IMPLEMENTATION OF A RECYCLING DESIGN WORKSHOP INSPIRED BY BIOMIMICRY

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ABSTRACT
Sustainable design and the use of recycled materials are essential for reducing environmental impact. Teaching these practices to future engineers and designers is crucial for promoting more responsible development. The objective of the workshop was to raise awareness and train students in the use of recycled materials through a design method based on the Biomimicry spiral, "From Biology to Design." This allowed first- and second-year Industrial Design Engineering students to propose products using materials donated to ELISAVA Material Depot, sourced from various activities and projects at the university.
The workshop consisted of three 3-hour sessions, during which the five stages of the proposed methodology were implemented. These sessions took place in a classroom and in the university's workshops. Materials used included wood and wood products, metal tubes, laminated plastics, fabric, and thread, among others. The proposed products included an organizer, a table/magazine rack, an eyeglass holder, a jewellery box, a coffee table, and a storage container. Among the results of this experience, we can highlight the knowledge and application of nature-based design methods; the dynamics of working to solve a specific problem under pressure and with limited time; the collaborative work and creativity displayed in an environment similar to professional practice, among others.
In the future, we intend to conduct more workshops under similar circumstances, but considering improvements focused on complexity, execution times, and scope. We believe that these types of learning experiences are very valuable for engineering and design students, as they promote more responsible and environmentally friendly practices.

Keywords: Sustainable design, recycled materials, biomimicry, ELISAVA material depot, educational innovation, higher education

1 INTRODUCTION
The overexploitation of natural resources began in the late 18th century with the Industrial Revolution and intensified with the onset of the Anthropocene (mid-20th century). Short-term economic gain has been prioritized over long-term sustainability, causing significant damage to our planet, particularly to the climate and biodiversity. Therefore, it is crucial to find new ways to contribute to environmental conservation by making better use of natural resources and even waste materials. In this regard, initiatives and strategies such as zero waste, recycling, and regenerative design have emerged in recent years. Among these, recycling processes, such as downcycling and upcycling, have significant potential for development and application. Both concepts aim to reduce environmental impact and decrease the consumption of natural resources, differing in the final value of the product. Therefore, training future engineers and designers in these practices is essential to raise awareness and foster more responsible development. To achieve this, nature-based design methodologies are of great support, especially those related to biomimicry [1], [2]. Biomimicry, which emerged at the end of the last century, learns from and imitates the strategies of living species to create sustainable solutions, valuing nature for its wisdom and not for what can be extracted from it [3].
Furthermore, these 3 days downcycling workshop had as its main objective to raise awareness and train Industrial Design Engineering students in the use of recycled materials through a design method based on the Biomimicry spiral, "From Biology to Design", also called "Biology to Design" [4]. This practice has significant pedagogical value and contributes positively to the training of designers and engineers [5]. It is important to mention that three previous implementations have been carried out with students from various creative disciplines on a private university campus in Mexico. These implementations used

methodologies based on the two spirals of Biomimicry: "From Biology to Design" and "Challenge to Biology" [6], [7]. While design and engineering methods exist for developing products with recycled materials [8], the authors considered it pertinent to rely on nature-based methodologies. This makes sense, given that both methodologies seek, among other things, to minimize the environmental impact from the manufacturing process through use, maintenance, and final disposal.

2 METHODOLOGIES

2.1 Objectives

The objectives of this downcycling design workshop were the following:

Sustainability Education: To teach students the importance of recycling and the environmental benefits of using recycled materials in product design

Design Innovation: To foster creativity and innovation, drawing inspiration from nature, to develop sustainable and functional products.

Hands-on Practice: Provide students with practical experience in the techniques and processes of developing and manufacturing products made with recycled materials.

Environmental Awareness: To increase future designers' awareness of the environmental impacts of their design decisions.

2.2 Participants

This workshop was attended by 13 Industrial Design Engineering students from ELISAVA, Barcelona: 9 first-year students and 4 second-year students, in five teams of two students and one team of three students (with first-year students). That is, the students formed teams freely and with members from the same year. The workshop was held in the afternoon to avoid disrupting students' classes. Participation was voluntary and by direct invitation from the Coordinator of the Industrial Design Engineering Degree. The only requirement for participation was basic knowledge of using tools and equipment for material transformation (primarily standardized materials). Participants were also asked to bring drawing materials and appropriate clothing for working in the ELISAVA workshops.

2.3 Methodology

The methodology, as mentioned, is based on the biomimetic design spiral "From Biology to Design." Figure 1 presents the original methodology in Spanish in the center, and around it, in a clockwise direction, we can see the corresponding adapted stage and its description (every effort was made to maintain the meaning and objective of the original stage of the biomimetic design spiral). The originally proposed implementation days for this workshop are also shown (day 1 = D1, day 2 = D2, day 3 = D3), three hours each day (9 in total), although some minor adjustments were made during implementation.

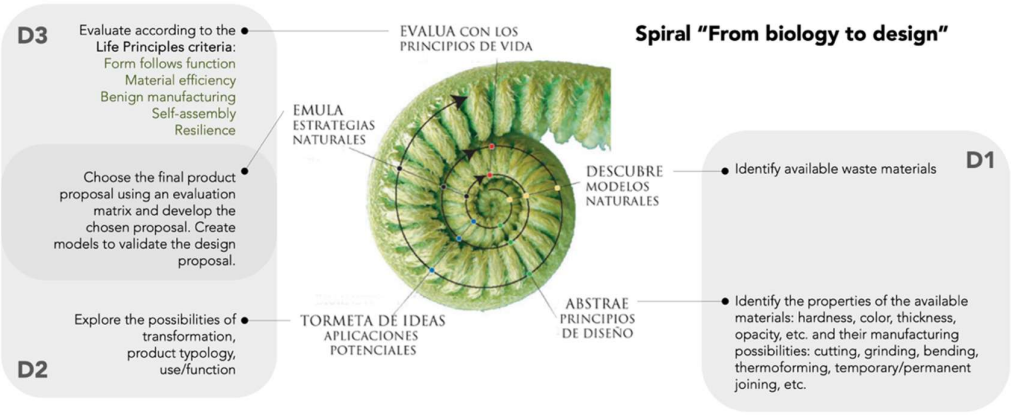

Figure 1. Design method based on the spiral "from biology to design"

Before implementing the methodology, an introduction was given, considering the instructor's presentation, a brief explanation of what circular economy and recycling design are, as well as the explanation of each step of the methodology.

The following details each stage of the methodology:

- **Discover.** *Identify available waste materials.* Figure 2 shows the selection of materials at ELISAVA Material Depot, a system and physical space inaugurated on the third floor of the ELISAVA Faculty of Design and Engineering in Barcelona, designed to promote the circular economy and the reuse of materials [9]. Day 1.

Figure 2. Students reviewing and selecting materials at ELISAVA Material Depot

- **Abstract.** *Identify the properties of the available materials: hardness, colour, thickness, opacity, etc. and its manufacturing possibilities: cutting, roughing, bending, thermoforming, joining, etc.* The selection and identification of material properties were carried out empirically due to the limited time available for this activity. In this regard, and if more time were available, methods offering a more scientific approach to this stage are recognized [8]. The materials chosen included wood and wood derivatives, cardboard, metal tubes, laminated plastics, fabrics and threads, among others. There was no specific procedure for classifying and preparing the recycled materials for use in the workshop. Day 1.

- **Brainstorming.** *Explore the possibilities of transformation, product typology, use/function.* This was done through text, sketches, and quick models, with minimal guidance and advice from the professor (see Figure 3). This stage was scheduled to begin on the second day of the workshop (as shown in Figure 1), but in practice it started at the end of the session on day 1. Days 1-2.

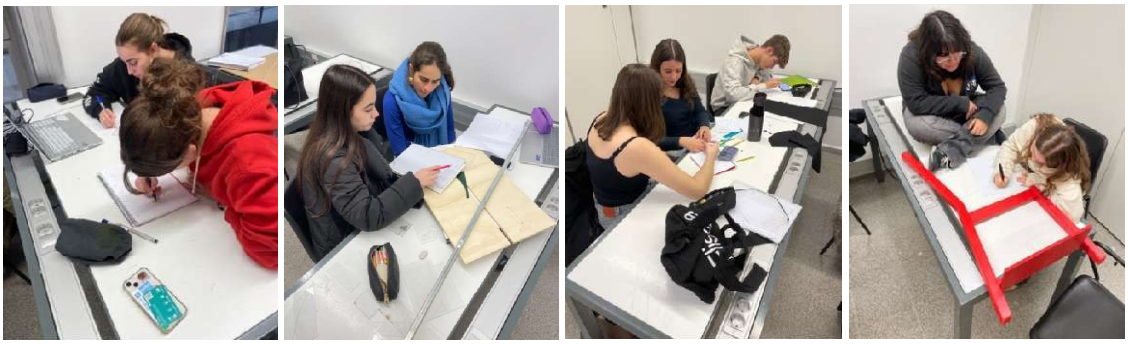

Figure 3. Students analysing the properties of materials and their potential for a new product

- **Emulate.** *Choose the final product proposal using an evaluation matrix. Make models for validation.* At this stage, the intention is for decisions to be made regarding the best design proposal based on an evaluation matrix, but some teams opted to create rapid models for the validation/evaluation of their ideas, before manufacturing the prototype. This stage was carried out mainly in the ELISAVA Prototype Workshop without feedback from the instructor. Support was provided only by the workshop staff, as tools and different equipment were used on-site, such as a jigsaw, laser cutter, milling machine, and sewing machine, among other equipment and tools. Figure 4 shows students working on their projects. Days 2-3.

Figure 4. Students working on their projects

- **Evaluate.** Evaluate under the criteria of Principles of Life. To conduct this assessment, students were given an evaluation matrix with a scale of 0 to 5 (0 being deficient and 5 being outstanding) and colour-coded indicators (see Table 1). After completing the self-assessment, the teams shared their numerical scores and gave oral presentations of their prototypes. Figure 5 shows students from Teams 1, 2, 3, and 5 presenting their projects. Day 3.

Table 1. Evaluation matrix

	0	1	2	3	4	5
The form follows the function						
Use of the material						
Benign manufacturing						
Self-assembly						
Resilience						

Figure 5. Students presenting their projects

3 RESULTS AND DISCUSSION

As a result of this workshop, the products developed by the teams were the following:
Team 1: Wall organizer with adjustable shelves. Made with pine plywood and acrylic mirror, using a laser cutter.
Team 2: Magazine rack with side table. Made with pre-curved metal tubes, fabric and pine wood, mainly using a saw, milling machine and sewing machine.
Team 3: Double glasses holder. Made with polypropylene and Velcro, cut with a cutter and scissors.
Team 4: Jewellery box. Made using an existing chair leg and cotton thread, using a saw and handmade knots.
Team 5: Coffee table. Made with corrugated cardboard and MDF. Cut with a jigsaw.
Team 6: Storage container. Made with wood and various fabrics, using a saw, scissors, and knots.

The prototypes presented by the six teams are shown in Figure 6.

Figure 6. Prototypes presented by the teams

The choice of product type and functionality was neither questioned by the instructor nor justified in the prototype presentations. However, it can be observed that teams 1 and 2 (comprised of second-year students) developed products with more complex functionality and manufacturing processes than the other teams (3, 4, 5, and 6), which were made up of first-year students. This is easily explained by the fact that the process of acquiring knowledge and developing skills increases throughout university studies. During the first year, students typically work with simple, standardized materials and basic transformation methods.

Regarding the evaluation, each of the aspects to be evaluated is briefly explained below:

- **The form follows the function.** An important aspect was that the product had to have a high level of functionality, avoiding purely ornamental objects.
- **Use of the material.** Maximizing the use of available materials was also a non-negotiable condition for this exercise.
- **Benign manufacturing.** Another aspect to highlight, and one requested from the beginning of the workshop, was that the processes be as environmentally friendly as possible.
- **Self-assembly.** The objective was self-assembly, temporary or pressure-fit joints. The use of adhesives or permanent bonds between product components would be penalized.
- **Resilience.** Finally, the product was required to be resilient. This meant it could withstand use and handling, minor impacts, and even occasional drops. It also meant proposing simple designs, avoiding unnecessary complexity.

The self-evaluation of the proposed products, meanwhile, was based on the Principles of Life (observable in Figure 1 and Table 1). The highest score (23/25) was obtained by Team 2, the lowest by Team 4 (17/25), and the average was 20.33/25. Although this evaluation could have been carried out by the instructor, with greater experience and impartiality, the authors believe that self-evaluations strengthen students' critical thinking, as well as their environmental awareness. Furthermore, this workshop would not have been possible without the support of ELISAVA Material Depot, a project of ELISAVA, the Faculty of Design and Engineering in Barcelona, which aims to optimize materials management by centralizing donated materials from various university activities and projects [9].

4 CONCLUSIONS

Based on a downcycling design workshop, students became aware of the environmental impact of their design decisions and were encouraged to adopt more sustainable practices. Creativity and innovation were fostered, drawing inspiration from nature-based design methods.

Students gained hands-on design experience, generating solutions quickly with the support of agile prototyping using recycled materials. In this regard, it is important to highlight the value of trial and error through prototyping.

The most significant aspect of this workshop was that it fostered ecological awareness among the participating students. They learned the valuable lesson that it is possible to create new design solutions with a lower environmental impact and that methodologies exist to achieve this. In this regard, guidelines were established for creating products that are easy to disassemble and recycle at the end of their useful life. The workshop promoted downcycling, a design practice with great potential, due (unfortunately) to the increasing number of products and materials that can be reused after their useful life [10]. This can contribute to reducing the amount of waste in landfills, thus mitigating pollution and environmental degradation [11]. The workshop also addressed the design and business opportunities related to waste, scrap, and leftover materials from industrial waste.

By participating in projects that prioritize the use of recycled materials and eco-friendly design techniques, students develop crucial skills and knowledge for innovating in a world that increasingly demands sustainable solutions. While it is acknowledged that, due to time constraints, it was not possible

to compile a formal and systematic record of student feedback and reflections during the workshop, the observed indicators, such as their active participation, the questions they asked, and their problem-solving skills, suggest a positive impact in these areas. Undoubtedly, these types of learning experiences are extremely valuable for engineering and design students, as they not only foster more responsible and environmentally friendly practices but also prepare them to face current and future sustainability challenges.

5 FUTURE WORK

In the future, we plan to conduct more workshops based on this methodology, incorporating significant improvements such as more complex challenges, longer execution times, and a broader scope. Furthermore, we will implement more robust empirical research, including surveys and interviews with participants to more accurately assess the workshop's results and impact. As a potential further improvement, we are considering limiting the design solution to a specific type of product or problem to focus our efforts and achieve more concrete results.

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