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# Industrial waste transformation through an immersive experience in industrial design education

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***Abstract***
*Industrial waste management needs sustainable and creative solutions. This study addresses an immersive approach to teaching industrial design, integrating academia and industry to transform waste into valuable resources. Collaborative workshops with companies applied a structured six-step method, ranging from material identification to prototyping and technical validation of practical solutions. Immersion in industrial environments favored students' creativity and reflective learning. Furthermore, academic-business partnerships have strengthened the educational impact, aligning the training of future designers with market demands and the challenges of environmental sustainability.*

***Keywords:*** *industrial waste; sustainability; design; immersive approach*

## 1. Introduction

Industrial waste is one of the greatest global challenges, with significant environmental, economic and social implications. The search for sustainable solutions positions industrial design as a fundamental field for transforming waste into valuable resources, using innovative approaches. However, traditional teaching methods often do not provide the immersion needed to effectively address the complexity of this topic. Teaching outside the classroom, in non-formal and extracurricular spaces, can significantly increase the effectiveness of learning, promoting the consolidation of knowledge and skills. These spaces are recognized as important sources of knowledge (Oliveira & Gastal, 2007; Scherer Júnior, 2018). When used as an extension of the classroom, they contribute to the diversification of pedagogical practices, offering more comprehensive learning (Rosa, 2002; Nogueira, 2016). Several authors have investigated teaching practices that go beyond the traditional classroom space, such as online teaching (Garrison & Vaughan, 2008; Horn & Staker, 2015; Means et al., 2010). Within these practices, the use of virtual reality (VR) stands out as an immersive tool, capable of enhancing participation and knowledge retention (Chen et al., 2019). In the context of our immersive experience, the concept of learning outside the classroom expands beyond online learning to encompass business and industrial environments. The ability to make complex decisions based on reflection during action is central to the concept of "reflective practice." Introduced by Schön (1983), this concept demonstrates that continuous learning, combined with practical experience, is essential for creative professions such as industrial design. Although it is a consolidated approach, its relevance persists in contemporary times and in design teaching. Furthermore, collaborations between academia and industry have shown a positive impact on industrial design education. These partnerships enrich pedagogy by integrating real market challenges with educational practices, allowing students to develop practical and innovative solutions. Such initiatives highlight the importance of aligning education with industry needs to prepare designers for the future (Blevis & Stolterman, 2007). In this context, the following question was asked: how can immersive educational practices in industrial design, integrating advanced technologies and partnerships with industry, promote the sustainable transformation of industrial waste into innovative solutions? This question aims to address innovative teaching practices, the connection with industry needs and the creation of sustainable solutions to the problem of industrial waste. Therefore, this article shows how the transformation of industrial waste can be promoted through immersive educational practices in industrial design. By incorporating advanced technologies, immersive methodologies and industry partnerships, aiming to foster sustainable innovation while promoting education aligned with market and environmental needs

## 2. Method and planning

To find an answer to the question posed, a working method was established with the aim of planning a series of steps and procedures whose result would lead to a possible answer. The method presented is composed of six main steps, organized sequentially, which structure the development of the project involving the reuse of industrial waste (Figure 1). Each phase presents well-defined inputs and outputs, ensuring systematization and clarity in the process. In the first stage, called Project Preparation, companies suitable for the type of material to be addressed are identified and selected. Preliminary visits are carried out to structure the briefing with the company management and prepare the workplace. At this stage, workshop participants are selected, and relevant communication materials are prepared.

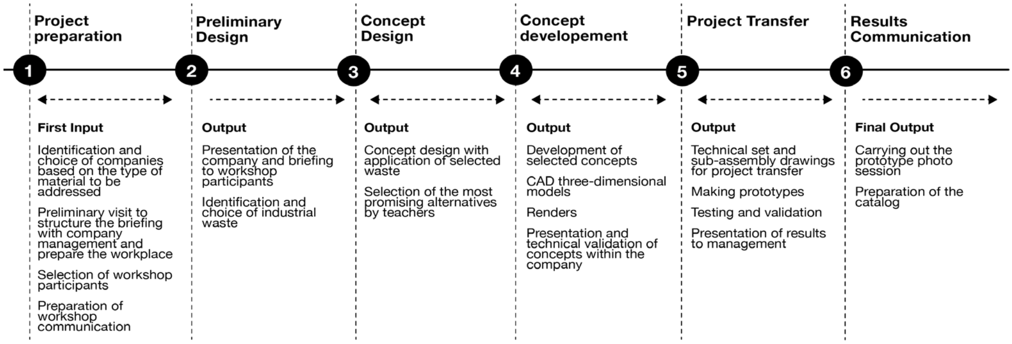


*Figure 1. Flowchart of the structured method for project development.*

The result of this stage is the presentation of the company and the briefing to the workshop participants, establishing the initial alignment and corresponding to the second stage of the process. The third stage, called Concept Design, involves identifying and selecting industrial waste that will be used in the project. The objective is to generate initial concepts that use this waste in a creative and functional way. In this phase, the most promising alternatives are chosen, resulting in the development of concepts applicable to the proposed context. The fourth stage, Concept Development, focuses on the evolution of selected concepts through three-dimensional CAD modelling and the creation of renders. These visual materials are presented for technical validation, ensuring alignment with the company's expectations and needs. The main output of this stage consists of technically validated concepts, accompanied by detailed three-dimensional representations. In the fifth stage, Project Transfer, the technical subassembly drawings necessary for project implementation are prepared. Prototyping is carried out, followed by testing and validation. As a result, the finalized and technically validated prototypes are ready to be used or demonstrated. Finally, the sixth stage, Communication of Results, includes the final presentation of the project to the company's board of directors. This phase includes complementary activities, such as carrying out photo sessions of the prototypes and creating a catalogue to document the results. This method stands out for its structured integration of stages, focusing on the reuse of industrial waste in a creative and technical way, ensuring alignment with business needs and providing consistent and well-documented results.

## 3. Discussion and results

### 3.1. Project Preparation

To effectively address the proposed research question, the professors selected industries with concrete concerns about sustainability and waste management, exploring alternatives to conventional recycling. The research was organized in annual workshops, held at the end of each school year, allowing students to experience immersion in industrial contexts, focusing on local raw materials such as iron, aluminium and wood, given the location of ESD-IPCA in the region. from Minho in northern Portugal. The companies were formally invited and, after accepting, meetings were held between the teachers and the CEOs, where the purpose of the project was presented: to implement innovative pedagogical practices, align with the needs of the industry and develop sustainable solutions. These meetings allowed us to adjust expectations and ensure efficient collaboration. In the first workshop, BySteel, part of the DST Group, challenged participants to create urban furniture using waste metal structures destined for Schiphol Airport. The students worked in an office in the centre of the factory, immersed in the industrial environment. In the second year, with Navarra, participants developed urban furniture for rest areas in the factory, using defective aluminium profiles. The project was carried out in a vacant and fully equipped warehouse. In the third year, in partnership with Tmodular, objects were created for a prototype microcity, the Living Lab, a project led by Norman Foster, with students working in several meeting rooms on the DST campus. Participants were selected by invitation from 10 students with suitable profiles, while the workshops were widely publicized to inform the school community and foster student interest in future editions. Each workshop began with a company presentation and briefing, establishing a solid foundation for the development of practical and sustainable projects.

### 3.2. Preliminary Design

This phase begins with the formation of work groups, followed by a guided tour of the factory facilities to provide an overview of the production processes, the characteristics and possible transformations of the materials and to understand construction techniques, such as fitting, joining and cutting. At Bysteel, students observed an industrial metalworking shop equipped with advanced technology for working with metals such as iron and steel, following the entire process, from project planning in CAD/CAM software to the precise shaping of raw materials, with high quality standards. and security. At Navarra, specialized in aluminum profile extrusion, they had the opportunity to see the entire production cycle, from design to shipment, highlighting the precision required in the production of products. In addition, the factory areas were also presented for intervention. At Tmodular, participants delved deeper into the workings of an industrial carpentry shop, focused on customized interior solutions. The visit highlighted the integration between the stages, the qualification of the teams and the use of specific machinery, with a strong emphasis on modular construction. After the visits, the groups identified and selected industrial waste to materialize their ideas. This stage was crucial, as the careful selection of materials is essential to achieve excellent results in projects (Figure 2).

*Figure 2. Collection of waste and industrial waste from Bysteel, Navarra and Tmodular.*

### 3.3. Concept Design

In the three case studies analyzed, participants transported the waste samples they considered most relevant to their respective workplaces. The objective was to generate initial concepts that integrated these materials in a creative and functional way, responding to both technical constraints and practical needs. The ideas were initially conceptualized and recorded in the form of drawings, representing the first proposals for solving the challenges presented. These proposals went through several iterations and alternatives, resulting from brainstorming sessions carried out in collaboration with each of the factories involved. The initial concepts developed were submitted to the teachers for validation. Based on this analysis, the most promising proposals were selected and underwent further development.

### 3.4. Concept Development

The Concept Development phase focuses on selecting the most promising ideas and developing a more in-depth concept. This evolution of concepts is developed and validated through three-dimensional modeling in CAD and the creation of renders. 3D CAD modeling is performed using Solidworks parametric modeling software. At this stage, the teams proceeded to virtually implement the ideas, a materialization where the detailing, dimensional control and all functional and construction details were carried out. To finish and as a way of validating the modeling, materials and proportions, renders were created, that is, realistic images of the proposals. The result of these images, in addition to the approval of the ideas by the participants and advisors, were also essential to support the presentation of the proposals to the technical and design department of the companies. The projects were exhibited, by groups, and presented to the CEOs of the companies involved and their respective technical and design teams. With this presentation and the evaluations, the participants obtained approval of their projects and indications of technical changes for the implementation of the proposals. This ensured that the ideas aligned with the proposed objectives and thus moved on to a new phase, the preparation of projects for production.

### 3.5. Project Transfer

Simultaneously with the renderings, the teams created the technical drawings for each solution. In addition to the execution of conventional technical drawings, developed in accordance with established standards and rules, detailed axonometries of the sets were also prepared. These axonometries allow a clear and precise three-dimensional representation, providing a global vision of the products and their structural relationships, facilitating the understanding of the product, both for the technical teams responsible for production and for other actors in the process. In this way, technical drawings play a central role in technical communication, in optimizing production and in ensuring the final quality of the products developed. The prototype construction phase is one of the most intense and favorite for all participants, it is when the projects come to life, the ideas leave the paper and become reality. Whenever possible, and for safety reasons, the members of each group actively participate in the prototype production process under the guidance of the responsible technicians (Figure 3).

*Figure 3. Production of prototypes as Bysteel, Navarra and Tmodular.*

Prototypes aim to test and evaluate the functionality, design and feasibility of the concept before final production. At this stage, it is possible to identify and correct problems, validate ideas and improve the design, ensuring that the product meets established expectations and requirements. After identifying, correcting and improving the issues detected in the initial prototypes, production of the final prototypes began. In this phase, the objects materialized as they had been idealized and designed, fully meeting the criteria defined in formal, functional and aesthetic terms. The production process of the final prototypes involved rigorous quality control, ensuring that every detail was aligned with the predefined objectives and the established technical and conceptual parameters.

### 3.6. Results Communication

After the prototypes were completed, they were installed in strategic locations in the participating industries, allowing the projects to be presented to company managers. The solutions were praised by the CEOs for their aesthetics, functionality and ergonomics, as well as for the results achieved in the short period of the workshop. Certificates of participation were given to all participants. Some solutions were later produced and implemented by industries. The photo sessions of the prototypes were carried out by professionals, also highlighting some functional details (Figure 4). At Bysteel, the photos were taken in a concrete setting, highlighting the finishes of the pieces. In Navarra, the workshop pavilion was used, while at Tmodular, due to industrial secrecy restrictions, the session took place in the factory's paint shop. Each workshop resulted in a publication that systematically documented the results and methodologies applied. The organization was coordinated by teachers, ensuring academic rigor. At Bysteel, the graphic component was developed internally and in the workshops with Navarra and Tmodular, the collaboration of designer Marco Oliveira was counted on, ensuring high visual and editorial quality, reinforcing the value of publications as instruments of scientific and technical dissemination.

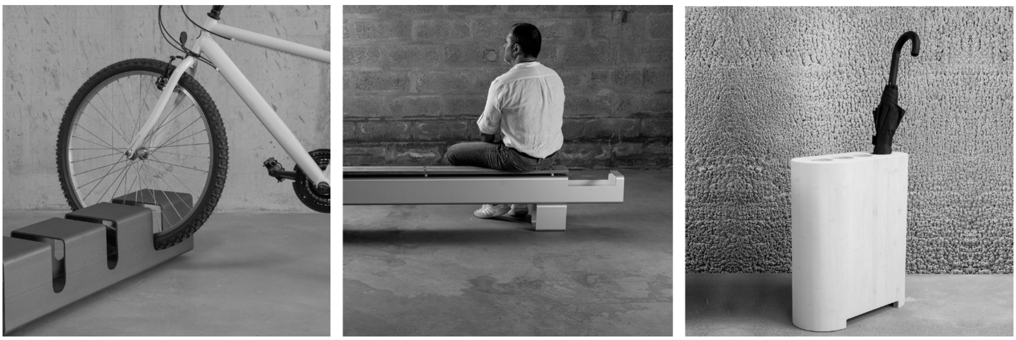

*Figure 4. Prototypes photography at Bysteel, Navarra and Tmodular.*

## 4. Conclusions

It is concluded that industrial waste management requires innovative solutions that reconcile sustainability and creativity. The immersive approach adopted in teaching industrial design has proven to be effective in integrating students into real business environments, promoting practical and reflective learning. The structured six-step method allowed developing viable and technically validated solutions aligned with industrial needs. Partnerships between academia and companies have strengthened the training of future designers, meeting market needs and reinforcing the commitment to responsible environmental practices. Thus, similar initiatives can foster innovations that contribute significantly to the global challenges of sustainability and circular economy. As future work, it is suggested to explore the application of emerging technologies, such as artificial intelligence and additive manufacturing, to further optimize the process of transforming industrial waste into innovative solutions.

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