What Got Us Here, Won't Get Us There

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Implementing circular design education and open resources for plastic circularity in a municipal laboratory.

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This paper describes a project undertaken by a Mexican municipality to establish a recycling lab to create new plastic products for the local community. The Design Department at a local university proposed a program called "immersions in Circular Design", which included an educational component to develop attitudes and skills for the circular economy. The program set the participation of the staff from the recycling lab, design professors and students, and lab technicians. The program included an intensive summer program for elementary and middle schools, which taught about circular economy and circular design through experiential learning workshops. Through the program, open resources for plastic material circularity and entrepreneurial opportunities were developed. The paper details the contents, activities, and resources used in the workshops and summarises the results of the project highlighting its feasibility and describes the innovation process.

Keywords: Circular economy, Material culture, Experiential learning, Plastics recycling, Design for sustainability

1. Introduction

In recent years, the quest to implement the circular economy in communities has become mainstream (Betancourt Morales & Zartha Sossa, 2020; Kryshtanovych et al., 2020; Spekkink et al., 2022). Previous efforts such as design for sustainability, ecological design or cradle to cradle initiatives (Moreno et al., 2016) have transformed the way in how we value materials, transform industries and change human behaviour towards consumption and production.

Because of their desirable properties and massive design freedom (Bucknall, 2020), plastics are one of the most widely used materials. The pollution caused by plastics is currently aggravated due to the lack of reuse and recycling practices (Patrício Silva et al., 2021). There is also an unorganised effort of industries and local or regional government systems for their management (Andersen et al., 2022). For example, the effects of microplastics and related debris on the environment are considered harmful in the way we interact with it (Hale et al., 2020). Bucknall (2020) deducts that humans and what they

do with plastics are the problem. On the other hand, our culture of understanding residues is to invisibilize it.

The World Bank estimates that 35 million tons of plastic waste were generated in North America during 2016 (Oyinlola et al., 2022). In Mexico, the local ministry for the environment and natural resources (SEMARNAT) estimated that 4.93 million tons of plastic waste were generated just in urban areas during 2017 (Flores-Martínez et al., 2019). From the plastic waste in Mexico, it is estimated that only 6% is recovered for proper handling (Reciclaje en México, s. f.). There is significant opportunity for a systemic intervention in the Mexican setting.

There is potential for economic development and entrepreneurship in the plastics recycling sector. Firstly, the large volume of generated material allows for cooperative relationships with little to no competition within the sector (Oyinlola et al., 2022). However, the activities related to recycled plastic often attract people with low education as a means to combat poverty and unemployment, and when it comes to setting a price for the recyclable materials, collectors and processors have little control over the price (Bala et al., 2021). The ability to manufacture products with higher value is part of the potential for greater economic development in the sector.

This research represents an exercise undertaken by the local government from the municipality of Zapopan in the State of Jalisco, Mexico, along with students and teachers from the School of Architecture, Arts and Design at Tecnologico de Monterrey (TEC). Workshops and experiments were developed for the handling of diverse types of plastics to be used in the construction of didactic materials (as listed in Table 1) and utilitarian objects (see example figure 6) for the immediate community. Also, the practices and processes were shared and transferred to establish a creative space for future entrepreneurs to use recycled plastic.

This article demonstrates how the design process can be shaped to formulate effective design-driven innovation that links academia, government, and society. This linking of stakeholders identified and described from the lens of the circular economy and design has been proposed in different locations in the world influenced by the Precious Plastic project born in the Netherlands (Spekkink et al., 2022) which manifests a replicable pattern that is triggered from the design academy and adapting it to different contexts around the world (Korsunova et al., 2022; Stroober, 2017), now well replicated with innovative formats.

2. Educating on circularity

2.1 Academia, Government and Schools

The municipality of Zapopan approached the Design Department at TEC to learn about processes and potential operation of a plastics lab, through their Office of Training and Educational Offer (OTEO). Their objective was to establish Zapopan's Recycling Lab (LARZ, as it is known in Spanish), an open innovation lab to create new plastic products to benefit the local community. The Lab was set next to a public park, a child-care centre and the main offices for OTEO.

TEC's Futures Design Lab and Design Research Group worked together to propose a program called Inmersions in Circular Design. Before going into the creation of new plastic products, the team recognized the importance of adding an educational component to the program. The research by Rivera-Huerta (2022) indicated that education levels should be prioritised, "developing trust in the government and encouraging interaction between diverse agents that may become part of potential local innovation systems". As recognized by previous experiences, "most of the people do not see waste as a resource" and "awareness/education about sustainable waste management within the general public, especially the youth" is required (Oyinlola et al., 2022). To address these issues and to develop attitudes and skills of the circular economy, the program set its objectives in developing:

- A culture of materials management vs. a culture of waste management.

- Participation in new production and consumption systems.
- Visibility of the product transformation processes.

The program set the participation of the staff from LARZ and professors, higher-ed students, and lab technicians from TEC. Students were involved in two projects: An intensive summer program and a six-month internship. The participation of the students was voluntary, with a period of promotion of the objectives and the scope of the activities by the professors.

2.2 Summer program

In its plan, LARZ was established to connect with the local community, specially children and teenagers, through an experiential learning offer for elementary and middle schools. At most schools, it is challenging to provide experiential learning due to large class sizes and insufficient teaching staff (So, 2019). Teachers are interested in providing their students with learning experiences, but they lack the time to plan and prepare the experiences for a large class size, and schools lack the resources to set ephemeral activities. To address these needs from LARZ, professors and students designed a series of workshops about circular economy and circular design as part of an intensive summer program. The participating students were mostly from the Design Program (8 designers, 1 architect and 1 mechanical engineering) . The main phases of the summer program are shown in Figure 1.

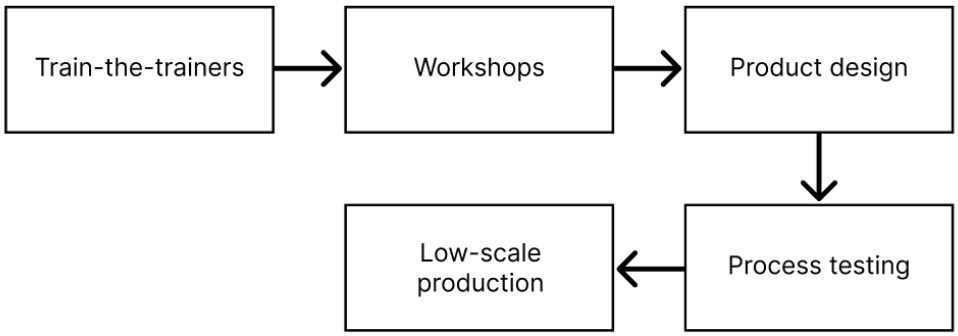

Figure 1. Phases of the summer program. Author's own creation (2022).

During the train-the-trainers, design students received instruction and researched best practices for the circular economy and circular design. The series of activities for the workshops were planned considering the experiential learning cycle from Kolb's Cycle, shown in Figure 2. Based on that, designers grouped activities into 4 main moments: Experience, Observe, Conceptualise, Experiment.

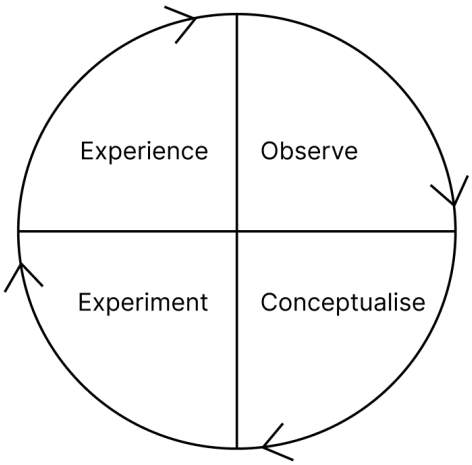

Figure 2. Stages of the activities in the workshops with elementary school students. Author's own creation (2022).

3. Implementing Open Resources for Circularity of Plastic Materials

3.1 Activating Circularity in Public Schools

The workshops on circular economy and circular design were implemented in three different beneficiary institutions selected by the municipality:

- *María Magdalena Vidaurri de Cosío* Elementary School (30 pupils)
- *Hogar Cabañas*, a foster home for children and teenagers. (17 pupils)
- *Ludoteca COMUDE Zapopan*, an after school day-care centre for children. (40 pupils)

From the elementary school, participating pupils were between 10 and 12 years-old. From the foster home, participating teenagers were between 15 and 17 years-old. From the day-care centre, participants were between 6 and 8 years-old. Although the structure of the workshops was similar, some of the activities were adapted to try to best fit the ages and potential interests of the participants. The contents considered plastic classification, circular and linear economies, upcycling, and environmental issues, as other similar experiences covered through the use of worksheets and other learning materials (So, 2019).

Table 1. Contents, Activities and Resources by Stage of the Workshop.

Stage	Contents	Activities and Resources
Experience	Plastic coding system. Plastic waste sorting.	Residue sorting Infographics
Observe	The current situation of plastic waste and recycling in Mexico. Plastic recycling.	Videos Jeopardy game
Conceptualise	Circular and linear production. Characteristics of the circular economy.	Memory game Card sorting Board game
Experiment	Processes to recycle plastic. Products that can be made from recycled plastics. Upcycling materials.	Sketching Upcycling activity

The resources listed in Table 1 for each stage and activity are available as open educational resources though the website ***. Other educators and instructors can use these resources to replicate the workshops, especially when in a collaboration with LARZ. The main use of the resources is to begin the immersion into the circular economy and circular design at the school setting, and then complement the experience at LARZ's facilities. Some of the resources are digital, like the videos and the Jeopardy game, while other resources are designed to be printed, like the cards for sorting, the memory game, and the board game in Figure 3.

Figure 3. "The Game of Plastics" board game consists of a way to reflect on the lifecycle of plastic products. The green colour refers to sustainable practices and the red colour indicates bad practices that set you back.

3.2 Designing and Producing Recycled Plastic Products

The main outcomes from the workshops were sketches and upcycled models that became the inspiration for designers to create a first set of recycled plastic products. These concepts represented needs from the participants' environment, like organisers for crafts materials and school bags. Other concepts represented toys and games.

As part of the restrictions, the products had to consider injection moulding as their main process. The available injection moulding process required a mould with upper and lower plates that held a core. These parts were fabricated from discarded iron plates from a construction site of the municipality, following the spirit of the circular economy. The recycled material had to be HDPE or LDPE plastics due to the temperatures that the machines to be used could reach, avoiding the use of PP and PET plastics.

The recycled plastic products were conceptualised and 3D modelled. The mould cores were then traced as a 2D path. This path was then cut with plasma into a 3mm iron plate, as shown in Figure 4. Since the core was made from discarded iron plates, it required sanding and polishing for better mounting during the injection process. Additionally, two sets of plates to hold the moulds were made. A 2D path for the upper and lower plates was traced and cut with plasma on iron plates. A threaded tube was then welded to the upper plate to provide the connection to the injector. With a complete set of plates and cores, designers could move over to the process testing phase.

The first injection tests served to identify suitable operating conditions. The injection machine used met the characteristics of the open-sourced model listed by Precious Plastics (2022a). This machine has two heating elements with separate customizable temperatures. Also, working with recycled plastics and even with an adequate separation process before shredding, the recommended operating temperatures had to be adjusted between batches and colours.

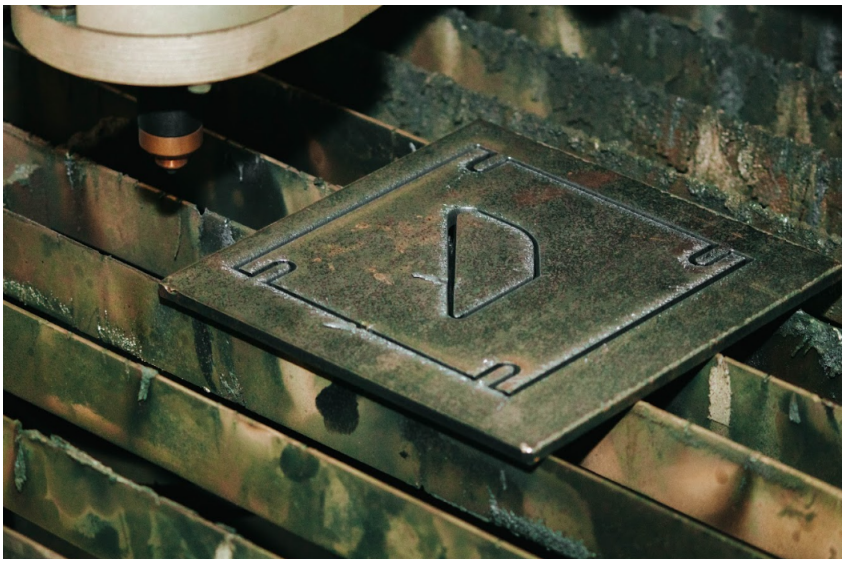

Figure 4. An iron core after plasma-cutting.

The first tests were run with single cavity moulds with HPDE shredded into flakes, as described previously and shown in Figure 5. This process proved to be fast and reliable, after a few batches to adjust the temperature to get best results for a particular type of plastic and colour. Demoulding needs to be done as soon as the plates are manageable to avoid stuck parts. The second tests were done with double cavity moulds, in an effort to achieve wider pieces with the same type of iron plates. Without the use of a mould with ejectors, demoulding with a double cavity proved cumbersome, time consuming and with a high risk of damaging the pieces during this part of the process.

Figure 5. Injection results from a single-cavity mould.

The resulting parts from the injection process were rigid, hard, and durable. The results were consistent and the process can be described as replicable and reliable. Parts can also be cut with blades and saws to further transform them. They can be easily cleaned with household cleaning products without affecting their characteristics or appearance. Figure 6 shows a playset from a variety of injected plastic parts made from recycled HDPE plastic.

Figure 6. A playset from recycled HDPE plastic flakes.

Tests with a sheetpress were carried out with a 50x50 cm iron frame using the available information from Precious Plastics (2022b). The first test used long shredded pieces of HDPE plastic. The resulting plastic sheet had a high number of trapped air bubbles. In a second test, a plastic sheet was made from plastic HDPE flakes, resulting in the sheet in Figure 7.

3.3 Internships on Circularity to Develop Entrepreneurs

The second implementation was a call to receive students as interns in the project for a period of four months. A mentor was assigned to provide instructions and introduce the LARZ project. The students then interviewed the staff at LARZ and practised with the processes upon the experience from the first implementation. From these experiences, the student team set the following objectives with the mentor:

- To improve the health and safety conditions for all visitors at LARZ.
- To achieve more repeatable and consistent results in plastic injection.
- To achieve more repeatable and consistent results in the sheetpressing of 50x50 cm sheets.
- To enable the production of 100x100 cm sheets.
- To develop new replicable products for the LARZ community.

The first activities were set to improve the health and safety conditions. LARZ was installed in two 20-ft containers in a large open area. Due to the city's conditions, the temperatures during the afternoons can be considerable. Therefore, one of the first decisions was to establish a schedule that ended at most at 14:00 hours, to avoid the hot weather. The second action was to review the space's ventilation. A mask wearing policy was set along with opening at least three of the four available doors while working. This is of particular importance to handle the fumes from the processes. Finally, the areas for

the equipment were marked on the floor with safe areas around them, recalling that this lab was meant to be a demonstration area for children and teenagers.

Figure 7. Plastic sheet, 50x50 cm, made of recycled HDPE flakes.

After correcting particularities and studying the importance of circularity the interns came with great tenacity to explore further ways to develop new products and business models. Nowadays circular products, services and processes are responding to the demand of conscious users defining a new typology of entrepreneurs (Cullen & De Angelis, 2021; Suchek et al., 2022). Several interns began to create object collections as described in section 3.4.

3.4 Improvements to the Processes

The action with the greatest results to improve the injection process was the improvement in the separation process. All plastic containers from the same brand and product were shredded, transported and stored together, limiting the combination of colours until the moment of injection. Following this protocol resulted in better pieces, with less waste and less injection failures. This also provided a better way to handle plastics with fibreglass, an additive for a consistent size for plastic bottles. The plastics mixed with fibreglass left more residues in the injection machine, requiring more clean-up and draining time before moving to a new batch. Although the benefits in production, maintaining the new proposed protocol set challenges in logistics and for the storage areas at LARZ and the Plastics Lab at TEC that aided with the shredding of plastic material. The recovery of waste materials from the process was also addressed, since the plastic materials can be recycled more than once. The extent to which this recycling is feasible needs to be tested, and in each cycle so far recently shredded material was used.

The sheet-pressing process was improved following and adapting from much of the information available through Precious Plastics (2022c). The open-source project provides adequate information about the input material and the sheet-pressing settings for different resulting plastic sheets. The

improvements for the layout and the specifications of the process reduced the total process time from 3 to 2 hours per plastic sheet produced.

3.5 New Products, Entrepreneurship Opportunities and Government Innovation

During the four-month period, a variety of different products were created. With each new product, a different set of manufacturing processes were tested to build and assemble parts. Some of the products explored were toys, skateboards, pots, picture frames, and jewellery. In larger items, some plastic parts were used in covers for furniture such as nightstands. The tools and processes that aided in the manufacturing of the products were similar to those used in woodworking.

One of the main outputs of this internship was connecting with the local community. Participants in the internship provided demonstrations of LARZ's processes and potential to government officials, school administrators, and local media, directly impacting more than 100 visitors. Tours and demonstrations were also conducted for students from elementary school to higher education, directly impacting nearly 1,000 students.

The experience demonstrated the challenges of working the complete cycle of the recycling process with children and teenagers in a space such as the one at LARZ. The first part of the immersion demonstrated how the mindset and practice of the circular economy can start in settings such as schools. The creation of new products through upcycling was also feasible. The production of new products through injection moulding and sheet-pressing is not as easy. These semi-industrial processes posed risks to children and teenagers. Even with safety measures in place, it was difficult for students at these stages of their life to follow the safety instructions and regulations. There is an opportunity for new ways to explain and communicate to them the effects of exposure to a temperature of 200 °C. The participation of higher education students and entrepreneurs presented itself as a more interesting opportunity for the creation of new products. These were students interested in spending time independently in the development of potential products for their context. Then, they would approach either the staff or the interns to find opportunities to manufacture their products at LARZ.

The new products that were created and manufactured at LARZ allowed for the exploration of entrepreneurship opportunities based on design. The first products to be commercialised were jewellery items. The main channels were local markets of other small producers and craftspeople. "The circular plastic economy is a meeting point and melting point of distinct stakeholders and is well suited to multi-sided platforms" (Oyinlola et al., 2022). This experience quickly attracted other local designers to learn from the practices and the available resources at LARZ. The Lab is an open space for shared resources for education, craft, and entrepreneurship.

Another dimension beyond entrepreneurship is how the municipality, by noticing the engagement with the community and the transcendence of this project within its Environment Office will be able to replicate in several locations this kind of lab formula which demonstrates not only the feasibility but also the offering in terms of social innovation manifesting sustainable policies implementation.

4. Conclusions

Through this academic exercise, not only recycled plastic products were generated, but also the integration of the community, the participation of the local government, the generation of pedagogical materials and the awareness of future generations in the use of what is traditionally identified as waste (see Figure 8).

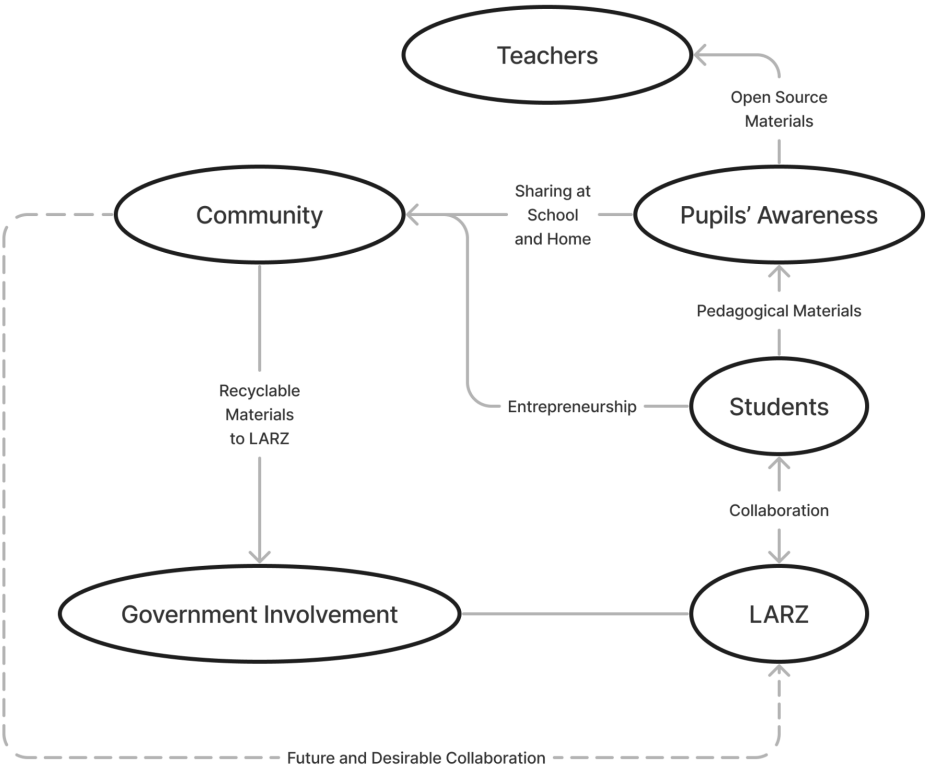

Figure 8. Multi stakeholder process involvement diagram

The integration of the community was projected through the ninety five pupils that undertook the training, the materials collected in their houses and the possible effect within their families. The participation of the local government through this single project within the municipality was a tipping point that marked the interest to establish this type of circular initiatives. The involvement of the academy inspired the generation of pedagogical materials supported by research and proven design methods and finally the awareness of future generations towards caring for the environment and its resources was proven on how they responded taking into account this topic in early stages at school, middle school and undergraduate level of university.

The formula in which a government institution, the academy and the community are linked, demonstrates effectiveness in activating the circular economy. A fundamental trigger is to have the spaces for the development of these exchanges. Correspondingly, the interest of the academy to involve students in the exercise of circular design through creative experimentation in development of an entire production process facilitates another fundamental ingredient. Finally, inheriting a tool for educational institutions and other interested parties on material culture (vs. waste management) promises the continuity and effects of a circular economy. Regarding scalability, this project challenges the way in which we create and capture value from the material collected in municipalities and the designed products to be marketed by entrepreneurial students as limited series or editions. Replicating this kind of systemic approach can provide good advantages in terms of entrepreneurship, social innovation and government sustainability policies.

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