Social Technology for Local Recycling of Plastic: An Example of Circular Economy

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The pollution caused by an improper disposal of plastic is a problem that the current recycling model, based on large industrial plants, still needs to solve. An alternative is the so-called Local Recycling, in which people without specialized training transform discarded plastic into valuable objects in the disposal environment. This work presents a technology for recycling, with a robust social bias, which transforms plastic waste into solid bars and plates, later used in the production of furniture and other valuables. This technology is being applied in the field at the modular recycling unit in Pedra Furada – SE, where young people without technical training produce objects of high commercial value.
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Introduction

Pollution due to improper disposal of plastic threatens the planet's biodiversity. Plastic waste, when found in soils, rivers, and oceans, can cause degradation or destruction of natural habitats, impact the health of fauna and flora, alter air quality, and harm biodiversity in water and land systems [1]. Despite this, the production and consumption of plastic have been increasing systematically. Global production jumped from 2 Mt in 1950 to 380 Mt in 2015 [2] and continues to grow: the amount of plastic circulating is estimated to reach 417 Mt per year by 2030 [2].

One mechanism to mitigate the problem of plastic pollution is recycling [3], whether mechanical, chemical, or energy [3-5]. Mechanical recycling is the most common form of recycling as it is cheaper than the other two. Through it, it is possible to move from an economically linear to a circular consumption model. Typically, thermoplastic polymers such as Polypropylene (PP), Polyethylene (PE), Poly(ethylene terephthalate) (PET), and Polyvinylchloride (PVC) can be mechanically recycled [6,7].

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Although mechanical recycling allows the plastic produced to remain in the economy for longer [7-9], the current recycling industry cannot prevent the problem of plastic pollution from spreading [10]. Today, the global average of recycling is less than 20%. The 4 countries that produce the most plastic waste in the world are the United States, China, India, and Brazil, with recycling rates of 34.60%, 21.92%, 5.73%, and 1.28%, respectively [10].

An alternative to the current model, based on large industrial plants, is the so-called Local Recycling. In it, discarded plastic is transformed into valuable objects in the disposal environment by ordinary people without technical training [11].

Implementing Local Recycling of plastic depends on the availability of technological solutions that can effectively be appropriated by ordinary people and applied on a large scale.

This work aims to present technology for local plastic recycling with a strong social bias. Equipment has been developed that transforms plastic waste into solid bars and plates. Equipment can be specified for recycling different types of thermoplastics. The current set was designed for recycling polypropylene as a first case study. These types of equipment are low-cost and can be operated by people without specialized training. Subsequently, plastic bars and plates are used in the production of furniture and other utilitarian and decorative objects.

The parts produced have applications such as furniture, and recycled materials are being thermally and mechanically characterized to compare their properties with materials commonly used to manufacture similar objects, such as wood and steel.

This technology is being applied in the field at the modular recycling unit in Pedra Furada – SE, where young people without technical training are producing objects of high commercial value. It is believed that this technology can not only contribute to the reduction of pollution caused by the accumulation of plastic, but it can also be a tool for reducing social inequalities linked to traditional recycling.

Materiald and Methods

Figure 1 presents the method used.

Project Requirements

The first step to define the project requirements was to hold meetings with representatives of non-governmental organizations (NGOs), associations, and cooperatives, aimed to establish the necessary prerequisites.

The criteria defined were:

1. Production of parts that could compose the objects instead of producing them in a single step, giving flexibility and versatility for production.
2. Easy-to-learn technology and low execution time. The equipment must be simple enough to dispense with any operating manual.
3. Easy maintenance of the equipment to avoid specialized personnel (repairments would have to be done locally).
4. The equipment must be of low cost so that the technology is scalable.
5. The equipment must be robust, as it would usually be placed in environments with dust and other harmful elements.

Selection and Preparation of Raw Material (Plastic Material)

The plastic material (polypropylene) was selected in an Association of Collectors and crushed in a commercial shredder, generating millimeter-sized residues.

Equipment Design and Operation

Two groups of equipment were developed for the production of bars and plates.

Design of Equipment for the Production of Bars

The equipment design was done in 3D modeling software (SolidWorks).

The bar equipment group is designed to produce bars of the approximately 1-meter length and different profiles. The equipment consists of: a stainless-steel heating chamber, surrounded by electrical resistance, a thermal shielding device (shield), and a pressure device (Figure 2a), which, when manually activated, compresses the molten plastic in the heating chamber, conforming it to the shape of the profile.

Design of Equipment for Plate Production

The group of equipment that produces the small and medium-sized circular and rectangular plates has a heating chamber formed by 2 commercial aluminum molds with Teflon coating and an

Figure 1. The flowchart used in the study.

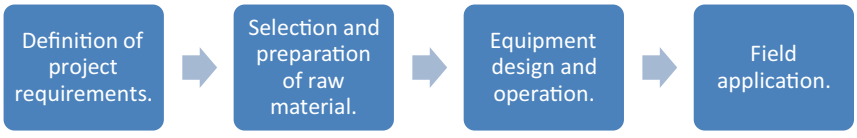
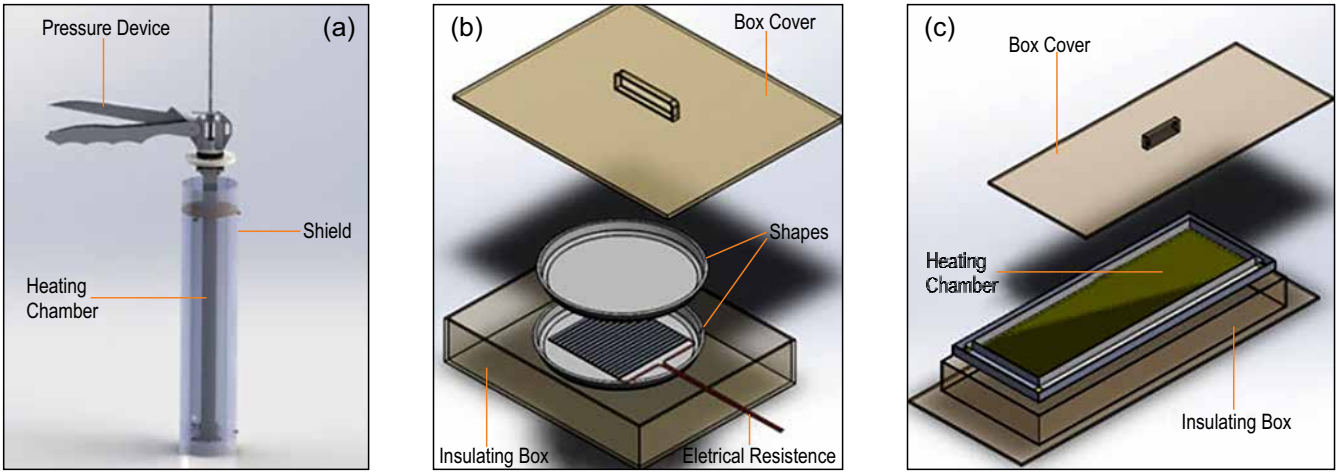


Figure 2. Three families of equipment for the local recycling of plastic. a) Equipment for the production of Bars. b) Equipment for the production of small plates. c) Equipment for the production of large plates.



electrical heating resistance placed between them (Figure 2b). For large equipment, there is a tempered glass plate as a non-adherent surface in its heating chamber and an electrical resistance supported by a stainless-steel profile (Figure 2c). In all equipment of the two groups, there is a plywood box with an internal aluminum coating for thermal insulation. The resistance for all equipment was designed based on the thermal energy required for the fusion of the chosen plastic (PP).

Definition of Equipment Operating Parameters

By monitoring the melting temperature of the plastic material (PP) by two thermocouples coupled at the ends of the equipment, the time required for heating was defined. The manual pressure device used in bar equipment was defined by economic and ergonomic criteria and used to facilitate compressing the molten material. The compression time depends on the operator's strength of each piece of equipment.

The crushed plastic residue must be inserted on the surface of the heating chamber, varying the amount according to the desired plate thickness or profile type. The heating time and temperature were defined according to the properties of the chosen plastic material. In this case, polypropylene. Tests were performed to determine the best operating time and adjusted.

Field Application

The technology developed can be transferred to society by creating Modular Recycling Units (MRU). A complete MRU is a physical space composed of a place for storing and sorting plastic, an environment for washing and crushing plastic, a space for operating equipment and storing plates and bars, a place for producing furniture and value, and a space for administrative and commercial activities. MRUs can be created in partnership with associations and cooperatives of recycled material collectors, NGOs, municipalities, or even commercial companies.

In modular recycling units, people without technical training can be trained to operate the equipment and produce solid plastic bars and plates. Once this technology is mastered, these people will be trained to manufacture furniture and other valuables for future commercialization.

Results and Discusion

Equipment prototypes from different families were produced and tested in a laboratory

environment. Modifications and improvements were carried out in dozens of development cycles using Computer Modeling and Digital Fabrication Techniques (3D Printing and Laser Cutting). In the end, equipment was produced that satisfied all project requirements. Nine pieces of equipment were produced to produce bars and plates of different shapes and sizes (Table 1).

For them to have a low manufacturing cost, materials, components, and devices available on the market in a standardized way were used for other purposes. Its estimated production cost ranges from US$140 to US$400 for plate production equipment and US$400 to US$500 for bar production equipment. The equipment has no monitoring and temperature control device, LCD panels, or adjustment buttons. They are as simple to operate as the most straightforward home appliances. Because they have few components, preventive maintenance can be carried out quickly in the working environment and with fewer tools.

Hundreds of polypropylene parts were produced in this equipment, with different shapes, dimensions, and colors (Figure 3). The pieces resemble wooden pieces, generally found in commerce, used to manufacture furniture and other objects.

Once the equipment was produced and tested, the field application stage began by implementing the first Modular Recycling Unit (MRU). This MRU is located in Pedra Furada, municipality of Santa Luzia do Itanhy, in Sergipe, Brazil. It was created with the support of the Institute for Research in Technology and Innovation (IPTI), a Social Organization that for 18 years has been developing Social Technologies to fight misery and poverty. Next, the nine pieces of equipment developed were installed at the MRU, which allows the recycling of one ton of plastic per month.

Ten young people from the village were trained to operate the equipment in this MRU. At the end of the 12-hour training, everyone could operate all the equipment, already producing usable parts (bars and plates). Two of the young women were hired by IPTI and were trained to manufacture high-added-value objects after producing dozens of bars and plates (Figure 4). As a result, their furniture begins to be commercialized, showing that the enterprise can reach its economic viability, generating decent work and income.

Table 1. Features and specifications of the equipment.

Equipment	**Equipment Specifications**				**Produced Pieces Characteristics**	
Bar Production	**Power (W)**	**Operating Time (minutes)**	**Energy (KWh)**	**Plastic Mass (g)**	**Cross Section (mm)**	**Length (m)**
Q4040	470	45	0,47	1500	40 x 40	~ 1
Q5050	620	90	0,93	2500	50 x 50	~ 1
C50	500	60	0,5	2000	50 (diameter)	~ 1
R7030	610	60	0,61	1600	70 x 30	~ 1
Plate Production	**Power (W)**	**Operating Time (minutes)**	**Energy (KWh**	**Plastic Mass (g)**	**Dimensions (mm)**	**Thickness (mm)**
D300	280	120	0.57	750	300 (diameter)	8 to 20
D350	360	120	0.72	1250	350 (diameter)	8 to 20
D500	640	120	1,28	2500	500 (diameter)	500 (diameter)
R400	420	105	0.74	1250	400 x 300	8 to 20
R1000	1500	120	3	2500	1000 x 300	8 to 30

Figure 3. Bars and plates are produced from shredded polypropylene.

Source: Authors.

Figure 4. Valued objects produced in TW.

Source: Authors.

Conclusion

This work presented a simple and effective technology for the local recycling of plastic, with a strong social bias. The equipment developed allows the production of massive plastic plates and bars from crushed polypropylene. Hundreds of pieces were produced in different formats, colors, and sizes. This equipment satisfied all previously established design requirements. Once the development phase was completed, the equipment was taken to the village of Pedra Furada, in Sergipe, where the first Modular Recycling Unit was installed, a space in which discarded plastic is transformed into objects of commercial value.

This small Modular Recycling Unit can recycle one ton of plastic per month. Young people without any technical training from the village of Pedra

Furada were trained in equipment operation and the production of furniture, utilitarian objects, and decoration. Pieces produced by these young people are starting to be commercialized, showing market potential for this type of product. It is believed that, by scaling this technology, it will be possible to contribute to reducing the impacts caused by inappropriate plastic disposal and, more importantly, to generate decent work and income for people without technical training, who are generally on the fringes of the job market.

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