DESIGN FOR CIRCULAR ECONOMY: DESK ORGANIZER WITH RECYCLED POLYMER

DESIGN PARA A ECONOMIA CIRCULAR: ORGANIZADORES DE ESCRITÓRIO COM POLÍMERO RECICLADO

DISEÑO PARA LA ECONOMÍA CIRCULAR: ORGANIZADORES DE ESCRITORIO CON POLÍMERO RECICLADO

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ABSTRACT
The issue of sustainability is increasingly present in discussions about production and consumption. In this context, polymeric materials raise serious concerns, being considered one of the most harmful to the environment due to their slow degradation. However, as a highly versatile and relatively inexpensive material, polymers make up a large part of everyday objects. Due to the concern generated by the often incorrect disposal of their waste, efforts are being made to find ways to change this. One viable approach to mitigating environmental challenges is the adoption of the circular economy, which aims to reintegrate materials into the production cycle. Design, in this context, plays a key role by designing products in such a way as to minimize their disposal as much as possible. This paper presents the development of a line of desk organizers made from recycled polymer, based on circular design principles. For production, post-consumer polypropylene and polyethylene packaging was shredded and hot-pressed to form sheets. Subsequently, the sheets were laser-cut, resulting in interlocking modular pieces for assembling the organizers. Therefore, mechanical recycling was presented as a possible resource for recovering polymers and using them as raw materials for the production of new artifacts in the context of the circular economy.

KEYWORDS
Design; Circular Economy; Sustainability; Polymer; Recycling.

RESUMO
A sustentabilidade é uma questão cada vez mais presente nas discussões sobre produção e consumo. Nesse contexto, os materiais poliméricos suscitam sérias preocupações, sendo considerados um dos mais prejudiciais ao meio ambiente devido à sua lenta degradação. Porém, por ser um material bastante versátil e relativamente barato, os polímeros compõem grande parte dos objetos utilizados cotidianamente. Devido à preocupação gerada pelo descarte de seus resíduos, muitas vezes incorreto, esforços vêm sendo feitos para se encontrar possibilidades de mudança. Uma abordagem viável para mitigar os desafios ambientais é a adoção da economia circular, que visa reintegrar os materiais no ciclo produtivo. O design, nesse contexto, desempenha um papel fundamental ao projetar os produtos de maneira a minimizar ao máximo o seu descarte. Este artigo apresenta o desenvolvimento de uma linha de organizadores de escritório a partir de polímero reciclado, sob conceitos do design circular. Para a produção, embalagens pós-consumo de polipropileno e polietileno foram trituradas e prensadas a quente, formando chapas. Subsequentemente, as chapas foram cortadas a laser, resultando em peças modulares encaixáveis, para a montagem dos organizadores. Portanto, a reciclagem mecânica apresentou-se como um possível recurso para que polímeros sejam recuperados e possam servir como matéria-prima na produção de novos artefatos sob o olhar da economia circular.

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PALAVRAS-CHAVE
Design; Economia Circular; Sustentabilidade; Polímero; Reciclagem.

RESUMEN
La sostenibilidad es una cuestión cada vez más presente en las discusiones sobre producción y consumo. En este contexto, los materiales poliméricos suscitan serias preocupaciones, siendo considerados uno de los más perjudiciales para el medio ambiente debido a su lenta degradación. Sin embargo, por ser un material bastante versátil y relativamente barato, los polímeros componen gran parte de los objetos utilizados cotidianamente. Debido a la preocupación generada por la disposición de sus residuos, muchas veces incorrecta, se han realizado esfuerzos para encontrar posibilidades de cambio. Un enfoque viable para mitigar los desafíos ambientales es la adopción de la economía circular, que busca reintegrar los materiales en el ciclo productivo. El diseño, en este contexto, desempeña un papel fundamental al proyectar los productos de manera que se minimice al máximo su descarte. Este artículo presenta el desarrollo de una línea de organizadores de escritorio a partir de polímero reciclado, bajo conceptos del diseño circular. Para la producción, envases postconsumo de polipropileno y polietileno fueron triturados y prensados en caliente, formando planchas. Posteriormente, las planchas fueron cortadas a láser, resultando en piezas modulares encajables para el montaje de los organizadores. Por lo tanto, el reciclaje mecánico se presentó como un posible recurso para que los polímeros sean recuperados y puedan servir como materia prima en la producción de nuevos artefactos bajo la perspectiva de la economía circular.

PALABRAS CLAVE
Diseño; Economía Circular; Sostenibilidad; Polímero; Reciclaje.

1. INTRODUCTION

Referring to industrial design in its contemporary sense became possible only after the Industrial Revolution, which occurred in the mid-19th century. This is because it was a time when large-scale production replaced artisanal production and the massive growth in demand generated the need to improve products so that they could adapt to the industrial production method (Burdek, 2006). The Industrial Revolution was not a planned event, and there was probably no perception of the environmental implications that large-scale production would cause.

> For obvious reasons, the design goals of early industrialists were quite specific, limited to the practical, profitable, efficient, and linear. Many industrialists, designers, and engineers did not see their designs as part of a larger system, outside of an economic one (McDonough; Braungart, 2002, p. 24).

Moving forward a little further in history, the 20th century was a period of several global transformations. As a result of the two World Wars, technology began to develop even more frantically to meet existing needs, and many new products were produced. In the mid-1920s, concerns about market saturation began to be a relevant issue for designers and industry (Viemeister, 2019). Modifications then began to be made to the structure, functionality, materials, and style of products, so that they would need to be replaced or go out of fashion more quickly (Gouvea, 2020).

In parallel, in the context of the scarcity of natural resources that had been felt since the 19th century, synthetic materials began to become popular, and among them, the first polymers emerged. These materials became popular within the industry, conquering the market and consumers, revolutionizing the production of everyday utensils and packaging, in addition to playing a significant role during the Second World War (Freinkel, 2011; BPF, 2014; Dennis, 2024). Being such a moldable material, polymers provided new creative possibilities for designers, so a wide diversity of shapes could be achieved (The Genius of Design, 2010). This breakthrough coincided with the growth of industrial development that occurred in the 20th century, especially with the expansion of production after the Second World War.

What went unnoticed at the time, however, was that the properties that made polymers so versatile would soon turn it into an environmental problem. Being so durable, polymers remain in the environment for centuries after disposal, and their low density means they are easily carried away by wind and water, causing ocean pollution even in remote areas (Ryan, 2015).

Alternatives have emerged to alleviate this situation, among which the circular economy stands out. This concept was created with the intention of preventing all the labor and economic value invested in a product from being lost through disposal. Or to avoid that only after the end of its useful life a way of recovering a product begins to be thought. The objective of this approach is for products to exist in a closed system, where they can be reused, recycled, or remanufactured to continue circulating in the market or become raw material for new products (Ellen MacArthur Foundation, 2013).

In this context, this paper aims to discuss design for the circular economy as a possible solution to the environmental challenges presented by polymers, especially thermoplastics. In addition to the theoretical aspects addressed, the development process of a set of desk organizers produced from post-consumer packaging is reported.

2. DESIGN FOR CIRCULAR ECONOMY

Polymers are materials that have a molecular structure consisting of the repetition of small units, called "meres", and joined by covalent bonds that form a macromolecule (Lesko, 2018). Polymers can be natural or synthetic and, according to Ashby and Johnson (2011), can be divided into thermoplastics, thermosets, and elastomers.

Most thermoplastics and thermosets are derived from petroleum distillation, from the thermal cracking of naphtha. Both can be mechanically formed, as they become fluid materials through heating and pressure (Lesko, 2018). Thermoplastics can undergo this process fairly several times, which allows for their mechanical recycling, with Polyethylene Terephthalate (PET), High-Density Polyethylene (HDPE), Polyvinyl Chloride (PVC), Low-Density Polyethylene (LDPE), Polypropylene (PP) and Polystyrene (PS) being the most common. Thermosets, on the other hand, degrade and burn when subjected to new temperature and pressure cycles (Lesko, 2018). However, technological advances have made it possible for these materials to be remelted and reused (Lesko, 2018).

There are records of thermoplastic polymers being developed since the late 19th century (Ryan, 2015). Parkesine and celluloid were materials derived from cellulose nitrate, the former intended to replace rubber and the latter to be used in place of ivory, used in billiard balls (Dennis, 2024; Stanley et al., 2025). In 1907, the first completely synthetic polymer was presented by Leo Baekeland, Bakelite, a highly heat-resistant thermosetting material formed by phenol and formaldehyde (Martins, 2020; Freinkel, 2011).

From then on, the development of polymers conquered the market and consumers, revolutionizing everyday utensils, packaging manufacturing, and having relevant use during the Second World War (Freinkel, 2011; BPF, 2014; Dennis, 2024). Until the middle of the first half of the 20th century, the development of materials such as polyamides (nylons), polyethylene, polyurethane, polytetrafluoroethylene (Teflon) and polyvinyl chloride stood out (Dennis, 2024). After the war, polymers began to be used on a large scale by the industry (Martins, 2020), replacing the use of paper, glass, and metals in several products.

The widespread use of polymers was due to several factors, such as their physical characteristics of malleability, processability at low temperatures, low density, possibility of applying different colors and textures, durability, and their relatively low cost. These attributes contributed to making several products more accessible to the population (Freinkel, 2011).

However, this material, which revolutionized industry in the last century, is now an environmental problem that needs to be solved. Due to their remarkable durability, polymers remain in the environment for centuries after disposal. And their low density makes them easy to be transported by wind and water, making waste management even more challenging (Ryan, 2015). According to a report by the UN Environment Programme, 7 billion tons of polymers generated between 1950 and 2017 became waste, with three-quarters of them going to unmanaged landfills or ending up in nature and oceans (UNEP, 2021).

There is no single solution to reduce the impacts caused by these materials and several alternatives can be adopted simultaneously. One such approach is the circular economy, which opposes the current linear economic model based on extract-produce-dispose, and proposes that the concept of a product's 'end of life' be replaced by a closed-loop, waste-free production model, optimized for disassembly, recycling, reuse, or to serve as biological nutrients.

> A circular economy is an industrial system that is restorative or regenerative by intention and design. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models (Ellen MacArthur Foundation, 2013, p. 07).

According to Highmoore et al (2024), shifting to a circular economy could avoid plastic to end up in the environment and to recover value from waste, but with attention to its complexity. The role of design for the circular economy lies in the possibility of a positive change in the design of products, their structure, choice of materials, production and distribution processes, the planning of their life cycle, and even in the system of use and ownership of products (McDonough; Braungart, 2002; Manzini; Vezzoli, 2002; Kazazian, 2005; Ellen MacArthur Foundation, 2013; Sareh, 2024). Design for circularity demands that the design of a product considers strategies for its reuse, repair, remanufacturing, or recycling.

For example, a structure that facilitates disassembly can extend the useful life of the product, as it facilitates its repair and enables the viability of technological updates (Manzini; Vezzoli, 2002). In addition, it extends the life of materials, as it allows components made of different materials to be separated and used in remanufacturing or recycling. When there is the possibility of disassembly and separation, the opportunity is created for recycling to be upcycled and there is no loss of material quality. These material recovery processes must be taken into account from the beginning of its design.

It is essential to emphasize that recycling is also a strategy adopted in the linear economic model. The problem, however, lies in the fact that products are not designed and optimized for this purpose. Therefore, thinking about recovering materials when they have already been discarded does not solve the environmental problem and does not present a long-term solution to the situation of natural degradation and lack of resources (Kazazian, 2005). In the current context, however, recycling avoids disposal and extends the useful life of the material, presenting itself as an alternative until the transition to circularity happens. Sobkowicz (2021) reports that the global recycling rate for all plastic is a mere 9%, while the rate for plastic packaging stands at 14%.

Specifically for polymers, according to the Ellen MacArthur Foundation ([202-]), the circular economy would be the key element to achieving sustainability. This can be reached through three actions: (i) eliminating unnecessary polymers, replacing them with other materials, creating reusable packaging and refill systems; (ii) innovating through new technologies that ensure that the polymers that are needed are reusable, recyclable or compostable; and (iii) making the necessary polymers circulate, with a redesign for circularity, keeping them in the economy.

Therefore, until the emergence of materials that can replace polymers in terms of cost, lightness, and easy moldability, in a way that is beneficial to the environment, one of the ways to deal with the production of consumer goods that needs to be made from thermoplastic is through projects that aim for recycling at the end of their useful life (Kolluru, 2024). In an ideal context of circular design, these products would be easy to recycle without loss of quality. However, it is known that, in practice, polymers undergo some level of degradation in the recycling process (Sobkowicz, 2021), particularly during shredding and heating, for example.

For recycling to be effective, it must be considered during the product design phase, so that not only the recyclability potential of a material can be analyzed, but also the energy expenditure of recycling and the market value of the polymer after the process (Manzini; Vezzoli, 2002). Furthermore, when choosing the material, it is preferable not to use co-polymers, which combine more than one type of polymeric material, and to avoid the addition of pigments and stiffening additives, in the latter case, preferring to use materials with resistance already adequate for the use of the product (Manzini; Vezzoli, 2002; The Pew Charitable Trusts; Systemiq, 2020). And, to facilitate the recycling stage itself, the products must contain the resin code of the thermoplastic material, which facilitates its identification.

It is important to understand the prospects for solutions to the environmental problem caused by polymers since concerns about the sustainability of products are increasingly demanded, whether by consumers, public policies, or companies themselves, which seek to differentiate themselves in the market. Recycling materials is not an easy solution and requires the incorporation of new technologies, changes in business models, as well as the transformation of the economy itself and the current consumption model.

A bibliometric analysis of international publications on Design for the Circular Economy from the last decade (Mai, Mello, & Palombini, 2025) reveals a growing trend that underscores the topic's rising importance. The study found that Europe leads in both the volume of publications and the number of top-ranking universities, suggesting a concentration of relevant research on the continent (Mai, Mello, & Palombini, 2025).

Based on the above, a project was developed for a desk organizer made from recycled thermoplastic polymer sheets from post-consumer packaging. By using materials that come from linear logic, in which the destination would be their disposal, the objective was to shift this paradigm, giving rise to a product designed with a focus on circularity. Thus, the desk organizer project seeks not only to reuse polymeric waste but also to incorporate studied premises on circular design, avoiding the addition of pigments, external paints, addition of glues as well as permanent bonding with other materials.

3. PROJECT DEVELOPMENT

The desk organizer project was based on the premise of using recycled thermoplastics, enabling the development of a prototype of the product. Due to the decision to manufacture it using recycled polymer, the design was also subject to the physical and mechanical limitations of the material, as well as the production process. Therefore, preliminary tests were carried out in order to understand the feasibility of recycling this material. It is worth noting that these experiments, conducted in an academic environment, aim to explore the possibilities of recycling in a non-industrial context.

The design methodology used for product design was based on the Design Council's Double Diamond (2023) with the use of techniques and tools suggested by Bonsiepe (1984) and Baxter (2021). The Double Diamond methodology consists of four phases: (i) Discover, (ii) Define, (iii) Develop and (iv) Deliver, which are divided into two diamonds, a format that provides visualization of the divergence and convergence of creative thinking at each stage (Figure 1).

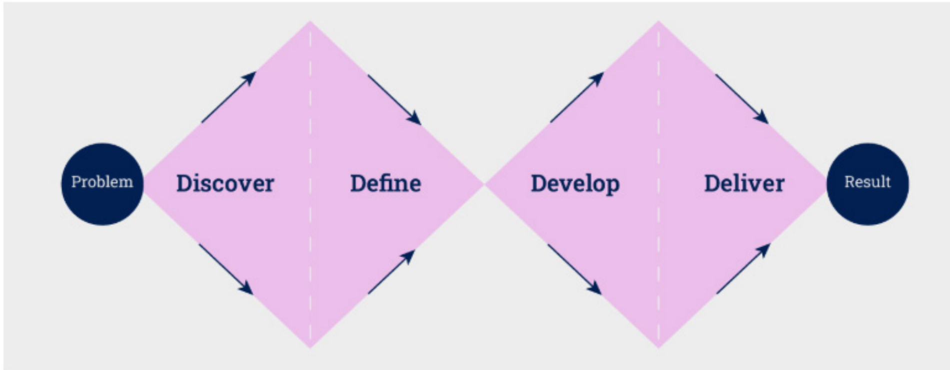

Figure 1: Methodology schematic.
Source: Adapted from Design Council (2023).

Starting from the Problem, which consisted of developing a desk organizer, the Discover phase aimed to explore the topic through in-depth research. This sought to provide a more comprehensive understanding of the various aspects involved in the project, including the context, market, and potential users of the product. Next, a Diachronic Analysis was carried out, in which it was possible to understand how office desks have changed over time, losing their various compartments and drawers and becoming simple pieces of furniture, which created the need for organizing objects to hold writing, stationery and technology utensils.

In the Synchronic Analysis, three lines of products for office organization were observed. These samples were chosen due to the characteristic of not being single objects, but rather products that offer the possibility of purchasing separate pieces, according to the needs of each user. It was possible to verify that, due to the enormous range of possibilities of artifacts to be organized, which change according to each person, the ideal would be for the modules to have spaces of varying sizes, but without specifying the type of artifact and to be stored, providing greater use flexibility.

The Usage Analysis aimed to understand which objects people usually leave on their desks and which utensils are used to store them. To this end, photographs of desks in domestic and work environments were collected. From the images, it was possible to see that many people do not use desk organizers, but adapt cups and containers to support writing materials, in addition to not storing other office utensils. The gathering of this information also made it possible to create a list of utensils for study, work, and writing purposes that were in the images. With this information organized, images of the utensils were printed on a smaller scale, and possibilities for arranging them were considered, according to their shape and use (Figure 2).

Figure 2: Utensils listing.
Source: The Authors.

It was then possible to advance to the Define phase, in which previously explored ideas are understood and narrowed down to more precise decisions. To this end, requirements for materials, processes, concepts, and target audience were established. For Bonsiepe (1984), the List of Requirements serves to guide the project and establish goals to be achieved. Attributes for the product are proposed through affirmative sentences, indicating whether they are mandatory or desirable. Mandatory requirements define the core identity and function of the project, whereas desirable requirements are features that would ideally be added to the final product. For the project list in question, the technical and aesthetic requirements were established (Figure 3). In this phase, the words 'simple', 'versatile', 'innovative', and 'light' were also established as semantic attributes of the product. According to Baxter (2000), the semantics of the product encompasses the definition of the visual appearance, which must be aligned with the functioning and use of the product.

Figure 3: List of Requirements.
Source: The Authors.

Later, in the Develop phase, preliminary experiments were carried out with the polymeric material. This was due to the need to decide which type of thermoplastic would be used and which production method would be most suitable for the organizers. Initially, High-Density Polyethylene (HDPE) and Polypropylene (PP) packaging were selected. The packaging materials used in this study were sourced from the authors' own post-consumer waste. The HDPE samples consisted predominantly of personal care and household cleaning product containers, whereas the PP samples were derived from food packaging. Which were cleaned, cut, and separated by color. The polymers then were melted, both at 180°C, in a silicone mold inside an industrial oven, muffle-type kiln with a digital controller (Zezimaq® Ltda., Belo Horizonte, Brazil), at the Laboratory of Three-Dimensional Studies (Laboratório de Estudos Tridimensionais - LABETRI) of the Federal University of Santa Maria (UFSM). According to Souza and Almeida (2015), the processing temperature of HDPE varies between 160°C and 180°C, while that of PP varies between 170°C and 280°C. This experimentation provided cutting tests with a saw, sandpaper, and laser cutting, in a EXLAS-X4 with laser plotter (Figure 4).

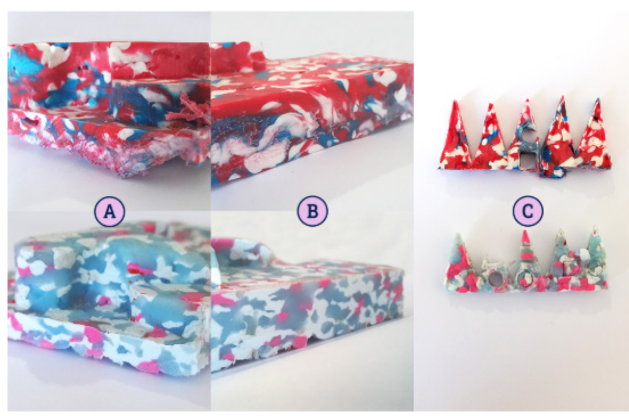

Figure 4: Sanding (A), saw cutting (B), and laser cutting (C) tests.
Source: The Authors.

Some factors, such as the impossibility of the material being well compressed in a mold without the pressure loading as well as the small size of the oven used, led to a second experiment, producing a polymer sheet in a hydraulic press. It was realized, however, that cutting the packaging with scissors would be a very laborious and time-consuming process. To perform the press test, therefore, it was decided to grind the materials in a horizontal granulating mill, model 250LR (SEIBT®, Nova Petrópolis, RS, Brazil) at the Polymer

Processing Laboratory (Laboratório de Transformação de Polímeros) of the Santa Maria Technical Industrial College (CTISM). As previously done, the PP and HDPE packaging were cleaned and separated by polymer type and color. Initially, the objective was to grind the polymers in the same way they had been separated. In the facility, however, it was realized that the collected material was not sufficient to be ground separately, since the knife mill was quite large. It was therefore decided to combine the HDPE and PP and grind them together, differentiating them by color. Due to their very close melting point, mixing the resins would not pose a problem for practical recycling for the exploratory purposes of this research.

The melting experiment in the hydraulic press was carried out at the Laboratory of Wood Chemistry (Laboratório de Química da Madeira - LAQUIM) at UFSM. The press has two plates that heat up, allowing the material to be melted. In addition to enabling the use of the press, with the help of the responsible technician, a metal mold was also borrowed for the test, which was 4 mm thick, 60 mm wide, and 260 mm long. The result was a plate of the PP and HDPE mixture, well compacted in the center, but with some flaws due to lack of material at the ends. With this sample, it was possible to perform some tests of joining the parts (Figure 5): with screws, by welding, and by fitting the machined parts on a 4-axes machine tool, model MDX–40A (Roland® DG Co., Hamamatsu, Japan).

Figure 5: Fitting, welding, and screwing.
Source: The Authors.

Among the studied possibilities, it was decided to continue with the fitting project, since a more precise result was obtained, with less chance of failure and less need for finishing. After that, it was possible to start generating alternatives for the organizer. Initially, the idea was for the organizers to have angles and triangular shapes, however, it was soon realized that fitting parts at angles greater or smaller than 90º would be more complex and would not fit the requirements of a simple design. Later sketches sought parts with a rectangular base, using the resource of angles in parts of the part that would not affect the fittings. The alternatives generated also sought ways for the organizers to interact together and accommodate all the office objects detected in the Discover stage.

From that moment on, mock-ups were made out of triplex cardboard in the formats designed for the organizer line (Figure 6). The goal was to perceive the three-dimensionality, and the silhouette and to test whether they had adequate sizes for the objects that would be placed in them. They also made it possible to visualize the versatility of the organizers, both in terms of what each one would hold and how they would be arranged on the table. And, also, the possibility of fitting one inside the other and making them more compact.

Figure 6: Paper mock-ups.
Source: The Authors.

The mock-ups allowed some refinements to be made to the alternatives, reducing the height of the pencil holder and the angle of the upper lines. From then on, it was possible to start drawing geometric definitions, made in vector drawing software. The measurements of each organizer were designed with the goal of allowing them to be placed one inside the other.

As found in the experiments with the material, the best way to produce the organizers, within the possibilities presented, would be through panels made in a hydraulic press. The metal mold that had been used in the test, however, was too narrow for the desired size of the organizer pieces. Two identical models of the mold were then obtained, which could be cut and welded together so that the mold for producing the panels would now be 24 cm wide and 26 cm long.

The production of the panels started with the preheating of the hydraulic press for approximately 90 min, until it reached a temperature of 200ºC. This temperature was determined to reduce the polymers' viscosity, thereby accelerating plate production. A sheet of greaseproof paper was placed on an aluminum plate and, on top of it, the metal mold, which had its sides greased with petroleum jelly. A 180g sample of polymers was selected, placed in the mold, and spread out. Another sheet of greaseproof paper and another aluminum plate were placed on top of it. The entire assembly was placed in the hydraulic press for 30 min and at a pressure of 60 kgf. After the stipulated time, everything was removed from the hydraulic press. When removing the panel from the mold, a utility knife and some spatulas were used. However, it was noticed that the greaseproof paper did not come off easily and, when cooled, ended up wrinkling the surface of the panel. After being removed from the mold, it was placed in a cold press for 8 minutes. Those processes are demonstrated in Figure 7.

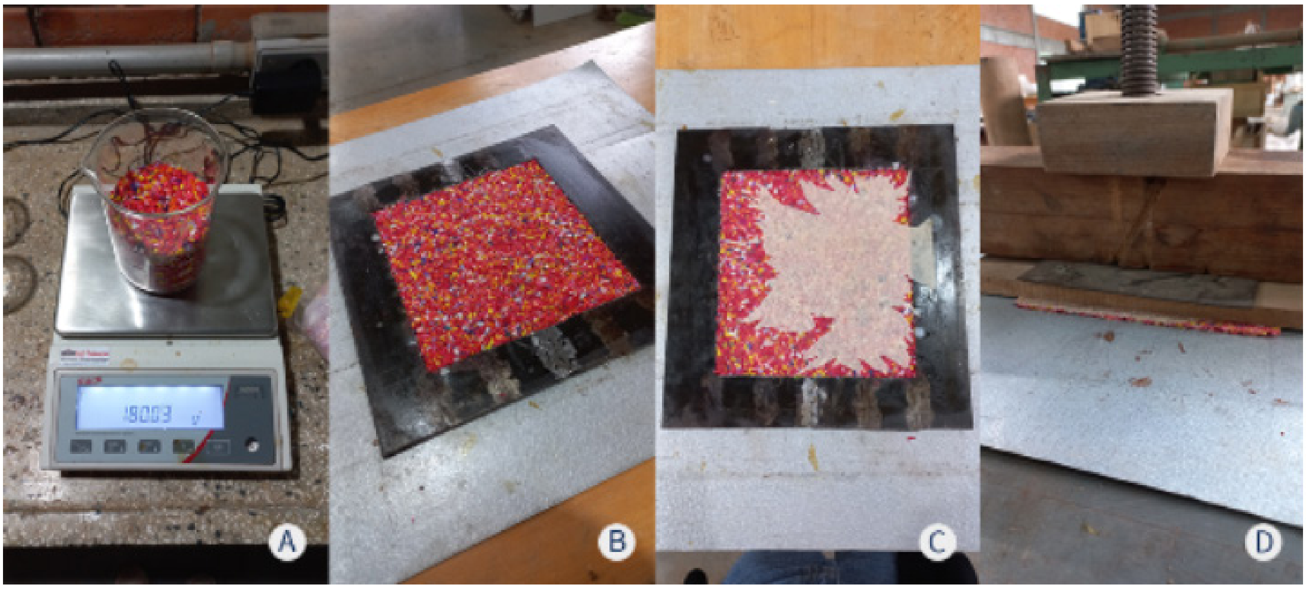

Figure 7: Weighing the material (A), placing the material in the mold (B), removing the parchment paper after removing it from the press (C), placing it in the cold press (D).
Source: The Authors.

Although most of the panels appeared to be compacted, the sides still showed a lack of material. Therefore, for the subsequent production of the panels, another 15g of polymer was added, totaling 195g, and the sheets of greaseproof paper were not used, ensuring that the aluminum sheets were greased well with petroleum jelly. It was also decided to place everything in the cold press immediately after being removed from the hydraulic press. Figure 8 shows the production of the remaining panels.

Figure 8: Weighing the material (A), placing it in the mold (B), placing it in the cold press after being removed from the hydraulic press (C), finished panel after being unmolded (D).
Source: The Authors.

The entire process described above was written down and photographed, which later provided the organization of a step-by-step diagram of the different stages (Figure 9). The intention behind these notes was to facilitate the replication of the process in future work, providing a visual and informative guide.

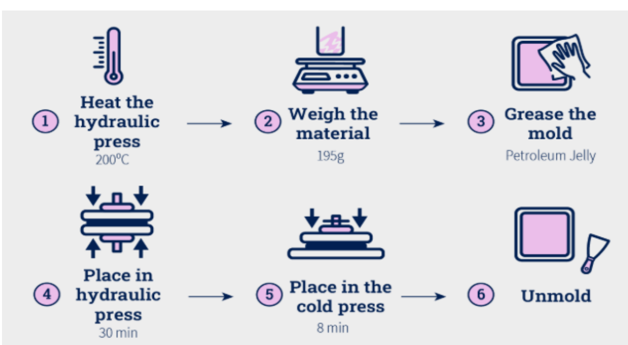

Figure 9: Diagram of the panel production process.
Source: The Authors.

As the first panels were being manufactured, it was observed that the corners often had a shortage of material, despite the efforts to do so. To get around this, it was decided to remove about one centimeter from each side of the panels. Therefore, it was concluded that six panels in total would be necessary to make the four organizer models (Figure 10).


Figure 10: Panel results.
Source: The Authors.

In an ideal situation, the panels should be uniformly 4 millimeters thick. However, the ones produced had variations in the measurements in some regions. The designs were made taking these variations into account, with the intention of avoiding any gaps in the joints. The holes were 3.8 millimeters wide, while the rods for the joints were 5.0 millimeters wide. These measurements were determined to ensure that the joints between the pieces would be firm, so that if there was excess, the pieces could be sanded, wearing down the material.

After the panels were produced, it was possible to start cutting the organizer parts. During the experiments, laser cutting and machining were tested. Laser cutting showed that it was necessary to improve the machine parameters, and machining cutting had good results. However, the machine was too small for the panels that were developed. Therefore, a new test was carried out on a more modern

Delta CNC L9060 laser cutting machine, a plotter, located at CTISM. This test was carried out with the help of the technician in charge, cutting the corner of one of the panels at different speeds and powers until the ideal parameters were reached, which were 4 millimeters per second of speed and 95% of power, with the machine's power being 100W. It was then possible to start cutting the panels according to what had been stipulated in the utilization.

After the pieces were cut, finishing work was carried out in the LABETRI carpentry shop (Figure 11). The parts were sanded to ensure all joints fit together. Some burrs, resulting from the laser cutting that caused a slight melting on one of the surfaces of the pieces, were removed with a utility knife. The organizers were assembled and a heat gun was used to ensure that some grooves resulting from both the sandpaper and the removal of the aluminum sheet during the production of the panels disappeared. Finally, 1200-grit wet sandpaper was used on parts that were still a little rough.

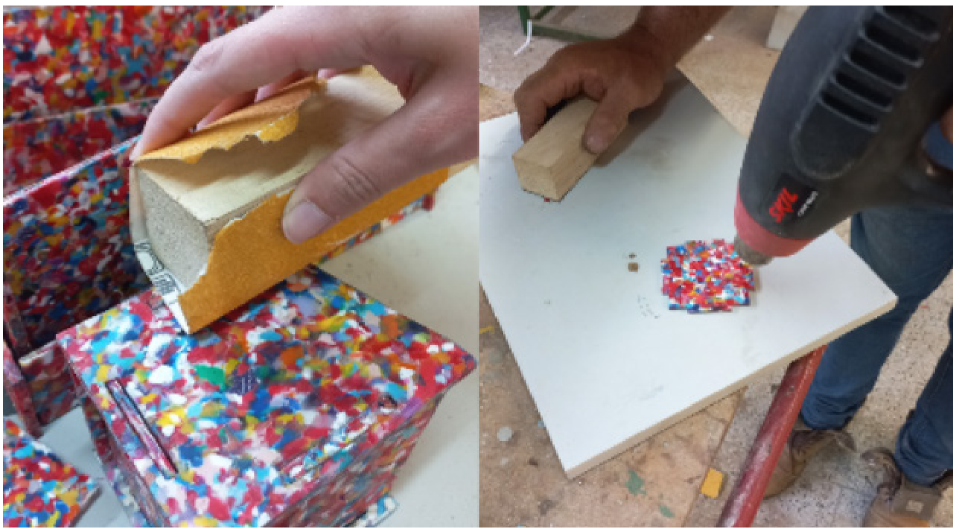

Figure 11: Finishes.
Source: The Authors.

The finishes enabled the completion of the pieces, representing the final stage of the organizers' production process, in the Deliver phase. As planned, the line includes four organizers, two smaller and two larger, which can hold most of the objects that were considered present on office and home office desks (Figure 12).

Figure 12: Desk organizer line results.
Source: The Authors.

The organizers can be used separately, according to the user's needs, and have a pleasant arrangement when placed together, even allowing them to fit inside each other. Figure 13 shows how they can be compacted inside each other and how one of the models looks when completely disassembled.

Figure 13: Fitted and disassembled organizers.
Source: The Authors.

The final products do not use glue or other materials and can be disassembled, allowing them to be very small and compact for transportation, factors that respect what has been studied about sustainable and circular characteristics. Within the circular economy, this is a product made entirely from post-consumer packaging, becoming a durable good, extending the useful life of the material and preventing its premature disposal. The design was thought out in such a way that it can be recycled again since it is not joined with other materials, paint, or glue. Although a mixture of HDPE and PP was used, it is known that this is a situation that can be used as an alternative so that it would be feasible to create this prototype.

The theoretical issues previously studied provided an understanding of sustainability in the design of industrial products, which was reflected in the development of the line of office organizers based on the circular economy. It is important to highlight how essential it is for design professionals to understand the life cycle and the impacts caused by a product, foreseeing, during the design phase, ways that allow its recovery.

4. CONCLUSIONS

This paper sought to investigate sustainable themes related to design in order to understand the problems caused by polymers and to seek alternative solutions through a circular economy, focusing on the mechanical recycling of polymeric materials. In addition, this study presented the design of a line of office organizers through the premises of circularity. It was possible to understand how polymers began to be part of everyday objects, making up for the lack of natural resources, and the importance they had for the industry and product design of the last century. However, they have become a cause for great concern due to the environmental pollution due to their difficult degradation.

In this context, it was investigated how circular economy can present itself as a strategy that prevents materials from becoming waste, recovering them and keeping them within the economy. In the case of polymers, it is important to replace the material whenever possible, innovate in technologies that allow their recovery, and facilitate circularity through design.

In products that need to use polymeric materials, the alternative of recycling can be adopted. Therefore, in this study, experiments were carried out to understand the viability of mechanical recycling in an academic context, using equipment that can be found with relative ease.

Using high-density polyethylene and polypropylene, it can be concluded that recycling can be feasible with this equipment, but it requires a relatively long time, which impacts energy costs. It is important to understand its relevance, within the academic environment, as an experimental material, both in terms of raising awareness of the need to include sustainability as a design requirement and to stimulate perception of materials and creativity in ways of applying them.

Regarding the line of office organizers, despite being a low-complexity product, many generations of alternatives and mock-ups were needed to find a simple way to make the fittings. This process occurred along with experiments with the material, which was foremost in understanding the project as a whole and the specificities and possibilities of polymers.

The surface result of each sheet can be highlighted, which always presents a unique pattern. Even using the same color mix, the appearance is never exactly replicated, which makes the material more exclusive and adds greater value to the artifacts that will be produced with it.

It is expected that the tests and results presented in this project can contribute to the development of other activities related to polymer recycling, whether in the academic environment, in the maker movement, in FabLab workshops, or in initiatives that can generate income for organizations that select recyclable materials.

Finally, designers need to pay attention to the issues that permeate the development of sustainable products, in order to understand the impacts caused by materials and production processes and, within their possibilities, contribute to the creation of products within circular logic, thus avoiding the introduction of more waste into the environment.

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