Design Methodologies for Sustainable Products from Mixed Waste Plastics and Foundry Sands

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Abstract. This design research proposes, through cooperation between the private sector (industry) and the public sector (university), new furniture and cladding solutions to integrate the urban environment. It seeks to raise awareness on the reuse of industrial waste originating from mixed plastics and foundry sands, promoting collection, valorisation, and transformation. It potentiates sustainable advances that allow contributing to a Circular Economy, through the premise of safeguarding natural resources, as well as environmental ones. For the development of the proposal, a design methodology that combines the Double Diamond model with the Circular Design model is applied. From this conjugation, sustainability is explored as an intrinsic condition of the product, capable of producing added value through design and innovation, minimising the impact of industrial waste on the environment. Simultaneously, the modular concept was explored, that is the application of a single component in the development of several solutions, thus reducing production costs and increasing the range of design possibilities. With this approach, we intend to contribute to a change in the design paradigms, through sustainable and environmentally friendly production techniques. The results obtained contributed to the awareness of designers, architects, or engineers, allowing the identification of new ways and contributions of design in industrial customs and traditions, as well as, transferring technical-productive knowledge about the positive impact of the reuse of industrial waste in the design of new products.

Keywords: Circular Design, Circular Economy, Eco Design, Foundry Sand, Plastic Waste, Product Design.

1 Introduction

Following the Stockholm Declaration of 1972, the debate for the conservation of the human environment began, a warning for present and future generations. Twenty years later, following the Rio Declaration, in the environmental and development field, a course was set in terms of environmental care, assuming from then on, the relevance of sustainability, having as main axes the social, economic, and environmental dimension [1]. Despite these warnings, contemporary society consumes raw materials at an unsustainable rate, and it is common knowledge that many of these raw materials, available in nature are finite and non-renewable, can be obtained with the desired characteristics and applied in the manufacture of new products. On the other hand, with the current unbridled consumption of renewable raw materials, nature's regeneration capacity is exceeded, emerging the need to apply in design recycled materials, from the end of the product life cycle, as well as the replacement of these raw materials by secondary raw materials [2].

Today it is crucial, both in environmental and economic terms, to consider Circular Design, from the beginning of the design process, as well as at all stages of product creation. Supporting sustainable strategies and targeting the fundamental principles for the Circular Economy, promote product maintenance for the maximum lifetime, decoupling consumption from finite resources and help companies in the transition towards the consumption of renewable resources [3]. These fundamentals have been promoted by the Ellen MacArthur Foundation [4], through the slogan "It's time for a circular economy", which considers "Through design, we can eliminate waste and pollution, circulate products and materials, and regenerate nature, creating an economy that benefits people, business and the natural world." With the aim of alerting to the fact that the production cycle of a product can be more sustainable. Considering that the current economic model (take → make → use → dispose → pollute) is reaching its limits both environmentally and socially. The principles of Circular Economy seek to redefine society, support a transition to a circular model (recycle → make → use → reuse → remake → recycle), build economic, natural, and social capital, building on three principles: 1) eliminate waste and pollution from the start; 2) keep products and materials in use; lastly, 3) regenerate natural systems.

Within the scope of the project "D'ECO – Design Economic Circular Opportunities" [5], this design research aims to strengthen sustainable technological development and innovation in design. Through the application of composite material – developed by the Department of Mechanical Engineering (DEM) of the University of Minho – resulting from the union of industrial waste from the industrial and construction sectors. With origin in mixed plastics and foundry sands, a quality composite was obtained, with functional properties of technical and economic interest. A viable alternative to a serious environmental problem, it promotes the reduction, reuse, and recycling of this waste.

2 State of the Art

We live asphyxiated by increasingly diversified products that uncontrollably consume the planet's natural resources. Design is diving into the era of the 10Rs of sustainability (Respect, Refuse, Reduce, Reuse, Renew, Recycle, Responsibility, Rethink, Replant, Restore) as a policy to achieve environmental conservation goals and social identity. In this sense, design does not prefigure tomorrow, but participates in its formation, being able to improve the future through the instruments made available by it, offering new solutions, revealing new possible and different paths [6]. On the other hand, designers, architects, and engineers, play an important role in choosing and applying materials, as well as making decisions that ensure sustainability, a choice that should be understood as a systematic approach [7].

The current economy is largely linear. Traditional companies procure raw materials to produce products that end their life cycle after short and medium-term use. The application of sustainable policies offers unique opportunities for change, both in design and in the multidisciplinary development of technologies that enable the reduction, reuse, and recycling of waste from industry and the construction sector. It is possible to identify in the literature products (Fig. 1) from the recycling of various types of waste: (1) plastic waste and sand "Silica Plastic Block" by Rhino Machines; (2) plastic waste "Sea Chair" by Studio Swine, "Pots Plus" by The New Taw, "Jää Bench" by And New, "Substantial Chair" by Alexander Schul, "h-Bench" by Studio Segers, "Alex Chaise Longue" by Alessandro Mendini; (3) styrofoam waste "Refoam" by We Plus; (4) clay waste "Breathing Wall" by Celestin Tanari; lastly, (5) paper waste "PaperBricks" by Studio Woojai, "Paper Paper Bin" by Fritz Jakob, "Recycling Reject" by Tim Teven.

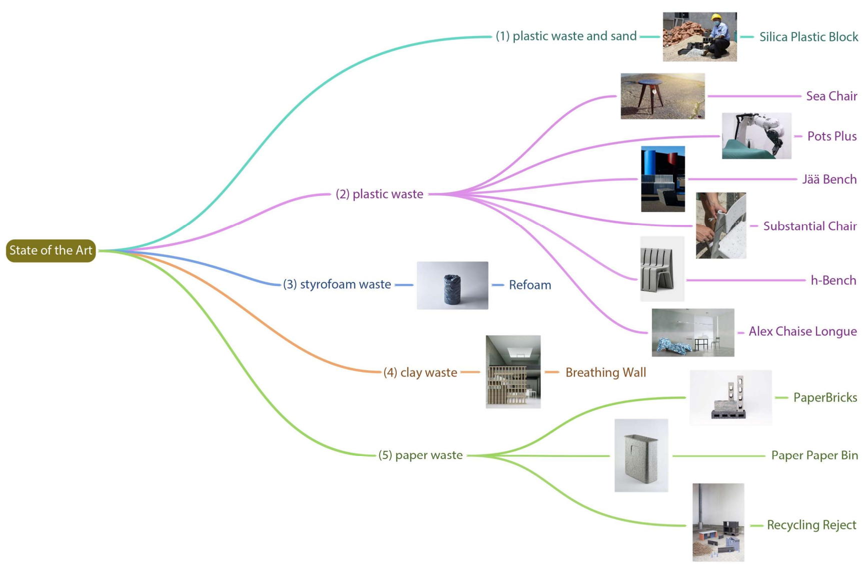

Fig. 1. Diagram showing products from waste recycling.

In a Circular Economy, products and/or their materials return to the industrial ecosystem, through a conscious process of sustainable production, and this return may occur at different stages of the production process.

2.1 Mixed waste plastics with foundry sands

During the activities promoted by the project "D'ECO – Design Economic Circular Opportunities", the Department of Mechanical Engineering of the University of Minho in cooperation with Resifluxo, Lda., a company responsible for the triage of much of the waste from the area of Vale do Ave, Portugal, developed a proposal for a composite material through the recycling of industrial waste, with 50% mixed plastics and 50% foundry sands.

It was possible to test, cutting and machining characteristics, through the transformation of a sample specimen produced in the scope of the project, into a sample with 90 x 40 x 25mm, using a simple mechanical saw normally applied in the cutting of solid wood, without compromising the chemical and mechanical properties of the composite, creating only a smooth surface finish (Fig. 2).

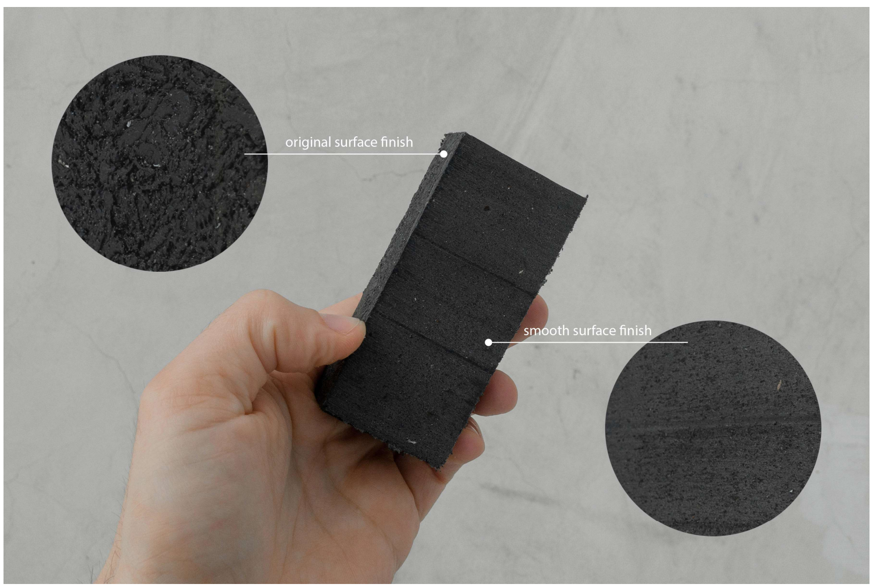

Fig. 2. Composite sample 90 x 40 x 25mm, weight/mass 108g, density 1200kg/m3.

2.2 Existing products on the market

Some research, especially for the construction sector, has been studying this type of composite material, as well as, demonstrated scientific interest [8, 9]. Above mentioned, the product "Silica Plastic Block" created by Rhino Machines, is an example of this, aspires to sustainable construction, through the application of a brick produced from the recycling of 80% of foundry dust/sand waste and 20% of mixed plastic waste [10]. Outside the remit of the "D'ECO – Design Economic Circular Opportunities" project and to date, the application of this composite typology in urban furniture design and related, does not seem to exist yet, or at least, we have not found it in the literature.

3 Materials and Methods

The research presents a design methodology (Fig. 3) applied to a case study, where the problem is addressed through research, synthesizing the findings and the idea development, proposing a unique solution, not encompassing the final testing phase. This is achieved by combining the Double Diamond model [11] with the Circular Design model [3].

Each interaction of this design process approach involves the creation of four distinct phases: 1) "discover—understand" corresponds to the research and discovery of the purpose, through sustainability and innovation criteria; 2) "define—define" corresponds to the determination and synthesis of the theme/problem, through intuition and opportunity criteria; 3) "develop—make" corresponds to the development of ideas, designs and prototypes, through context and technology criteria; lastly, 4) "deliver—release" corresponds to the delivery of a unique solution. To this end, it is understood: i) the purpose and legacy of the study (why); ii) the research method applied (how); iii) the solution implemented (what).

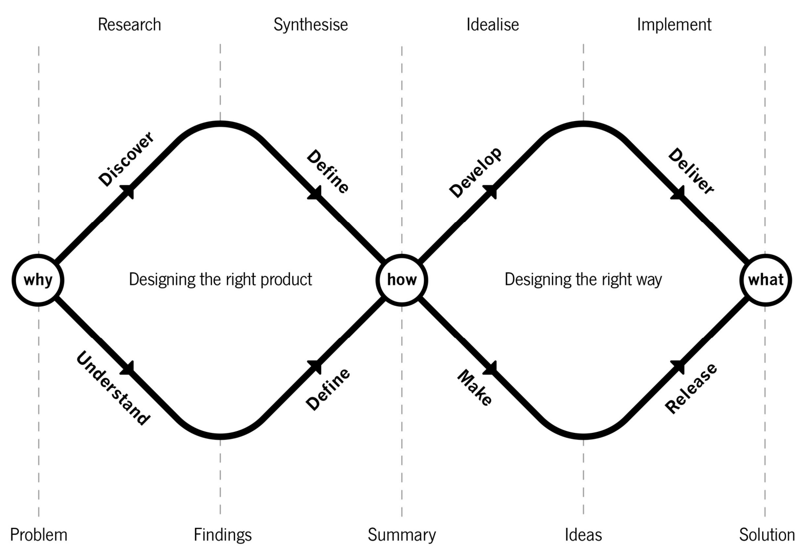

Fig. 3. Design methodology (the Double Diamond model with the Circular Design model).

3.1 Design process

Through a visit to Resifluxo, Lda. facilities, it was possible to understand both the manufacturing processes and the company's pretension to design a new product. The first phase of the "discover—understand" process, aimed to research and identify ideas, shapes, and morphologies. The theme was defined as the design of road and pedestrian barriers. Through initial research it was possible to select 24 safety barriers (Fig. 4).

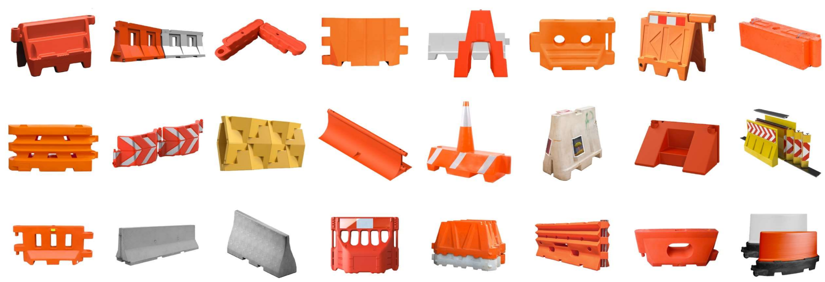

Fig. 4. Systematisation of 24 road/pedestrian safety barriers.

Their mapping using the web application “Coogle” exposed a morphological homogeneity, restricted to the volumetry of a triangular prism, which may present a grey pigmentation provided by the concrete, but also a brown, red, orange, or yellow pigmentation provided by the plastic.

After this result new research was carried out outside the scope of the defined archetype, as a result 12 design products were selected (Fig. 5). Although this selection did not present solutions with origin in industrial waste, the identification of these provided an analysis, even if superficial, for possible morphologies and manufacturing processes by pressing of the composite material. This information revealed itself important to glimpse the possibility of integration of the composite in a design proposal.

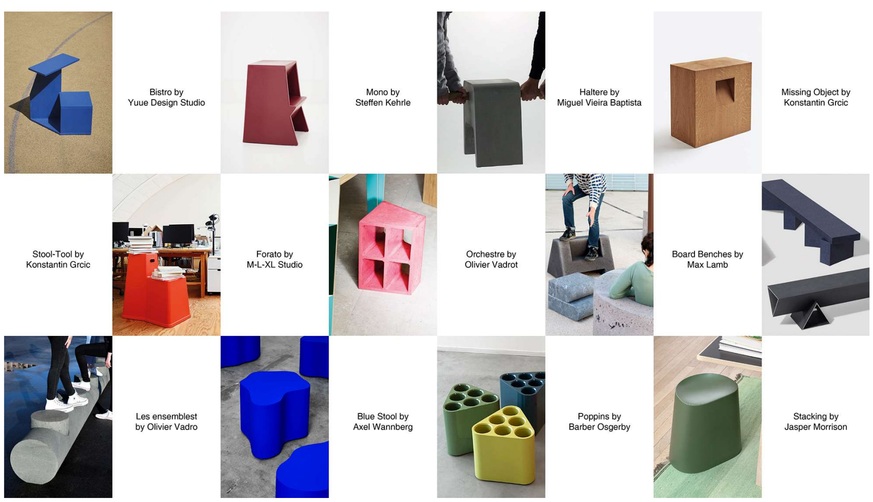

Fig. 5. Selection of 12 design products.

The second phase, “define—define”, aimed to systematize, and summarize the interpretation of the research of the identified ideas, shapes, and morphologies. For a redefinition of the program, new design aspects were identified. After this result, new research was conducted with the keyword “zig-zag” in several design blogs, as a result 12 design products were summarized (Fig.6).

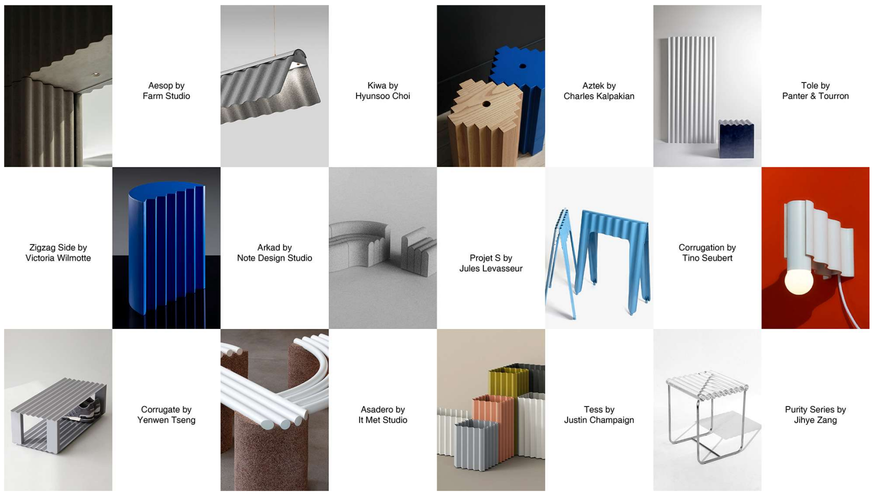

Fig. 6. Summary of 12 design products.

Although this selection also did not present solutions originating from industrial waste, their identification provided a deeper analysis of possible morphologies and technical-productive processes by extrusion. This information guided the definition, design, and development of the solution extruded with composite material, originating from industrial waste, composed of 50% mixed plastics and 50% foundry sands.

3.2 Concept definition and prototype in polystyrene foam

The third phase, “develop—make”, aimed to develop the idea through the construction of volumetric studies in polystyrene foam using CNC (Computer Numeric Control) machining. The first study corresponded to the mock-up of a profiled texture with a hexagonal base, developed using the software “Rhinoceros 3D”. It had as a starting point the technical-productive capacity for extrusion provided by Resifluxo, Lda., always considering the alternative by pressing (Fig. 7).

The creation of this profiled component had as a differentiating factor the modular design, allowing the conception of a set of design hypothesis. Through its development we intended to communicate, through modularity and aesthetics, the premises of the Circular Economy and Circular Design, protecting the environment through the resilience of sustainability. Creating the opportunity to respond to diversified sectors, for example, the street furniture or exterior cladding sector.

Fig. 7. Technical-productive process and mock-up for hexagonal profiled texture.

A second study made it possible to explore the modularity of the profiled component with circular base (Fig. 8a). The development of several volumetric studies in polystyrene foam allowed us to envisage various morphologies and hypothetical solutions for the urban furniture sector using the software 3D, such as bollards, chairs, benches, litter bins, barriers, or defences. The volumetric studies also made it possible to explore the surface textures of the profiled component with octagonal base (Fig. 8b). Through these it was possible to glimpse various aesthetic morphologies for the exterior cladding sector. In this way we respond to a hypothetical list of products that fit the Resifluxo guidelines, as a means of applying the composite developed by the D'ECO project, thus valorising industrial waste based on mixed plastics and sand resulting from foundry waste.

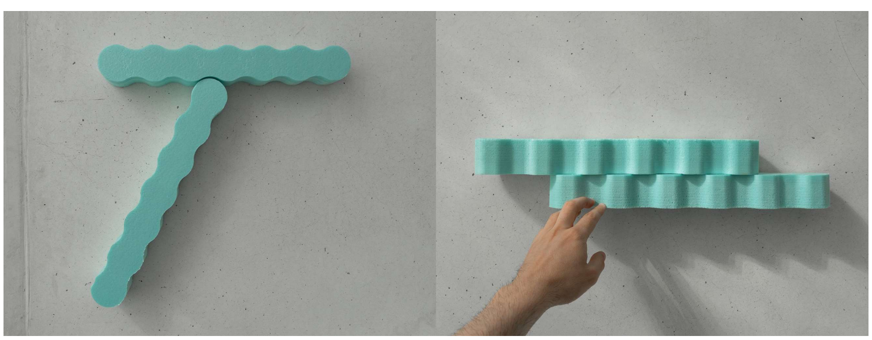

Fig. 8. Study for a profiled component: a) with circular base, and b) with octagonal base.

4 Results and Discussion

The fourth phase "deliver—release", aimed to present a unique solution, thus, it was proposed a profiled component with hexagonal base and circular ends, with a width of 420 mm and a maximum length of 3000 mm (Fig. 9).

Fig. 9. Solution for profiled component applied to a pedestrian safety barrier project.

Through the solution developed for the profiled component, the aim is to reduce resources and production costs, in a Circular Economy perspective, which favours the process chain to reduce energy consumption, increasing the product's lifetime and minimizing the impact of industrial waste. Simultaneously, it responds through a wide range of possible sustainable solutions (Fig. 10).

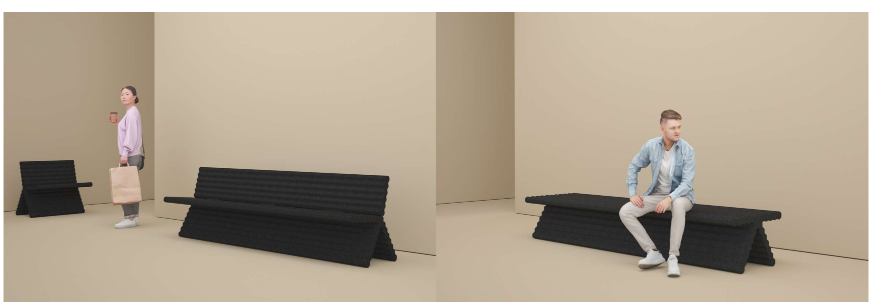

Fig. 10. Possible sustainable solutions for the design of benches.

This approach underpins the creation of a future prototype that supports the materialisation of the possible solutions, achieving a solution closer to reality, with a higher degree of confidence in both the design and the integration of the composite. The resulting material can be re-crushed and extruded, maintaining the circularity of the recycled raw material, although some mechanical characteristics may progressively lose qualities. This research also allowed the debate and presentation of ideas for urban environment, potentiating a Circular Economy, through the safeguarding of natural resources, and environmental, with the application of design methodologies, life cycle extension and green production process [12].

5 Conclusion

Scientific and technological research plays an important role in the path towards a Circular Economy. Through a design methodology, the Double Diamond model is combined with the Circular Design model to identify new paths, promoting research, discovery, and design, as well as waste collection, recovery, and transformation.

The aim of this study was to reuse industrial waste from the manufacturing and construction sectors in the design of new, more environmentally friendly products. Aiming to safeguard natural resources through the reuse of industrial waste, a case study was presented that values the application of mixed plastic waste and foundry sands, whose destination would be landfill. Based on this assumption, it is proposed as a solution a profiled component produced by extrusion of composite material, resulting from the union of industrial waste with 50% mixed plastics and 50% foundry sands. A modular solution that intends to contribute to new design solutions, without defining an exact product morphology, covering a wide spectrum of possible archetypes, making it possible to reach a sustainable solution, capable of producing added value. Morphologies oriented to the urban environment, products that normally end their life cycle after a long use. Contributing in this way to issues such as sustainability, reuse and modularity of the hypotheses presented. Promoting through product design the collection, valorisation, and transformation of waste.

Possible applications of this waste may need technical-productive adaptations, to adapt this waste to the characteristics of the final product. Future advances in a prototype, both for the component and the product, will enable tests to be carried out to understand the viability and resistance of the proposed connections between the modular components, to improve design issues and technical-productive knowledge. Finally, this study alerts designers, architects, and engineers about the importance of reusing industrial waste in the design of new products.

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