ISBN: 978-628-96613-0-9. ISSN: 2414-6390. Digital Object Identifier: https://dx.doi.org/10.18687/LEIRD2024.1.1.879

TLR6 Technology Readiness Process for the Design of a Prototype Beach Micro Residue Filter: Case Study in Santa Marta

Alexander Chaves-Ortiz[1], Sergio Martinez-Campo[2], Francisco José Coronado[3], and Merlis Pinzon Varela[4]
[1,3]ESTELAR Santamar Hotel & Centro de Convenciones, Colombia, a*lexander.chavez@hotelesestelar.com, francisco.coronado@hotelesestelar.com*
[2]Servicio Nacional de Aprendizaje - SENA, Colombia, *sdmartinez@sena.edu.co*
[4]Corporación Universitaria Minuto de Dios UNIMINUTO, Colombia, *merlis.pinzon@uniminuto.edu*

Abstract*– The problem of micro-waste on beaches negatively affects environmental quality and marine life. To tackle this problem, it is proposed to develop a filtering prototype specialised in the collection of micro residues smaller than 2.5 cm. This project focuses on implementing an effective solution to clean the beaches and reduce marine pollution on the beaches where the ESTELAR Santamar Hotel & Convention Centre is located. The technological readiness process, through TLR6, is crucial to ensure that the prototype works properly in real conditions. The development includes the design and validation of the prototype, testing in simulated environments and controlled parameters. Adjustments will be made based on the results obtained during testing to optimise the technology. The project is supported by Tecnoparque SENA, Santa Marta node, based on a shovel-type filtering prototype. The objective is to create an efficient, sustainable system adapted to local conditions that contributes to improving beach cleanliness and protecting the marine ecosystem. The successful implementation of this technology will have a positive impact on the quality of the coastal environment and the visitor experience. In addition, technology watch is carried out for decision making.

Keywords*— Miroresiduos, Technology Readiness Level 6, Tecnoparque SENA, cleaning, beach, filtering prototype, Technology Surveillance.

I. INTRODUCTION

The growing problem of micro-debris on beaches represents a significant threat to environmental health and marine biodiversity. These small fragments of plastic and other polluting materials not only affect the quality of water and sand, but also pose a risk to marine life that may ingest or become entangled in them. In this context, the development of effective technologies for the collection and filtering of micro residues becomes crucial, in addition to the fact that micro residues have the particularity of being invisible to the cleaning activities carried out with other machines [1].

Micro residues, such as cigarette butts, bottle caps and stay-on tabs, represent a significant threat to the marine and coastal environment. These small pieces of litter not only contribute to the visual pollution of beaches, but also have more profound harmful effects. Cigarette butts, for example, release toxins such as nicotine and heavy metals into the environment, which can pollute the water and affect marine life. Bottle caps and stay-on tabs are equally problematic, as although they are small, they can persist in the environment for years and fragment into even tinier pieces. Their size and shape make them extremely versatile and difficult to detect, as {[they hide easily in beach sand. This ability to hide among grains of sand not only makes them difficult to collect, but also increases the risk that they will be ingested by marine wildlife, causing damage to ocean ecosystems and harming the health of species that accidentally consume them [2].

The district of Santa Marta is one of the main coastal cities in Colombia, and faces similar challenges due to the high influx of tourists (domestic and foreign) and maritime activity. The accumulation of micro-waste on its beaches not only deteriorates the landscape and affects the visitor experience, but also has a negative impact on the local marine ecosystem [2].

To address this problem, the design and development of a prototype micro-waste filter specifically adapted to the conditions and needs of the beaches of Santa Marta is proposed. This project seeks to implement an innovative solution that allows the efficient collection of waste smaller than 2.5 cm, improving the cleanliness of the beaches and reducing marine pollution.

This development is monitored and accompanied by TECNOPARQUE, which is a technological innovation programme of the National Learning Service (SENA), which acts as an accelerator for the development of R+D+i (Research + Development + Innovation) projects, materialised in functional prototypes through the support of a specialised multidisciplinary team with extensive experience in the accompaniment of technology-based projects.

Within this process, technology level readiness, through TLR6 (Technology Readiness Level 6), is fundamental to ensure that the prototype is functional and effective in a real environment. This stage involves validation of the prototype under operational conditions in a controlled environment, including simulations, beach testing and adjustments based on empirical results.

Recent research has focused on developing innovative solutions for collecting beach debris and microplastics. Prototype designs include a portable robotic "beach buddy" for family use [3] and a solar-powered garbage collector [4], both aimed at engaging users in beach cleanup efforts. For marine microplastics specifically, a cleaning robot is being developed to automatically gather these particles from beaches [5]. Sand filtration has shown promise in removing microplastics from industrial wastewater, with laboratory-scale experiments demonstrating up to 100% efficiency in removing various types, shapes, and sizes of microplastics [6].

These studies highlight the potential of both mechanical and filtration-based approaches in addressing beach pollution and microplastic contamination. As plastic recycling increases, there is a growing need for effective microplastic removal strategies to meet potential future discharge regulations [6].

This article aims to present the design and development of a prototype sand filter to collect micro residues, which not only meets the technical and operational standards, but is also sustainable and adaptable to the particularities of the environment, specifically on the beaches of Santa Marta. The successful implementation of this technology will contribute significantly to the protection of the coastal environment and the improvement of beach quality in the region. The readiness approval of TRL6, allows the decision making of the prototype at TRL7 and TRL8 levels, which has the scope of the development and construction of the prototype in real dimension, in the real environment.

II. Conceptual Framework

A. *Theoretical Framework*

Small waste (less than 2.5 cm) is especially problematic due to its difficult detection and collection. This waste, commonly known as microplastics and other micro-waste, is a significant environmental problem. It is then classified into different types:

- Microplastics: Plastic fragments smaller than 5 mm, including microbeads that are used in cosmetic products and cleaners, and fragments that result from the degradation of larger plastics.
- Microfibres: Small fibres released by synthetic clothing during bathing.
- Cigarette butts: Small parts of filters containing microplastics.
- Glass and metal fragments: Small parts that break over time.

These wastes can be generated through industrial activities, fishing, recreational activities, product wastage, urban runoff, among others. Examples:

- Recreational Activities: Litter generated by beach visitors, including plastics and packaging.
- Product Wear and Tear: Disintegration of plastic items, such as bottles and bags.
- Industrial and Fishing Activities: Waste and fragments of materials used in these activities.
- Urban Runoff: Waste carried by rainfall that reaches the ocean.

Because they are micro residues and are hardly detectable in beach sand, they are considered to have an almost invisible environmental impact, which affects the environment to a large extent. For example, the ingestion of microplastics, where marine organisms, from plankton to large fish and marine mammals, can accidentally ingest microplastics. These residues can cause digestive problems, intestinal blockages, and alterations in nutrient absorption [7].

On the other hand, microplastics can adsorb toxic substances present in water, such as pesticides and heavy metals. These toxics are transferred through the food chain, affecting marine organisms and eventually humans [8]. Also, the presence of microplastics can influence the behaviour of marine animals, affecting their ability to hunt, reproduce and migrate [7], [9].

The accumulation of micro residues can damage crucial habitats, such as coral reefs and wetlands. Microplastics can disrupt coral formation and alter habitat conditions for other species, as well as being colourful and conspicuous. It also leads to changes in ecological relationships, as the presence of microplastics can alter interactions between species, such as predators and prey, and change ecosystem dynamics [10].

Controlling micro-waste pollution on beaches requires a holistic approach that includes reducing sources of pollution, improving collection technologies and raising public awareness. As mitigation strategies, education and awareness raising is crucial, as campaigns can reduce the use of plastics and encourage proper waste disposal. Also the use of collection technologies, through the development of specialised devices for the collection of micro-waste on beaches, preventing it from reaching the ocean. Finally, the implementation of public policies to reduce the production and use of single-use plastics and improve waste management.

To quantify the problem at the national level, Colombia has an extensive coastline that extends along two oceans: the Atlantic (Caribbean Sea) and the Pacific. The Caribbean Coast is approximately 1,600 km long, and its main beaches are: Tayrona, Cartagena, San Andrés, Providencia, Barú, Santa Marta, Palomino, Cabo de la Vela. While the Pacific Coast has a length of approximately 1,300 km, and its main beaches are: Bahía Solano, Nuquí, El Valle, Ladrilleros, Juanchaco, Playa Guachalito, Playa Larga. In total, Colombia has about 3,000 km of coastline. It is estimated that there are more than 300 beaches distributed, approximately, between the Caribbean and Pacific coasts [11].

B. *Project Identification I+D+i*

Project Name: Development of a Functional Prototype for the Collection of Beach Debris of Size Less than 2.5 cm.

Technological Readiness Level: TRL6 -Validation and demonstration in a simulated environment of the Functional Prototype.

Project objectives:

1. Develop a mobile prototype that can operate effectively on sandy surfaces and other coastal terrain.
2. Implement jam prevention mechanisms to ensure continuous and uninterrupted operation of the prototype.
3. Optimise collection capacity to maximise efficiency in capturing small waste.

Justification: The accumulation of small debris on beaches represents a significant challenge to conventional clean-up strategies. This project is aligned to the Sustainable Development Goals SDGs, and responds to the need for a specialised solution that can effectively address the collection of this waste, improving environmental sustainability and the quality of coastal recreational spaces.

Areas of Research and Development:

- Sand mobility technology: Research into mechanisms and materials that enable effective traction on unstable surfaces.
- Separation and filtering systems: Development of techniques to prevent small debris from clogging the prototype components.
- Operational efficiency and ergonomic design: Study of forms and functions that maximise device efficiency while minimising operational problems.

Expected Innovation: The project aims to offer an innovative solution in beach litter collection, combining advances in mobility technology and filtering systems, which will result in a prototype unique in its ability to address the specific problem of small litter in coastal environments.

Project beneficiaries:

- Organisations and entities dedicated to the cleaning and conservation of beaches.
- Local communities and visitors to coastal areas.
- Hotel chains.
- Researchers and developers in the field of cleaning technologies and environmental sustainability.

Expected Impact: Successful implementation of the prototype will contribute to more effective and sustainable beach cleaning, improve the user experience and reduce the environmental impact of small litter.

C. *CANVAS Innovation and Intellectual Property Model.*

The Canvas model is a strategic management tool that allows you to analyse and create business plans in a dynamic and visual way. Thanks to its canvas format, divided into blocks, it offers a global and simplified overview of the business strategy. Table 1, showing the innovation canvas, will help to detect and reaffirm the novelty of its creation, highlighting its differentiating effect and impact on productivity.

TABLE 1
INNOVATION CANVAS

Explore and define the innovative approach of the project, highlighting how the prototype brings new solutions to the problem.		
CHALLENGE OR PROBLEM	VALUE PROPOSAL	MARKET SEGMENTS
Inefficient collection of small waste on beaches, with mobility problems and clogging of existing equipment.	An innovative prototype designed specifically for the collection of waste smaller than 2.5 cm, with high mobility and mechanisms that prevent clogging.	Local authorities responsible for beach management. Hotel chains. Environmental organisations focused on beach clean-up. Tourist companies that maintain recreational beaches. Coastal communities concerned about the environment.
INNOVATIVE SOLUTION	KEY DIFFERENTIATORS	TECHNICAL FEASIBILITY
Modular Design: Facilitates quick adjustments and adaptations. Advanced Collection Technology: Specific mechanisms for small waste. Optimised Movement: Tracked wheel and suspension system for different types of terrain.	Small Waste Specific Design: Adapted to plastic fragments and other waste smaller than 2.5 cm. Advanced Mobility: Capable of operating in sand and other coastal terrain without clogging problems. Sustainability: Reduced environmental impact through effective cleaning.	Functional Prototyping: Carrying out simulation and adjustments to ensure functionality under various conditions. Research and Development: Use of advanced technology and materials to ensure effectiveness.
MARKET VALIDATION		
Testing under controlled environment. Talent feedback: Gathering of opinions.		

Own elaboration

On the other hand, Table 2 describes the intellectual property canvas, with the objective of identifying the possible protections or mechanisms of Copyright and Patrimonial Rights of the project.

TABLE 2
INTELLECTUAL PROPERTY CANVAS

Identify and protect intellectual property assets related to the project.		
INTELLECTUAL PROPERTY ASSETS	TYPES OF INTELLECTUAL PROPERTY	PROTECTION STRATEGIES
Prototype Design: Schematics and technical drawings of the device. Collection Technology: Innovations in collection mechanisms and mobility. Brand and Trade Name: Identification and naming of the prototype.	Patents: For the design and specific technology of the prototype. Trademarks: For the name of the prototype and logo. Copyrights: For technical documentation and promotional material.	Patent Application: Filing of applications to protect the design and innovative technology. Trademark Registration: Process to secure the trade name and logo of the prototype. Documentation Protection: Protection of manuals, drawings and any technical material under copyright.
INTELLECTUAL PROPERTY MANAGEMENT	RISKS AND MITIGATION	
Surveillance and Surveillance: Tracking possible infringements and ensuring continued protection. Licensing and Agreements: Negotiation of licensing agreements with third parties interested in using the technology.	Risk: Infringement of intellectual property rights. Mitigation: Active market surveillance and legal action if necessary. Risk: Costs associated with protection. Mitigation: Specific budget for intellectual property and consultation with experts.	

Own elaboration

D. *Technological Readiness Levels TRL.*

Tecnoparque's support is aimed at achieving and complying with the objectives of levels TRL6, TRL7 and TRL8. At this stage it is at TRL6. Fig. 1 below describes the structure of the maturity levels and the scope.

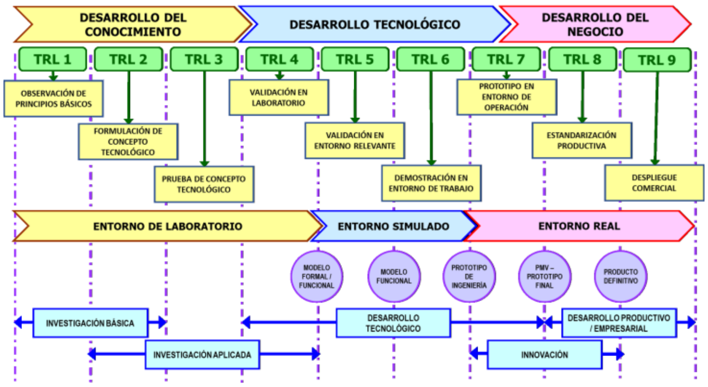

Fig. 1 Technology Maturity Levels

Source: Sennova, Juan Carlos Daza Rico, 2022.

The nine levels are distributed in 3 phases of development: knowledge, technological and business. The Tecnoparque programme accompanies IBT technology-based ideas through PBT technology-based projects at levels 6, 7 and 8. This article describes the scope and deliverables of level 6.

E. *Technology Surveillance TS for Decision Making*

Technology surveillance TS is a systematic process of collecting, analysing and using relevant information on trends, innovations and developments in its technological and competitive environment. This approach is essential in a world where rapid technological change and globalisation demand constant and proactive adaptation of research [12].

The Surveillance process develops from the identification of needs to the creation of knowledge, supported by the analysis of documentary sources and databases. It is essential to establish clear objectives for surveillance, which allows a proper contextual analysis for decision making. Patent information is crucial for identifying new products and systems in the sector, as it represents the most up-to-date information on technological innovation. On the other hand, scientific articles help to identify researchers and establish connections in specific areas, where the treatment of data and techniques is essential to formulate effective technological strategies. Fig 2. describes the ST process in four fundamental stages, each of which contributes to the creation of an information environment that supports strategic decision-making [12].

These four stages of technology watch allow you not only to collect and analyse information, but also to turn it into strategic knowledge that can guide innovation and decision-making. By following this process, you can better adapt to changes in your environment and take advantage of emerging opportunities in technology and research.

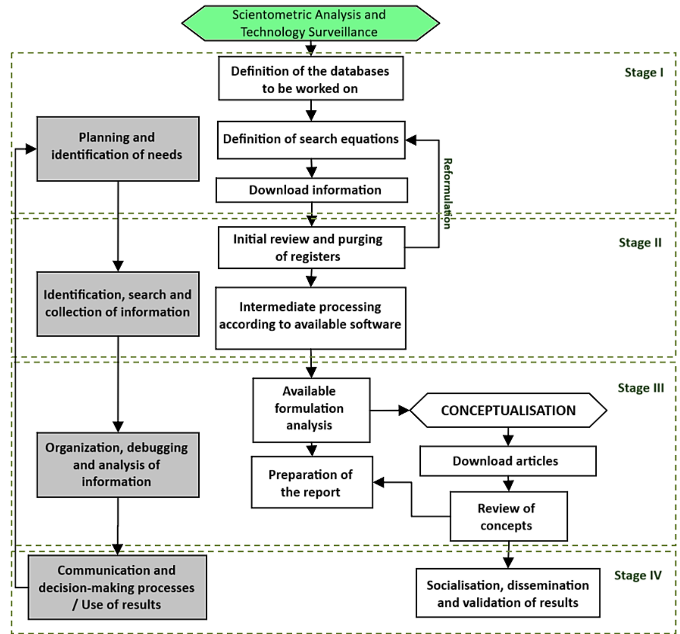

Fig. 2 Describes the Surveillance procedure

Source: Domínguez, C., & Fernando, O. (2009). RETOS Y NUEVOS ENFOQUES EN LA GESTIÓN DE LA TECNOLOGÍA Y EL CONOCIMIENTO. Ingeniería e Investigación, 29(1), 141–141.

III. METHODOLOGY

A. *Initial prototype and current procedure*

The ESTELAR Santamar Hotel & Convention Centre, as part of its beach clean-up strategies, has micro-waste collection and filtering activities, involving adults, young people and children, as shown in Fig. 3.

Fig. 3 Images of the activities they carry out

Fuente: https://infinityphotoexperience.pixieset.com/labsquedadeltesoro/

The initial prototype is a broom or rake type collector. However, this presents difficulties when filtering, due to the large accumulation of sand that prevents it from continuing with the dragging. This situation limits the active participation of young people and children.

Fig. 4 shows a larger and somewhat aerodynamic prototype, but the increased size increases the previous problematic situation. Therefore, there is a need to design and develop a prototype that adapts to the strategies presented by the hotel and the ecosystemic environment.

Fig. 4 Images of the activities they carry out
Source: https://infinityphotoexperience.pixieset.com/labsquedadeltesoro/

B. *Procedimento TS - Bibliometrix*

Definition of database: SCOPUS

Definition of search equation or formula: TITLE-ABS-KEY (beach AND cleaning AND equipment AND beach AND cleaning AND machines)

Download information: archive CVS.

Initial review:

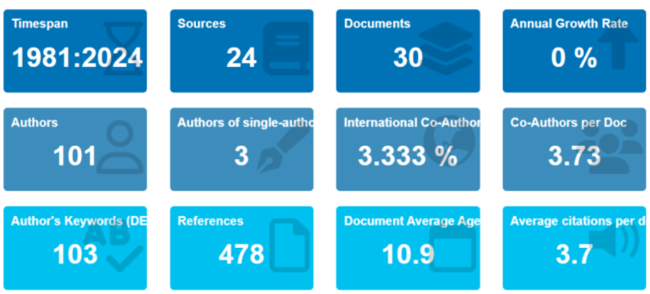

Fig. 5 Información Principal
Fuente: Bibliometrix/biblioshiny

Fig. 5 shows that the mapping yielded a total of 30 documents (articles) from 101 authors.

Analysis of available information:

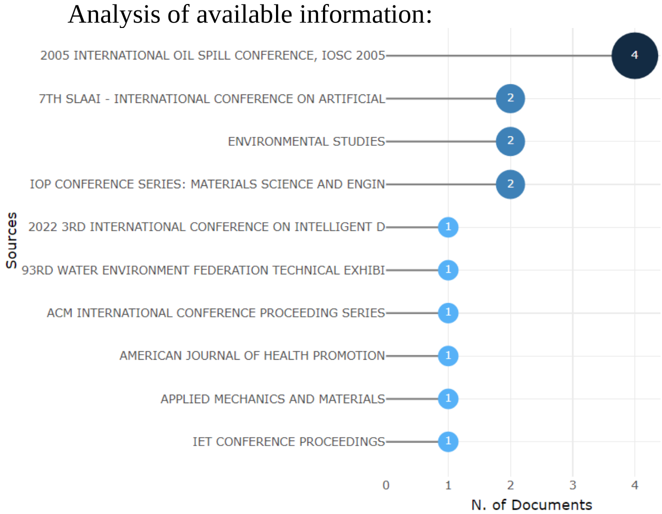

Fig. 6 Most revealing sources
Source: Bibliometrix/biblioshiny

Fig. 6 presents the sources with the most research on the topic of interest.

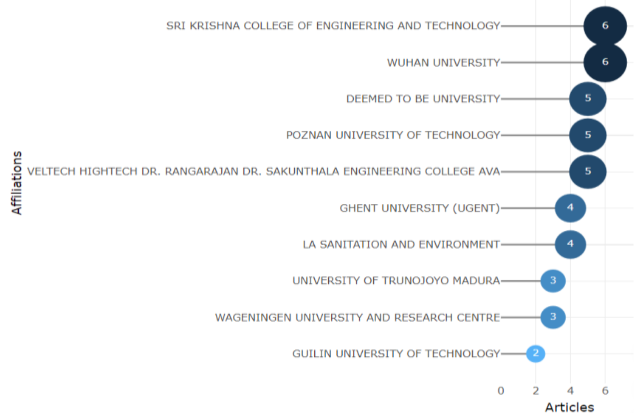

Fig. 7 Afiliaciones más relevantes
Source: Bibliometrix/biblioshiny

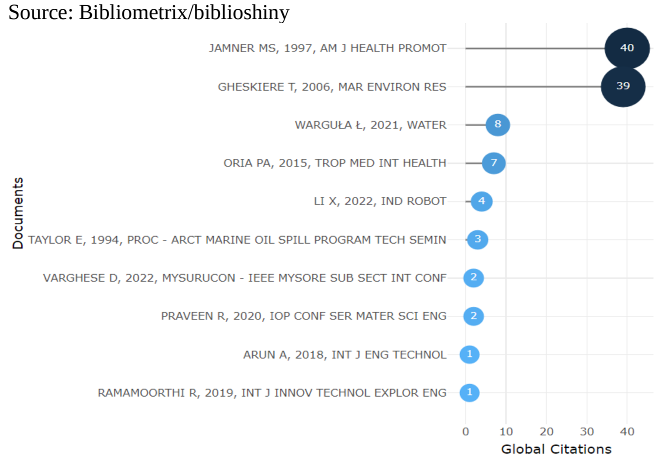

Fig. 8 Most cited global documents
Source: Bibliometrix/biblioshiny

Fig. 8 shows the most cited articles with respect to the prototype of interest. Therefore, we proceed with the review of these documents.

IV. RESULT AND RESULT ANALYSIS

Fig. 9 describes an autonomous functional prototype, with a caterpillar drive, but has difficulty with the electronic parts, due to deterioration from salt water.

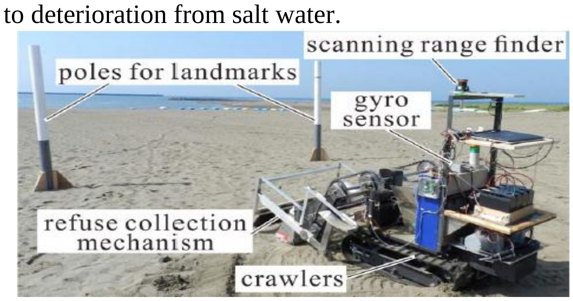

Fig. 9 Autonomous robot prototype
Source: T. Ichimura, 2016.

Fig. 10, describes a prototype with motorised rakes, but it presents the same difficulties as the previous one, and the translation system is deficient in beach sand.

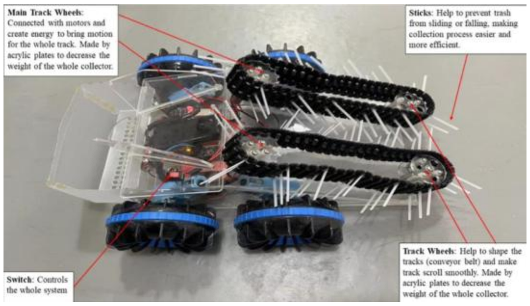

Fig. 10 Rake filter prototype

Source: Jin, 2024.

Fig. 11 shows a prototype with a pulley system to move the rakes. But its drive system is obsolete in sandy soil.

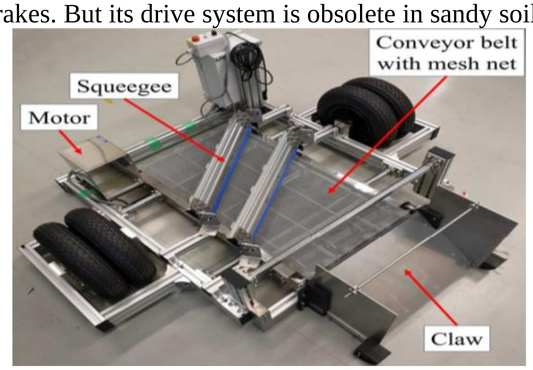

Fig. 11 Rake filter prototype

Source: Uno, 2024.

Decision making and schematic design of the prototype: Based on the analysis of the previous prototypes, the following 3D prototype is developed, Fig. 12, in order to simulate the whole system of gears, conveyor belt and other movements.

Fig. 12 Tecnoparque prototype

Source: Tecnoparque

It is intended to adapt the previous model, with the conveyor belt as a filter, and the gear system and so on, into this drag system, so that the person handling the prototype can determine the depth and amount of sand that the prototype will filter.

V. CONCLUSIONS

The development of this technology proposes the design and development of a specialised filtering prototype that allows the efficient collection of these micro-wastes, contributing to the cleanliness of beaches and the protection of the marine ecosystem. The successful implementation of this technology will not only improve beach cleanliness, but will also have a positive impact on environmental sustainability and the quality of life of coastal communities.

Technological Maturation Process is crucial to ensure that the prototype works properly in real conditions, which includes tests in simulated environments and adjustments based on the results obtained. In terms of collaboration and sustainability, the project is supported by Tecnoparque SENA and Hotel Estelar, which reinforces the importance of collaboration between institutions for the development of sustainable solutions that improve the quality of the coastal environment and the visitor experience.

REFERENCES

[1] Tsiaras, P. (2020). Microplastics in the marine environment. Science, 371(6526), 196-200. https://doi.org/10.1126/science.abd2917.

[2] Andrady, A. L. (2017). Global distribution, sources, and sink of microplastics in the marine environment. Science, 358(6360), 1233-1234. https://doi.org/10.1126/science.1258001.

[3] Jin, X. (2024). Trash collection gadget: A multi-purpose design of interactive and portable solution for beach cleanup. *E3S web of conferences*, *477*, 00002. https://doi.org/10.1051/e3sconf/202447700002.

[4] Arun., Nagasankar, Amirthalingam, Kumar. .E, B., Janarthanan., & As, M. (2018). Design and fabrication of garbage collector on the beach using solar power. *International Journal of Engineering & Technology*, *7*(3.34), 394. https://doi.org/10.14419/ijet.v7i3.34.19331.

[5] Uno, M., & Kurazume, R. (2024). Development of garbage collecting robot for marine microplastics. *2024 IEEE/SICE International Symposium on System Integration (SII)*, 1492–1497.

[6] Umar, M., Singdahl-Larsen, C., & Ranneklev, S. B. (2023). Microplastics removal from a plastic recycling industrial wastewater using sand filtration. *Water*, *15*(5), 896. https://doi.org/10.3390/w15050896.

[7] Wright, S. L., Thompson, R. C., & Galloway, T. S. (2013). The impact of microplastics on marine organisms: A review. Marine Environmental Research, 92, 117-127. https://doi.org/10.1016/j.marenvres.2013.10.004.

[8] Barnes, D. K. A., & Galgani, F. (2016). Microplastic pollution in the marine environment. Science Advances, 2(12), e1600745. https://doi.org/10.1126/sciadv.1600745.

[9] United Nations Environment Programme. (2016). Plastics in the Marine Environment. UNEP. https://www.unep.org/resources/report/plastics-marine-environment.

[10]World Wildlife Fund. (2020). Marine Plastic Pollution: Overview and Solutions. WWF. https://www.worldwildlife.org/pages/marine-plastic-pollution.

[11]National Geographic Society. (2019). The State of the World's Oceans: How the Plastic Crisis is Affecting Marine Life. National Geographic. https://www.nationalgeographic.com/environment/article/plastic-pollution

[12]S. M. Campo, S. Rada, L. V. C and L. Nieto, "Technological Surveillance of the Mathematical Modeling of COVID-19's Dynamics and Containment," 2023 World Engineering Education Forum - Global Engineering Deans Council (WEEF-GEDC), Monterrey, Mexico, 2023, pp. 1-9, doi: 10.1109/WEEF-GEDC59520.2023.10344021.

[13]Plastic Pollution Coalition. (2020). The Plastic Pollution Coalition. https://www.plasticpollutioncoalition.org/

[14] T. Ichimura and S. -i. Nakajima, "Development of an autonomous beach cleaning robot "Hirottaro"," *2016 IEEE International Conference on Mechatronics and Automation*, Harbin, China, 2016, pp. 868-872, doi: 10.1109/ICMA.2016.7558676.

[15] Yuliarman, Y., Rahmatia Ikhsani, S. ., Effiandi, N. ., Zulhendri, Z., & Yetri, Y. (2023). Rancang Bangun Dan Pembuatan Mesin Pembersih Pantai. Manutech : Jurnal Teknologi Manufaktur, 15(02), 141 - 149. https://doi.org/10.33504/manutech.v15i02.232

[16] Patil, M. P. B. (2021). CAD modeling and manufacturing of cleaning machine used for waste collection on beach. International Journal for Research in Applied Science and Engineering Technology, 9(VI), 5019–5021. https://doi.org/10.22214/ijraset.2021.36083.