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PRODUCT DESIGN METHODS WITH RECYCLED MATERIALS BASED ON BIOMIMICRY

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ABSTRACT
The damage that human activities have caused to our planet is undeniable, especially since the Industrial Revolution. We are in the era of the Anthropocene: characterized by the excessive consumption of natural resources and the generation of greenhouse gases, which have had a significant impact on the climate and biodiversity. Fortunately, in recent years related initiatives have emerged to reverse the above. Some of them are zero waste, recycling, downcycling and upcycling design, related to the reduction and maximum use of waste, as well as the extension of the useful life of products and/or the use of their materials. The circular economy, a production and consumption model that allows the useful life of products to be extended, has also brought benefits to the environment, the economy, and people. In congruence with the above, in the Product Design course, last year elective open course of the Industrial Design program, two design methods have been proposed based on the Biomimicry design spirals, for the development of products based on the use of recycled materials, especially derived from wood and plastics. The general objective of this work is to disseminate the new design methods and share the first results of their implementation. This paper shows the new methods and the results of their implementation in three courses, taught to students from different disciplines, this in the academic periods Summer 2022, February-June 2023 semester, and August-December 2023 semester.

Keywords: Recycling design, biomimicry spirals, higher education, professional education, educational innovation

1 INTRODUCTION
The overexploitation of natural resources has caused great damage to our planet, within an insatiable capitalist and consumerist system. An example of the above is the abuse in the manufacturing-consumption of products with plastic materials: There is evidence of the presence of microplastics (small plastic particles) in all the seas and oceans of the world, which represents a great danger to ecosystems. marine and for the human being himself. One of the professions that has contributed to this degradation of the planet is, unfortunately, industrial design. Discipline that emerged from the Industrial Revolution and whose initial mission was the configuration of objects for mass production. Although industrial design tries to improve people's quality of life, it has also been (most of the time) just another cog in the complex machinery of capitalism-consumerism.
In response to the above, and for some decades now, there have been efforts to rethink the profession, as is the case of the German designer Dieter Rams and his 10 principles of Good Design [1]. These principles state that a well-designed product should contribute to the conservation of the environment, through the better use of natural resources and the reduction of pollution throughout its entire life cycle. These principles are reflected in design methodologies, focused on solving human problems and needs through the development of products and services. Among these methodologies we can highlight the biomimicry spirals, which allow the development of products with the lowest possible impact and with nature as a reference [2].
Biomimicry, for its part and since the end of the last century, offers an empathetic and interconnected understanding of how life works; It is a practice that learns and imitates the strategies that living species use today. The goal is to create products, processes and systems, new ways of life, that solve our greatest design challenges sustainably and in solidarity with all life on earth. Biomimicry is about valuing nature for what we can learn, not for what we can extract, harvest, or domesticate. In the process, we learn about ourselves, our purpose, and our connection to each other and our home on earth [3].

Another initiative from industrial design is recycling design, which can be defined as the design of products based on waste materials/products, where the original form/function is lost, and the important thing is the raw material. A clear example of recycled design are products made with recycled plastics such as PS (Polystyrene), PP (Polypropylene) and PE (Polyethylene). A great advantage of this type of products is that eventually, at the end of their useful life, they can be raw material for new products. The possibility of cutting, roughing and/or grinding makes it easy to reuse these materials for a long time, without the need to use virgin material.

2 METHODOLOGIES

The innovation presented can be defined as the development and application of a new product design methodologies based on recycling and the biomimicry design methodologies (spirals) "From biology to design" and "Challenge to biology" [2]. It is important to mention that, although the reference methodologies are used for the development of products with low environmental impact and taking nature as an example, they are not designed for the creation of products based on waste materials. Strategies and means for recycling materials exist [4][5], but there is little evidence of exclusive design methods for the development of products based on recycled materials. Figure 1 describes the Biomimicry design spirals "From biology to design" and "Challenge to biology".

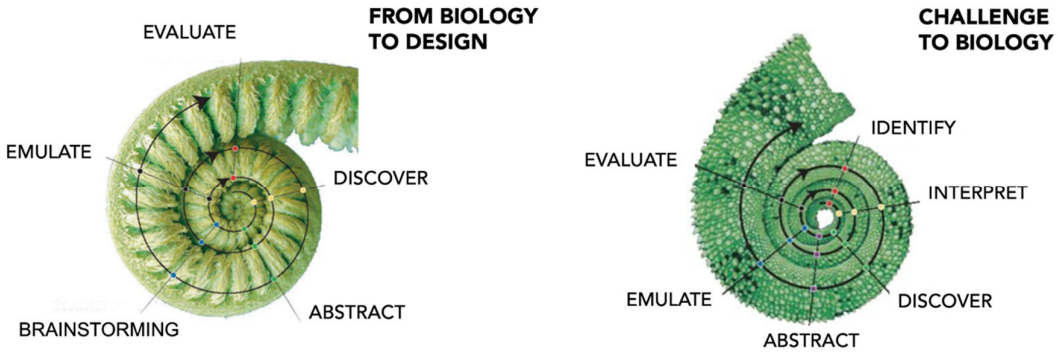

Figure 1. Biomimicry design spirals

The first new product design methodology is described below, based on the biomimicry design spiral "From biology to design":

- **Discover.** Identify available waste materials.
- **Abstract.** Identify the properties of the available materials: hardness, colour, thickness, opacity, etc. and its manufacturing possibilities: cutting, roughing, bending, thermoforming, joining, etc.
- **Brainstorming.** Explore the possibilities of transformation, product typology, use/function.
- **Emulate.** Choose the final product proposal using an evaluation matrix. Make models for validation.
- **Evaluate.** Evaluate under the criteria of Life Principles.

On the other hand, the second new product design methodology is described below, for a design based on waste materials, and based on the biomimicry design spiral "Challenge to biology":

- **Identify.** Identify a need or define a type of product.
- **Interpret.** Identifies requirements and restrictions of the materials required for the product.
- **Discover.** Identifies available waste materials and defines the ideal materials for your product.
- **Abstract.** Identify the properties of the available materials: hardness, colour, thickness, opacity, etc. and its manufacturing possibilities: cutting, roughing, bending, thermoforming, temporary/permanent joining, etc.
- **Emulate.** Choose the final product proposal using an evaluation matrix. Make models for validation.
- **Evaluate.** Evaluate under the criteria of Life Principles.

It is important to mention that it was considered to maintain the essence of Biomimicry [6], the practice of imitating life and nature, but applying it to the creation of products with the lowest possible ecological impact and taking nature as an example to follow. The new methodologies aim to be inspired by nature

engineering to solve the world's pressing challenges and guarantee a sustainable future for all life on earth, through the maximum use of waste materials.
Regarding the application of these new methodologies, the information on the implementations is presented in Table 1.

Table 1. Implementation of methodologies

Implementation of methodologies				
Information of implementations		Implementation 1 Summer 2022	Implementation 2 February-June 2023	Implementation 3 August-December 2023
Product Design group information	Number of students	11	27	24
	Academic programs	Architecture (3) Communication (3) Industrial design (3) Animation and digital art (1) Entrepreneurship (1)	Architecture (1) Communication (1) Industrial design (13) Animation and digital art (11) Mechanical Engineering (1)	Architecture (1), Communication (1), Industrial design (1), Animation and digital art (7), Mechanical Engineering (3) Digital Systems Engineering and Robotics (1), Food Industry Engineering (2), Biotechnology (1), Mechatronics (3), Marketing (1), Business Administration (1), Industrial and Systems, Engineering (1), International Relations (1)
Project 1 information	Methodology	From biology to design		
	Individual/Team	Individual	Teams of 3	Teams of 3-4
	Training partner	No	No	No
Project 2 information	Methodology	Challenge to biology		
	Individual/Team	Teams of 2-3	Teams of 3	Teams of 3-4
	Training partner	Yes	Yes	Yes

As can be seen in Table 1, the two methodologies developed specifically for the development of products based on recycled materials were implemented for the first time in an optional Product Design course. In this first implementation, carried out in Summer 2022, the methodologies were tested with academic projects and considering a Training Partner for advice and technical support. The training partner was Eng. Rubén Barrera from Precious Plastic León [7].
Similarly, the following two implementations conducted in February-June 2023 and August-December 2023 were applied in elective courses on Product Design. These periods were longer than the first implementation and involved a larger number of students and a greater diversity of disciplines. In both semesters of 2023, we had the participation of the Training Partner Kids Club Campus Querétaro, who requested our assistance in developing educational materials and products for the children attending the program.

3 RESULTS

Some of the results of the implementation of new design methodology based on recycling and based on biomimicry spiral “From biology to design”, can be seen in Fig. 2.

Figure 2. Examples of products with methodology based on biomimicry spiral “From biology to design”

To carry out these product proposals, scrap materials were used such as wood, foamboard, acrylic, clothes hanger, thread, among others. The intention was to develop products that contemplate simple transformations and that fulfil simple functions, such as structuring, supporting, containing, among others. No mechanisms were considered.
In this same summer period, a second project was carried out based on the methodology created based on the biomimicry spiral “Challenge to biology” and consisted of the development of products based on

a specific need or defined product but considering recycled plastic as the main raw material. It is important to mention that for this project we have the advice and technical support of Rubén Barrera, from Precious Plastic León. The above was possible because in our facilities we have equipment for recycling plastics, such as a crusher, injector, extruder, laminator and moulds. In Figure 3 we can see results of products made with plastic recycling and with the injection process.

Figure 3. Examples of products with methodology based on biomimicry spiral "Challenge to biology"

In this second project of the first execution, recycled plastic materials were used, specifically polyethylene, polystyrene, and polypropylene. The idea, in this second project, was to make simple products based on processes such as lamination and injection.
In the February-June 2023 iteration, Project 1 entailed the design of products utilizing waste materials. These materials encompassed acrylic, foam PVC, wood and its derivatives, foam board, screws, fabric, among others. The methodology employed for this project was "From Biology to Design," which facilitated the unfettered development of products ranging from small-scale pieces to furniture. Drawing upon research and information gathered from the CES-Edupack software [8], the physical properties and transformation capabilities of the waste materials were considered. Most students hailed from creative disciplines closely tied to design. Below (Figure 4) are examples of the products developed:

Figure 4. Examples of products with methodology based on biomimicry spiral "From biology to design" February-June 2023

The second project in this same period was developed using the "Challenge to Biology" methodology, inspired by the biomimicry spiral, and focused on creating products to meet the needs of the Training Partner Kids Club Campus Querétaro. The material requirement was to use a minimum of 60% recycled plastic in their product, mostly polyethylene and polypropylene. Additionally, they received guidance and technical support from Rubén Barrera of Precious Plastic León. They used plastic recycling equipment such as a shredder, injector, extruder, laminator, moulds, and dies available in our facilities. It is worth mentioning that, for the use of both methodologies, it was required to follow the Principles of Life: form follows function, optimal use of material, benign manufacturing, self-assembly and resilience. These principles governed its design and decision making for the use of material and the shape of its product. Examples of the products created are shown in Figure 5.

Figure 5. Examples of products with methodology based on biomimicry spiral "Challenge to biology" February-June 2023

In the August-December 2023 version, the requirements remained the same as the previous semester, although there was greater diversity in disciplines, most of them unrelated to design. Additionally, some students had never used machinery before. In this iteration, glass was included as an alternative material for Project 1. For Project 2, some students designed their own moulds and experimented with other processes to transform plastics. Images of the results are depicted in Figures 6 and 7.

Figure 6. Examples of products with methodology based on biomimicry spiral "From biology to design" August-December 2023

Figure 7. Examples of products with methodology based on biomimicry spiral "Challenge to biology" August-December 2023

As part of the Evaluate stage, students evaluated their project with the criteria of Life Principles and the Eco-Design Wheel and proposed a business model. In their conclusions they showed a genuine interest in the process and the importance of the meaning of the project. Quoting a group of students from this latest iteration "...the project demonstrates that sustainability can coexist with functionality to generate a product with human meaning; and the difficulties encountered offer valuable lessons for future similar projects."

4 CONCLUSIONS

As first experiences applying the developed methodologies, it is considered that they were a success in general terms. Beyond the results obtained, the most important thing was the fact of sowing the seeds of ecological awareness among the participating students. A genuine interest, commitment and awareness with the preservation of the environment could be observed. The possibility of new design solutions with less environmental impact is a lesson learned, but they even discovered new business ideas around the development of products based on recycling.

There are many design methods, but developing a unique approach for designing with recycled materials is crucial in an increasingly environmentally conscious world. It is fundamental to recognize and educate about the negative impact of excessive waste production on the environment. Designs using recycled materials can help reduce the amount of waste ending up in landfills, thereby decreasing pollution and environmental degradation [9]. Nature serves as a perfect model of efficiency and sustainability. By

observing how ecosystems function in nature, designers can draw inspiration to create products and systems that mimic these principles [10]. It is necessary to create methodologies and design tools that focus on recycled materials, including techniques for selecting, treating, and transforming them into design products. Additionally, guidelines are established for designing products that facilitate their disassembly and recycling at the end of their life cycle. Designing with recycled materials requires close collaboration among designers, engineers, materials scientists, and sustainability experts. It is important to educate both designers and the public about the importance and possibilities of designing with recycled materials.

Regarding the students' feelings in these first experiences, we can affirm that they were well received in general terms. The students maintained great interest and a good attitude in the development of the projects. This was reflected in the ECOA (Student Opinion Survey), with a very high numerical rating and very positive comments such as the following: "...I loved the content we saw, both projects were a great challenge". "I love that being such a diverse group, you were able to adapt so that everyone could bring out their greatest potential". "The project demonstrates that sustainability can coexist with functionality to generate a product with human significance; and the difficulties encountered provide valuable lessons for future similar projects."

In summary, developing a unique approach to designing with recycled materials involves not only creating innovative products but also a shift in the mindset and culture of design towards sustainability and respect for the environment.

5 FUTURE WORK

Due to changes in the academic plan, this exercise cannot be reapplied to this course. However, it is planned to implement it in the last third of this first semester in another Learning Unit (Creative Thinking Methodologies) with first-year students from different disciplines in the School of Architecture, Art, and Design, and the School of Humanities. This will allow us to instil sustainable awareness and introduce methodologies from early stages of their careers so they can practice them throughout their studies for a longer period. The available time for its implementation in this course will be 5 weeks, equivalent to 20 hours, shorter than previous exercises.

Additionally, it is planned to implement this educational innovation with university students in short workshops at Design Conferences to disseminate the methodology in other spaces.

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