possibility of transforming them into new products. What would otherwise be discarded is used with creativity and environmental responsibility. Its products also enter new reuse cycles and develop research into new materials.

Another praiseworthy example of reusing solid waste is found in Kenya, where artisans with creativity, goodwill and innovation transform flip-flops thrown into the sea into incredible and colorful animal-like crafts, as can be seen in Figure 04.

FIGURE 04: Kenyan artisans.



SOURCE: Adapted from Ocean Soles (2023).

According to Camargo (2018), the Ocean Sole project, which transforms flip-flops into works of art, provides a source of income for the region. More than 900 people benefit from it. This income comes from the collection of plastic flip-flops found in the Kenyan sea, 500,000 a year, making a positive contribution to the environment.

Biomimetics and *Life Cycle Design*

Benyus (2010) states that biomimicry involves understanding processes, systems and innovations in nature (Bio: Life - Mimesis: Imitation). It is not simply imitating formal aspects, but learning from them. Sustainable design seeks innovative solutions through the spectacular science of biomimicry, imitating its natural tactics (BIOMIMICRY INSTITUTE, 2023).

Life Cycle Design, like biomimicry, aims to design new products using the methods and teachings of nature (see Box 02). Manzini and Vezzoli (2008) state that the entire product development process must be systemic. The entire production process, from conception to final disposal, is considered as a single unit.

TABLE 02: Life Cycle Design strategies.

STRATEGIES	PARAMETERS
Minimizing resources	Reduce the use of materials and energy
Choosing resources and processes with a low environmental impact	Select the most eco-friendly materials, processes and energy sources;
Optimizing product life	Designing artifacts that last;
Extending the life of materials	Designing for the recovery (reuse) of discarded materials;
Easy to dismantle	Design for ease of separation of parts and materials

SOURCE: Adapted from Manzini and Vezzoli, (2008).

Over millennia of evolution, nature already has all the secrets of how things work perfectly. Every living being, plant, animal and microorganism is an expert and excellent designer and engineer. Using this knowledge to solve society's problems through circular and regenerative design is essential.

Biomimicry is used and inspired by nature to solve various human problems. Figure 05 below shows how the kingfisher bird was the inspiration for modifying the design of the bullet train's beak, which due to its high speed produced noise pollution. With this solution, the trains became quieter, faster and more economical (RICO, 2022).

FIGURE 05: Product design based on Biomimicry.



Concatenated with *Life Cycle Design*, *cradle-to-cradle* is an important concept created by architect **McDonough** and chemical engineer **Michael Braungart**, as a way of countering and questioning the linear production model that is based on the idea of considering the life of a product from

cradle to grave. Nature is the inspiration for the *cradle-to-cradle* method, whose functionality is based on cyclical processes (IDEIA CIRCULAR, 2023).

METHODOLOGY

The methodological approach used for this study was based on a descriptive case study, with the aim of demonstrating the design of a boat that was developed based on an analogy with the filtering system in the mouth of a whale shark, which took into account the methodological process of product design from the perspective of biomimicry and the circular economy aimed at social and environmental responsibility. The project was developed in the Project V discipline, of the UFCG Design course under the guidance of professor Itamar Ferreira da Silva, with the participation of students Adriano Ramos, Amanda Marinho, Matheus Ferreira and Yasmin Basílio. The methodological process followed the following phases, as exemplified in Table 03.

TABLE 03: Stages of the project process.

PROJECT	STRATEGIES
RESEARCH PHASE	<ul style="list-style-type: none"> - Definition of the problem based on the morphology and functional systems of the whale shark, guided by design, biomimicry and the circular economy; - Characterization of the objectives, delimitation and purpose of the project; - User definition; - Method and operating procedures (tools for collecting, analyzing, interpreting and concluding data); - Requirements and design parameters.
GENERATING SOLUTIONS	Presentation of the set of solutions generated through manual and digital drawings, virtual modeling and physical modeling (mockup).
ANALYSIS, EVALUATION AND SELECTION OF SOLUTIONS.	Presentation of the ability to distinguish solutions generated from a variation of the same solution.
REFINING THE SOLUTION	<ul style="list-style-type: none"> - Refining the chosen solution through developments in aesthetics, form, functionality, ergonomics, mechanics, manufacturing processes and materials...; - Product presentation with manual or digital drawings showing the refinement of the product with various views, product details, textures and materials, colors and basic schematic measurements.
TECHNICAL DETAILS	- Detailing functional systems, materials and textures;

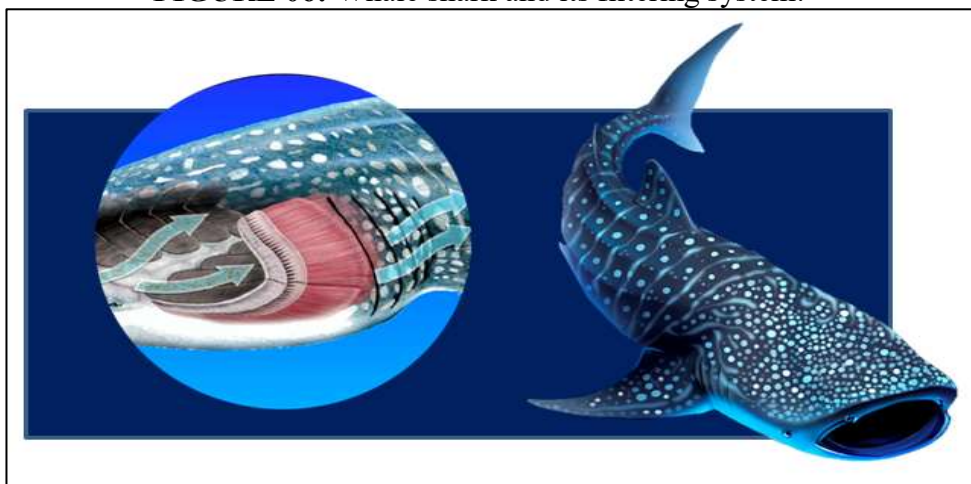
OF THE SOLUTION	<ul style="list-style-type: none">- Exploded perspective and digital renderings;- Manufacturing processes that will be used to make the product;- Technical drawing;- Ergonomics and usability;- Exposure of the product in the environment.
PRESENTATION OF WORK	<ul style="list-style-type: none">- Use of banners and virtual media with important project details;- Presentation of virtual and physical prototype.

SOURCE: Author (2023).

RESULTS AND DISCUSSION

The product was developed with the aim of filtering submerged waste at a depth of up to two meters, using biomimetic techniques applied to the Whale Shark. The marine animal has 10 pairs of filter organs, responsible for filtering its food from the water; a wide mouth measuring 2 meters in width, which allows water to enter and be filtered by 300 minidents; a pair of dorsal and pectoral fins, which help maintain stability in the water and provide better control when swimming; its caudal fin is moon-shaped and has the ability to detect vibrations produced by sound, which help locate prey or nearby marine life. Thus, the functional composition chosen was the cross-flow filtration system, where water enters through the mouth and exits through the gills leaving the food, exemplified in Figure 6.

FIGURE 06: Whale shark and its filtering system.



SOURCE: Design UFCG (2023).

The system also consists of a fiberglass structure attached to the underside of a small motorized boat. The boat is moved at low speed, so the animals move away during the process, allowing only solid waste to be dragged, ensuring the safety of marine species. The equipment is capable of collecting and storing approximately 400 kg of solid waste (Figure 07). See the parts below:

FIGURE 07: Product filtering system developed.



SOURCE: Design UFCG (2023).

1. Collection - Through the front opening, surface waste is collected and directed to two destination ducts. **2. Destination** - Ducts connecting the front opening to the side compartments. **3. Storage** - Compartments responsible for containing the catch nets and receiving the waste and water. **4. Removal** - Using the pressure gates, two users lift the lids to gain access to the catch nets and tie them up for transportation. **5. Transportation** - Using the handles on the bows of catch nets, users take a pole long enough to hold the net closed between them while supporting it on their shoulders. Figure 08 shows various orthogonal views of the system developed.

FIGURE 08: Boat for collecting surface waste in coastal waters in side view, front view, perspective view and perspective view.



SOURCE: Design UFCG (2023).

Environment of use

The sea is the environment in which the product would be used, specifically on beaches. It would be used to collect garbage and waste from the surface of the water. More than 95% of the garbage found on Brazilian beaches is made up of items made of plastic, such as bottles, disposable cups, straws, cotton buds, ice cream cartons and fishing nets. Figure 9 illustrates the environment in which the product is used.

FIGURE 9: Digital rendering of the final product in the environment



SOURCE: Design UFCG (2023).

CONCLUSIONS

First of all, it's worth highlighting the importance of the knowledge and lessons learned, aimed at preserving the environment and the search for a more sustainable ecosystem. A project that aims to reduce or eliminate solid waste in beach waters, improving both marine life and people's lives, is commendable and inspiring. The composition of the design project with the knowledge of bio-inspired solutions from Biomimetics, concatenated and aligned with the circular economy, broadens the field of conspiracies in the search for solutions aimed at improving the quality of life in the environment. The design of a boat that presents an analogy with the filtering systems in the mouths of whale sharks is an alternative or proposal for waste collection in coastal waters.

However, connecting design, biomimicry and the circular economy are concepts and characteristics that include increasingly sustainable solutions, where reduction and regeneration are essential parts of the process. Nature is economical and cyclical, it doesn't accept waste!

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