

# Possibilities for the Recovery and Valorization of Single-Use EPS Packaging Waste Following Its Increasing Generation During the COVID-19 Pandemic: A Case Study in Brazil



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**Abstract** In Brazil, from capitals to small municipalities, urban solid waste treatment deeply relies on the sorting of collected residues by local associations. Those Sorting Units are composed of low-income workers that rely on the selling of the waste as their main revenue source. However, the trading of the sorted residues hinges on the commercial interest from buyers, therefore only a few materials of interest are potentially recyclable, while the rest ends up being discarded in landfills or open-air dumps all over the country. Due to the COVID-19 pandemic, the country has observed a significant increase in the consumption and generation of polymeric packaging waste throughout 2020 and 2021. Particularly, expanded polystyrene (EPS) packaging has its use risen mostly due to lockdown measures and the consequent increase in delivery services and takeout meals. Despite the low cost and practicability of single-use packaging in terms of food safety, some materials are considered problematic regarding their recyclability, such as the case of EPS. This chapter addresses the case study of EPS packaging waste in two cities of southern Brazil, over recyclability issues considering social, environmental, economic, and political spheres. The possibilities for increasing the recyclability of EPS in Brazil are discussed as well as the main challenges of making the waste more interesting for potential buyers. In general, being EPS a notable low-cost and lightweight commodity, its transport as a residue for reuse purposes often is hampered by logistics costs, as well as the low intrinsic value of the recycled material for application in different products. Finally, we propose a new application of chemically recycled EPS as a gemstone for application in contemporary jewelry, using silver recovered from scrap sources. The material recycling and the gemstone manufacturing processes are described using simplified techniques as a way to permit its replication by both jewelry professionals and untrained workers, aiming at valorizing the residue. Parting from an extremely inexpensive material with a low-quality perception, we discuss the opportunities of the trash-to-treasure transformation as a way to potentially increase the material

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value and consequently the revenue of the Sorting Units workers, while reducing its environmental impact.

**Keywords** Sustainability · Problematic materials · COVID-19 · Packaging · Contemporary jewelry · Recycling · Gemstones · Plastic waste

## 1 Introduction

Brazil's current urban solid waste treatment system deeply relies on the action of collecting and selecting residues by local associations, called Sorting Units [14, 52]. In the country's current waste treatment system, the Municipal Solid Waste (MSW) generated is distributed by each municipality among those associations. The Sorting Units encompass a series of registered facilities that are designated by the respective sanitation departments of each city, where personnel may be hired to work. The main income of the workers from those units relies on the probability of the sorted MSW to be accepted by potential buyers [28, 52]. If the collected and sorted residue has some economic interest, it is then compacted and packed into bales to be sold as a source of material for further reprocessing and recycling procedures. However, if a certain type of waste has difficulties in finding potential buyers, or if it is already identified by the workers to be considered almost virtually impossible to sell, the residue is discarded. Besides, following the discarded treatment policies of MSW given by many cities in the country, a significant amount of waste is landfilled or even tossed into open dumps [52]. Despite a relative substantial gathering coverage of municipal solid waste in the country, where over 92% of the waste is estimated to be collected, according to the Brazilian Association of Special Waste and Public Cleaning Companies [1], Brazil still lacks important measures to fight the waste problem, and some materials are considered a key part in this matter. For instance, only 1.3% of the nearly 11 million tons of plastic generated annually in the country is estimated to be recycled and recovered [71]. Giving the lower price of most virgin, commodity-based polyolefins, recycling and using them as a secondary-sourced material becomes less lucrative, thus hampering the possibilities of finding potential buyers for the material. Sorting Units' associates are generally low-income workers from peripheral regions of major urban centers, and every increase in the selling of the sorted materials makes a big difference in their revenue. In this sense, finding newer ways of increasing the interest in certain types of the so-called "problematic residues" may contribute not only environmentally, but also in the economic and social spheres.

From a social point of view, by considering "problematic" in the Sorting Units [52] one material must be qualified as having little or no economic interest. According to the associations, residues that are made of those materials are less likely to be sold, thus being discarded. In that category, they include several types of film-like polymeric packaging, glasses and different ceramics, thermosets, and others. In addition to not being commercialized, these problematic materials also slow down the overall sorting procedure. Once the selection of residues is performed manually,

workers need to open the litter bags, spread the dry waste into the conveyor belt, and sort them according to the type of residue (aluminum, polypropylene, polyethylene, glasses, etc.) by either its appearance or, even, sound (*e.g.*, plastic resins make different sounds when crushed) [48]; then when a residue is not used, not only it is discarded but the workers also waste their time sorting it. Particularly one of the materials with the lower expectancy of being recovered due to commercialization is expanded polystyrene (EPS). In addition to being considered a commodity with a lower intrinsic value by itself as a virgin material, EPS foam also has a remarkable low density [25], which means that even more material is needed for a determined amount of weight. This leads to several disadvantages in their acceptance as a secondary material, from the viewpoint of the Sorting Units, giving that most sales are done by setting a price per weight instead of volume. First, the associations would have to reserve a significant space in their facilities just to store this type of material, in order to accumulate a significant amount of EPS worthy of commercialization. Second, since most of the Sorting Units do not have any sophisticated equipment for recycling or pre-processing polymeric residues, EPS would have to be deposited in its original form. Most residues are sold without any pre-processing, which also includes cleaning procedures, thus hindering the value of the secondary material. At the very most, some associations may use some hydraulic presses to form bales of residues for stocking. Third, even if the Units could store compacted EPS in large facility areas, the material would still be too light to be transported by buyers in a substantial quantity to be considered profitable to some extent. Furthermore, in major Brazilian cities, EPS has to be transported to far located facilities in order to be reprocessed, which makes the costs impracticable. For instance, there is the case of Porto Alegre, the capital city of the southernmost state of Rio Grande do Sul. According to the city's Municipal Department of Urban Cleaning (DMLU, in the Portuguese acronym), the closest EPS recycling facility is in the state of Espírito Santo, located at approximately 2100 km (or 1300 miles) away [18]; not mentioning the costs of filling up a whole truck with EPS and traveling that distance for all the material to be sold at just BRL 20 to BRA 50 (approximately USD 4 to USD 9, as in March 2021), according to the department [18]. Fourth, considering that someone has the possibility to acquire and transport secondary EPS, the buyer would still be in charge of cleaning and recycling the residue, prior to using it as source material. Once again, giving the lower price of opting for a virgin styrene resin to manufacture EPS in the first place, some tax subsidy policies would be required to favor the use of recycled EPS. Fifth, regarding the application of recycled polymeric material in the country, according to the current regulation from the Brazilian Health Regulatory Agency [3], no secondary plastic material can be used in direct contact with food, regardless of its origin, recycling treatment, and chemical constitution or condition. Therefore, even if a clean and reprocessed EPS—which could have been originally used as food packaging—is finally recycled, there are fewer applications to which the waste can be destined. And six, even that EPS can be technically considered a recyclable material [61, 65, 72], with all the practical difficulties faced by most municipal urban cleaning departments, the material's recovery ends up being virtually unfeasible. Brazil's National Policy on Solid Waste (PNRS, Portuguese acronym), defined

by Federal Law n° 12.305/10 [9] establishes an integrated management for USW as a “set of mechanisms and procedures that guarantee society’s access to information and participation in the formulation, implementation and assessment processes of public policies related to solid waste”. In the law, the control, management, and treatment measures of the generated solid waste should start from several spheres considering all stakeholders [52]. That means that in the case of EPS, both the manufacturer of the material and cleaning responsible agents, as the municipal departments, are in charge of dealing with it responsibly. On the other hand, the same Policy states that a “solid waste that, after having exhausted all the possibilities for treatment and recovery for available and economically viable technological processes, show no other possibility than the final disposal environmentally sound” [9]. Meaning that in the case of the city of Porto Alegre, giving the fact that EPS cannot have an economically viable recycling, the waste can be legally landfilled, as commented by DMLU [18]. All those points intensify the difficulty of finding buyers that could be potentially interested in acquiring and recycling EPS waste, thus increasing the concern this type of residue has in the environmental and in the social spheres.

Recently, another issue regarding the use of expanded polystyrene has gained the headlines in the country due to the increasing utilization of single-use polymeric products. The consumption of single-use plastics, such as cups, straws, plates, bags, or bottles, has been a current and urgent global environmental matter for many years [19, 68, 73], primarily because of the great discrepancy between the time at which the product is used and how long it actually takes to decompose. Meanwhile, studies have also highlighted the impact single-use plastic debris have including during their decomposition on multiple environments; particularly in marine ecosystems [59], where the polymeric chains are disintegrated very slowly, leading to the formation of macro- and microplastics in the sediment and sea, that are then mistaken by the fauna as being food [42, 53, 67]. Another case where single-use plastics have raised recent concern is in medic- and healthcare-related products [39, 43]. Once polyolefins are also a common choice material for the manufacturing of several disposable medical supplies, such as syringes, gloves, face masks, among others, their extensive use automatically implies the generation of a large amount of waste, that needs to be treated even more carefully in terms of post-use treatment, recovery, recycling, or landfilling, due to the risk of contamination. More recently, since the beginning of the COVID-19 pandemic, the consumption of single-use plastics has grown in several segments, due to a number of reasons, mostly related to the health condition of the country as well as the “stay at home” circumstance defined in the majority of cities. This scenario has led to a significant rise in the generation of USW, primarily related to single-use polymeric products. All over Brazil, the manufacturing and waste generation of single-use plastics, locally referred to as “disposable materials”, has increased from 25 to 30% in the second quarter of 2020 [27], compared to the same period of 2019, even though the generation of overall USW has decreased in about 9% in the same period [37]. A similar increase—from 15 to 25%—was expected to be registered throughout 2020 in the country, according to another report from the Brazilian Association of Special Waste and Public Cleaning Companies [2]. This consumption pattern has been noticed and reported in many major Brazilian cities,

both capital and inland. For instance, in São Paulo, the city administration pointed out a 39% increase in the selective collection of USW in 2020 when compared to 2019 [37]. In Porto Alegre, despite lockdown measures, the selective collection of USW increased over 9%, ever since the beginning of the COVID-19 pandemic, according to a survey from the Municipal Department of Urban Services [38]. In Santa Maria, an inland city of the center region of the Rio Grande do Sul state, in southern Brazil, the selective collection has increased up to 18% in 2020, according to the Municipal Department of Environment [74]. All this growth can be derived from two main reasons. The first one is related to the obvious increase in the consumption and the consequent waste generation of medical supplies due to the COVID-19 pandemic, in view of the fact that Brazil is one of the most affected countries in the world. According to the report from ABRELPE [2], the generation of this type of waste in 2020 is expected to be 10 to 20 times higher than the year before. Another recent report from the Heinrich Böll Foundation—Brazil [33] points out that the country would potentially be generating over 10.5 thousand metric tonnes of plastic waste per month with disposable face masks alone. In the same report, the medical waste generation of a COVID-19-infected, hospitalized patient (about 7.5 kg/day) is estimated to be almost seven times higher than the average USW generation per regular inhabitant in the country. But the increase in single-use plastics in Brazil is not only noticed in the medical and healthcare segment, directly. Several recent studies have approached the concerning increase of single-use plastics during COVID-19, however most are focused on waste derived from personal protective equipment [36, 54, 57, 63]. Therefore, in the second reason, following lockdown and more general restriction measures for the movement of individuals, when people are largely working at home and are—depending on the city regulations or health status—either avoiding, being unable or prohibited to going to restaurants or dinners, the usage of delivery and takeout meals has grown significantly [62]. The money spent on delivery apps raised almost 95% between January and May 2020, compared to the same period of 2019 [11]. As an example, in the city of Porto Alegre, the delivery sector grew up to 75% in 2020 [17], largely used by the transport of meals. Added to the fact that almost all types of meals are delivered using single-use plastics, this represents a large amount of polymeric packaging being employed. Giving the known characteristic properties of EPS of having an exceptionally low density, a great thermal insulation capability, a relatively high glass transition temperature (suitable for use with food), and a very affordable price [5], it becomes a preferred way of packaging hot meals for delivery. Adding up with the employment of polyethylene bags, as a consequence, the consumption of plastics with less than one year of usage has turned them into the type of product that has grown the most during the pandemic [33]. Despite the local prohibition of single-use plastics in many cities and states in Brazil in recent years, which impacted multiple branches of the food and service industries, from local restaurants to major supermarket chains, the Justice has been forced to revoke laws due to the pandemic. For instance, in the city of São Paulo, an injunction from the São Paulo Court of Justice suspended the municipal law that prohibited the supply of disposable plastic cups, plates, and cutlery as of 1 January 2021 [45], following a lawsuit of Direct Action of Unconstitutionality filed by the Union of the Plastic

Material Industry, Transformation and Recycling of Plastic Material of the State of São Paulo [64]. And not only Brazil is passing through the same controversy. In the USA, COVID-19 is also changing how the country consumes those products, given that single-use plastics are returning to the daily life of consumers. For decades, these types of products had been restricted or even eliminated from many cities and states, varying from taxes and fees to complete bans [32]. For instance, the states of New York and California have introduced measures for reducing single-plastic usages, particularly plastic bags. However, due to the COVID-19 shutdowns, single-use plastics have returned to grocery stores, restaurants, and cafes of most cities and states, reaching about 50 items that have reduction policies reversed across the country in 2020 [32]. The same resurgence has been observed all over Europe during 2020, despite recent efforts from the Single-Use Plastics Directive [55]. Just like Brazil, not only the usage of single-use medical and personal protective equipment has increased, but also disposable plastic cutlery, plates, cups, transport packaging, and many others in the continent. A recent report by the European Environment Agency [50] affirms that as most European restaurants were closed for on-site dining, many have shifted to takeout and delivery options, thus forcing them to once again adopt single-use plastic products. As the report also comments, the generation of this type of waste is particularly difficult to fight due to the great difference in the price of the virgin resin when compared to recycled alternatives. Additionally, a recent drop in oil prices has contributed to even widen the manufacturing and reprocessing cost differences between new and recycled plastics during the pandemic [10].

Following all the above-mentioned circumstances, it can be seen that the current scenario of the significant increase in the usage of EPS packaging and other single-use plastics globally is due to multifactorial reasons. However, considering Brazil a country with a traditionally poor reprocessing culture of EPS, even before the COVID-19 pandemic, finding alternatives for the recovery of this type of waste is crucial for environmental reasons in the country, as well as in many other regions facing the same difficulties. Since the waste reprocessing mechanisms in the country largely depend upon the selling success of a particular type of USW, as well as considering that it also serves as the main revenue source of a number of low-income families, this issue is also a social and economic matter. Additionally, the poor recyclability of EPS in Brazil is predominantly due to the lower intrinsic value the residue has, facing the high costs it demands on a large number of cities to transport and recycling it, especially when compared with the lack of options for applying the recycled material, as well as with the price of the virgin resin as a regular alternative. As a consequence, one of the ways of addressing the problem of EPS packaging waste in the country can be summarized as the need to increase the added value of the residue, to such an extent that it can become interesting to potential buyers. In this manner, this chapter presents one practical possibility to recover this type of waste by means of increasing its value on the market via its application in contemporary jewelry. Section 2 presents an overview of contemporary jewelry, briefly describing its origins and recent history, in addition, to present how it can be employed as a way to improve sustainability issues, by either be presented as an ecological method of producing newer goods, as well as a social mechanism to

benefit from it. The next section describes an experimental procedure proposed to chemically recycle valueless post-consumer EPS packaging resulting in application in contemporary jewelry. Finally, the last section discusses how simplified practices and different design-based approaches can contribute to a more sustainable society.

## 2 Contemporary Jewelry—A More Sustainable Approach

Over the past centuries, jewelry has developed a variety of different purposes, being able to carry symbolic, social, economic, and religious meanings, besides, obviously, having the function of adorning, beautifying. In addition, jewelry has also been considered a voiceless way of communicating between individuals, whether to express the bearer's thoughts, origins, or culture, for instance, or to identify peers with specific characteristics. Following this broad meaning, jewelry has been the object of numerous interpretations, being currently considered a multidisciplinary area, which encompasses art, materials, techniques, processes, anthropology, crafts, and design. Since the early period of human history (ca. 40,000 BC), materials and handling techniques have been discovered, developed, and improved by civilizations, starting with the wonder and curiosity about natural materials, such as bones, canines, tusks, and fangs, hides, skins, and leathers from hunting, as well as seeds, rocks, woods, shells, vegetable fibers, etc., and later evolved into the insertion of metal alloys and gems found in their habitats [8]. Traditional noble materials used in jewelry, such as gold, platinum, silver, diamond, ruby, emerald, among others, gained this name due to their general low reactivity (resistance to corrosion, oxidation, and deterioration), in addition to aesthetic and symbolic aspects. Gold, for example, was discovered around 5000 BC, where its aesthetics, malleability, and oxidation resistance, made it the symbolic material of the divine [4, 8, 29, 40]. Its beauty and resemblance to the maximum divinity, the Sun, both in terms of color and brightness, caught the attention of those who handled it. In addition to gold, other noble metallic materials traditionally used for the manufacture of jewelry are platinum and silver, in which the introduction of alloy elements with lower melting points, such as copper, brass, palladium, among others, was required for their manipulation [40]. These elements were introduced in pieces of jewelry mainly to provide greater mechanical resistance and hardness when compared to traditional materials. However, some of these materials have also been used as the basis for costume jewelry pieces, generally inexpensive or imitation materials, which were principally made of brass and copper.

According to Cappellieri et al. [15], on the one hand, there is art, with the pride of its authorship, on the other, fashion, with the transience of its present, and in between, jewelry with the defense of its noble materials as bastions of eternity and symbolism. If the value of a jewel has for a long time being synonymous with preciousness and nobility, today that idea is definitely being modified [6]. Materials and the tangible preciousness of the pieces are no longer the only characterizing elements to define whether or not an object belongs to the sphere of luxury [15].

The applied material, regardless of whether it is gold, platinum, diamonds, emeralds, wood, polymers, rocks, or even residues from waste, is a design choice, as for the techniques, technologies, finishes, and concepts employed in jewelry pieces are developed focusing on the changes that society has been presenting, in terms of choices, aptitudes, sustainable visions, social, cultural, and economic issues, among others. Including in this new jewelry design mode, referring to the creative processes, unusual material choices and suitable manufacturing processes are employed along with efforts to fabricate pieces with a high-quality finish, were shifted due to changes in several spheres in our societies over the centuries. Some authors mention that the initial boom occurred in the Industrial Revolution [12, 15, 29, 34], with the transition from artisanal manufacturing methods to machinery production, in the eighteenth century, passing through the so-called Second and Third Revolutions until Contemporary times. It is also important to highlight the parallelism between the contemporary development of the jewelry industry and that of product design, from modifications in the production processes to materials selection, and even the choices of aesthetics and style in the pieces. With industrialization, the consumption of gold and diamond-studded jewelry became relatively more accessible to a larger portion of society due to the advent of series production and the economic stage of society, which made it possible to buy them [29]. This stimulated the development of jewelry industries in Europe and the United States. However, with the industrialization of the production process, the driven force of all factories has turned into the need to obtain increasing profits through a growing volume of sales to the middle class, the new economic strength of the cities [58]. With this objective, the quality of life of a large part of the population has decreased, driven by the scope of the industrial districts and their productive styles. According to Heskett [34], with the need for sales growth, manufacturers started to further increase the division of labor, with the hiring of so-called “style consultants”, who sought new concepts that could be adopted by the jewelry market. Under his orders, untrained designers, and with almost no knowledge, produced cheap copies of other products, being manufactured with materials of ever-lower quality, in addition to a less significant aesthetic appeal, all manufactured at the expense of long and unhealthy working hours, with few safety conditions and even lower pay [34]. Dissatisfied with the paths industrial production was taking, some thinkers with reformist ideologies proposed changes in the production chains, aiming at the recovery of style and good taste [12]. Essentially, they sought a return to production based on the Middle Ages, believing that artisanal manufacturing would bring better living conditions for workers. This type of production with a high appreciation for aesthetics and function, culminated in the Arts & Crafts movement, in the late nineteenth century, in England [34]. The ideas and production models of the movement soon spread to other European countries and the United States, exerting a significant influence on the emergence of the first modernist actions aimed at jewelry and design [16, 49]. Even though the mass production of jewelry was set in a smaller volume, in comparison to that of traditional consumer goods, the jewelry industry has developed even more associated with handcrafted and distinguished processes [29], such as, for example, techniques that used filigree details, comprised of the use of very thin metallic wires, which are twisted and shaped, generating drawings



on the pieces [49]; and stamped with chiseling, in which reliefs, textures, and fine details are made with a chisel. Still, the work of notable artists such as René Lalique is important for this period, with the stylization of the forms of nature, represented by asymmetric and organic models, in which underappreciated or even neglected gems were used in jewelry with a great value, as long as they satisfied the intended effect [26, 29]. This represents one of the first applications of a low-valued decorative element into a much more valorized piece of jewelry, where the selling price of it outperforms by a large margin that of the sum of the materials employed costed at first.

The Contemporary Age has been marked by both the discovery and the first uses of important metals and alloys for jewelry, such as platinum, nickel, tin, titanium, palladium, and rhodium [29, 35]. The period also led to the development of multi-colored gold, through alloys with the application of different elements [35]. Still, manufacturers started to use electroplating processes of noble metals, such as gold and silver, which would later contribute to the development of bathing techniques in costume jewelry, aiming at the reduction of costs of making jewelry. The same period brought to the jewelry market the first pearls produced in captivity, which also started to be massified [35]. With the renewed appreciation of aesthetics and good quality in industrialized products, a movement known in Europe as *Art Nouveau* starts to grow. The period marked a sense of artistic life that should be reflected in everyday products [12]. The style also fought mass industrialization, associating art and hand-craftsmanship in main objects, with a great emphasis on ornamentation, through more organic and natural shapes [58]. Also, as a reflection of the massification of products at this time, European jewelers began to design adornments following the style known as *Belle Époque*, as a reaction to the “ordinariness” of diamond-covered jewelry inherited from the period of the Industrial Revolution. *Art Nouveau* and *Art Decó* also emerge strongly and have an effect on jewelry, since they sought to break with the usual lifestyle of the period [29, 44, 49]. The emergence of these artistic styles also contributed to the reintroduction of different materials in jewelry, such as iron, bronze, glass, ivory, and nacre, in addition to consecrating less valued gems [49]. During the period, regarding the use of innovative materials for jewelry the development of zirconia stands out, being used later as a synthetic replacement for diamonds, in jewelry pieces of lesser value [35]. In Brazil, the development of the jewelry industry took place in the middle of World War II, bringing characteristics of *Art Decó* and the Industrial Era [29]. For this reason, jewelry pieces of the 1940s became known as “cocktail” (or “*coquetel*” in Portuguese), due to the mixture of worldwide themes and inspirations from the twentieth century. Created in a context of crises and social changes, they found in light geometries—made with forged gold—a way to continue to reproduce ostentatious effects during the crisis, since they simulated thick and heavy pieces [29]. In Europe, at the end of World War II, which brought an end to deprivation, metals and gems were in short supply. Jewelers who managed to keep their businesses started to experiment and build pieces with gold-plated materials [13]. At the same time, during this post-war financial scenario, which inhibited the exhibition of fortune and luxury as jewelry, raises the design of pieces that imitated jewelry, the so-called costume jewelry. These are known as pieces

of little intrinsic value and are currently characterized by not using noble materials in their production, but metallic alloys such as brass (copper and zinc) and Zamak (family of zinc-based alloys with aluminum, magnesium, and copper); they are also characterized by being gilded or plated with thin layers of gold, silver, or nickel, as well as by not having an exceptional finish or even significant design variations. The 1950s and 1960s were marked by a rupture in the standards prevailing until then, by a strong reaction to the traditional and commercial form of jewelry production, as well as by social and moral transformations [15, 69]. But it was only in the 1970s that the imitation—or costume—jewelry reached its peak, bringing to the jewelry industries the need to innovate in their creations [29]. During the period, a new generation of jewelry designers were brought to the production ideas and concepts, in addition to materials, such as resins and polymers, both in view of the new aesthetic standards and the increase in the price of gold, which has since started to transform jewelry until the present day [23].

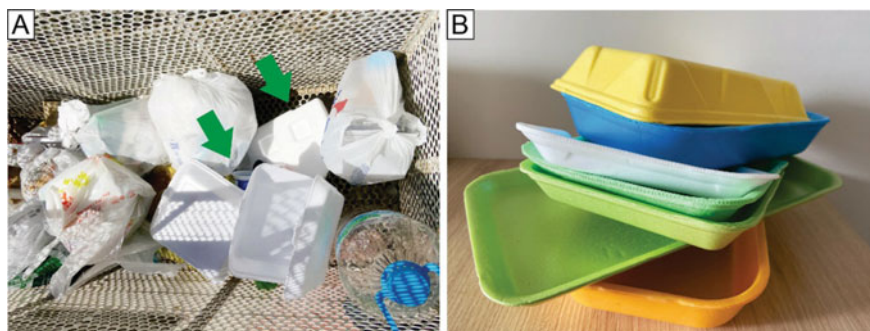
Until the end of the 1990s, the Brazilian jewelry industries followed international trends, and the pieces, in their majority, were considered copies of these versions [29]. Jewelry industries followed the big international fairs and reproduced their pieces, through catalogs and magazines, as well as invested in the import of machinery to manufacture them or even trained their goldsmiths to plagiarize them. With the market opening in Brazil, during the same decade, the trade-ins also brought competition, which led to a reformulation in the Brazilian jewelry market. Thus, the need necessity of acquiring technology and local materials arises, as well as the call for greater knowledge of market trends for the development of its aesthetic designs. With this in mind, many Brazilian industries sought new forms of obtaining profits, thus introducing design-trained workers to their teams for the development of exclusive jewelry. In this way, not only new trends in materials and manufacturing processes for jewelry appeared but also the emergence of styles and concepts of their own.

Unlike traditional jewelry, in which noble and rare materials are ever-present, such as gold, platinum, diamonds, and other precious gems, in the so-called contemporary jewelry, new and unusual materials and technologies have been introduced, such as wood, fabrics, seeds, ornamental rocks, fibers natural, multiple metallic alloys, rubbers, polymers, among others, applied with water jet, laser engraving additive manufacturing and others [6, 7, 15, 20–22, 24, 47]. The application of unusual alternatives has also often been used as the only material in the jewelry piece, as long as it has a high finish quality, through different technologies. In addition, contemporary jewelry has also been designed and manufactured by contrasting the presence of unconventional materials along with the addition of traditional and noble metals, such as silver. Nowadays, the metal is being widely used due to its interesting cost–benefit ratio combined with the countless ways of manipulation during its production process, for example, with the inclusion of textures and intentional differentiated oxidations (e.g., with the use of sulfur), making it also a contemporary material. By challenging the prejudices of traditional jewelry and its association with wealth, social status, in addition to potential cultural and religious positioning, contemporary jewelry employs new shapes and techniques to emphasize the value of the piece, rather than simply depending on the gross costs of the materials

utilized [69]. New sources of inspiration, creative processes, shapes and compositions, materials, and manufacturing processes are allowed to be extrapolated by the designer to unconventional methods, which can bring some distinction to the jewelry pieces developed, besides giving greater freedom to those who produce and use them. According to Gong and Yuan [30], the designer sees jewelry as an expression of emotions or personality, giving them a new concept of life through materials, colors, techniques, etc. With the insertion of this new way of imagining, designing, and manufacturing jewelry, a new concept is being increasingly used in this field. Sustainability, in the context of selecting the most appropriate materials and processes—aiming at both environmentally sound, economically feasible, and socially fair—has been rethought to include aspects of preservation, extraction, processing, commercialization, recovery, and recycling. Also starting from popular demand, in which society as a whole has demanded fair alternatives through all the ways of the productive process, the jewelry industry has been constantly adapting for this objective. Still, even in an initial way, designers, jewelers, and industries have been sought efforts to design and manufacture their pieces following these biases. Many project trends involving design and multidisciplinary experimentation, considered a result of a mixture of sectors, policies, processes, ideas, materials, among others, are integrating and creating something new. Today, experiments with alternative materials, which were once considered “problematic” or even derived from waste, for example, are becoming more frequent. Along with practices of artisanal jewelry manufacturing, which can also reflect on sustainable criteria, the use of newer sources of materials can increase the value of the pieces, although they also require a persistent search for higher quality standards on a product’s finishing. In jewelry, actions toward the merge of unusual materials with artisanal techniques can be increasingly observed in the latest years, and the employment of residues with a considerably low recovery rate may present even better benefits from a sustainable point of view.

### 3 Experimental Procedure

As commented before, the COVID-19 pandemic has led to a significant increase in the consumption of single-use plastics due to its disposable characteristic, particularly related to takeaway meal packaging. However, in developing countries with an incipient waste treatment system, such as Brazil, dealing with Urban Solid Waste is even more difficult. One type of post-consumption material that has one of the worst recovery rates in most parts of the country is EPS, due to the low economic interest to deal with this kind of residue. Therefore, newer practices of adding value to some problematic source material may be a way to diminish its recycling drawbacks, by reintroducing it into a circular economy. To demonstrate the potential jewelry has on transforming the intrinsic value of some disposed of material, with no direct commercial interest, this chapter presents the process of utilizing post-consumer EPS food packaging waste as source material.



**Fig. 1** Expanded polystyrene (EPS) packaging collected from waste: **A** dry waste with post-consumption single-use EPS for takeout meals; **B** examples of EPS packaging collected with different colors

### 3.1 *EPS Waste Material*

EPS post-consumer, food-packaging samples were collected from waste in the Porto Alegre and Santa Maria, the capital and an inland city, respectively, of the southernmost Brazilian state of Rio Grande do Sul. Samples with different EPS colors were sought, to investigate the possibility to use them as a gemstone replacement intended for contemporary jewelry. Almost all samples were originated from delivery or take-away meals from local restaurants, which represents a fast consumption of a product that leads to a slow decomposition residue, characteristic of a polymeric single-use packaging. The collected samples were first cleaned and divided by colors, prior to being cut into a smaller size (around  $3 \times 3$  cm), as seen in Fig. 1.

### 3.2 *Mold Fabrication*

Samples selected for recycling were molded into the shape of real gemstones, in order to be used as a replacement alternative for jewelry application. The mold was created using gemstones with different gem cuts. For this research, gemstones with cabochon marquise, cabochon cushion antique, brilliant marquise, and a mixed cut, which combines cabbing and faceting techniques, were used as original models. The cabochon cut, derived from the French “*caboché*” (“head”) consists of stones that have a flat back and a domed top [49]. The curved dome is smoothly polished and unfaced, mainly used on translucent and opaque stones, to highlight their color and pattern [66]. The cabochon marquise, also known as “*navette*” (derived from French to “incense box”) comprehends within the group with unusual outlines and faces called fancy cuts [49] and consists of symmetrically curve-sided, elliptical boat shape with equally shaped points at both ends [66]. The cabochon cushion antique is a somewhat rectangular, rounded corner shape, maintaining the original curved,

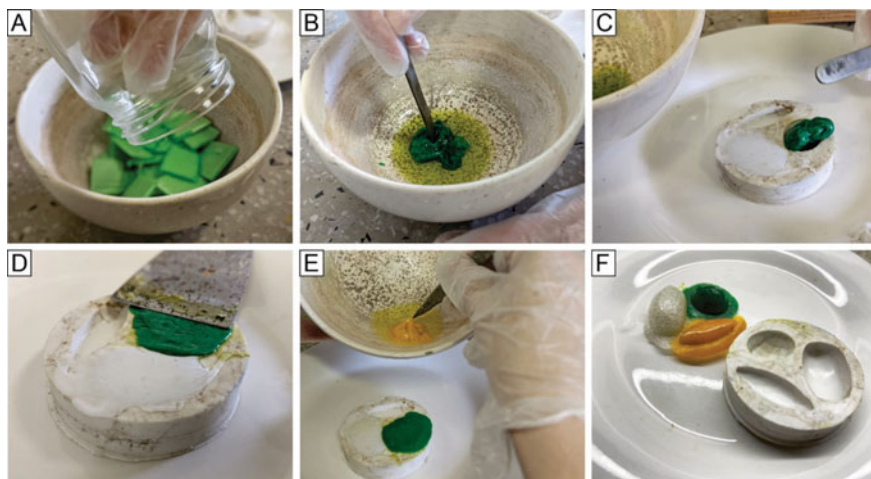


**Fig. 2** Silicone rubber mold created with gemstones with different cuts: **A** cabochon cushion antique cut; **B** cabochon marquise cut; and **C** mixed cut

cabochon domed top [66]. Brilliant is a group of faced cuts that maximize the brilliance of gems and are often used on colored stones to deepen their color [49]. In the contemporary jewelry scenario, mixed cut styles have been increasingly used, and consist of the merge of more than one traditional cutting techniques [60], and are often applied with the fancy cuts group, due to multiple outlines, shapes, and facets employed [49]. The manufacture of the molds followed the placing of the selected gems inside a round stainless-steel container, which was covered with a compound silicone rubber MA4000E (Kinner® Silicone Rubber Indústria e Comércio Ltda., Ribeirão Pires, SP, Brazil). Next, the silicone was thermoset in a vulcanizer (Zezi-maq® Indústria e Comércio de Máquinas e Fornos Ltda., Belo Horizonte, MG, Brazil) for 1 h at 180 °C. After cooling, the gemstones were removed from the mold. Figure 2 shows the finished mold and the gemstones used to create it, where the cabochon cushion antique cut is shown in Fig. 2A, the cabochon marquise cut is in Fig. 2B, and the mixed cut is presented in Fig. 2C.

### 3.3 Recycling and Pieces Obtained

Then, the cut samples with the same color were put in individual ceramic containers and processed in a fume hood for chemical dissolution [61] for the recycling procedure. Acetone ( $\text{CH}_3)_2\text{CO}$ , 99% (Anidrol® Produtos para Laboratórios Ltda., Diadema, São Paulo, Brazil) was used as the solvent. After dissolving, EPS was placed into prepared molds, and were left to evaporate for 48 h inside the mold to retain their shape. Finally, the pieces were removed from the mold and were left aside for around 1 week, for the acetone to completely evaporate and until the recycled gems become dry and rigid enough to be manipulated. Figure 3 illustrates the process of obtaining the polymeric gemstone pieces, via the recycling procedures followed.



**Fig. 3** Proposed experimental procedure: **A** pouring of acetone into the cut pieces of EPS; **B** mixing of the EPS until dissolved into a paste; **C** placing the dissolved EPS paste into the silicone mold; **D** flattening the top portion of the molded EPS; **E** repeating the process with a different EPS color; **F** pieces removed from the mold

Several pieces were created with the mold, using different EPS packaging colors, and the results are shown in Fig. 4. Additionally, experiments with different color combinations were followed, either by mixing cut EPS pieces that have distinct dyes, completely or partially with color gradients or by modifying the color shade with the addition of white or dark packaging pieces. Examples of the obtained pieces resulted from the process are seen in Fig. 4A. Generally, the obtained pieces retained the original mold shape fairly well. Even with non-cabochon gems, where faced cuts are employed, the recycled pieces maintained the original characteristics. It is noteworthy that the chemical recycling process of EPS resulted in the formation of air bubbles in the pieces during the solidification process, similar to reported by Gutiérrez and Colorado [31]. Despite reducing the volume of the material approximately 20 times [51], the formation of air bubbles was consistently found, regardless of how much the material was mixed during the process, or how long it was kept inside the mold. On the other hand, chemically recycled EPS of clearer colors, particularly white, produced significantly larger air bubbles after the acetone evaporates, in the solidification process. However, for the application as a gemstone replacement for contemporary jewelry, the formation of bubbles presented no issue and even gave character and individuality to each sample.

To illustrate the possibilities of the application of EPS chemically recycled into gemstones, two pieces of jewelry were developed. The pieces were manufactured using artisanal jewelry methods that are included during the addition of sterling silver (Ag 925). This type of silver alloy is produced using 92.5-wt% Ag and 7.5-wt% Cu, to improve the ductility of the silver and to make the metal more malleable. The sterling silver used in this process was obtained from scrap, being recycled from



**Fig. 4** Recycled EPS packaging for contemporary jewelry: **A** examples of obtained plastic gemstone pieces with different material colors; **B** application of a cabochon marquise cut piece with recycled silver into earrings; **C** application of a mixed cut piece into a pendant with recycled silver

other pieces. The first jewelry set produced consisted of a pair of earrings (Fig. 4B), where the silver was laminated with an electric rolling mill into a wire and then into a sheet until the desired thickness and length are obtained. The sheet was then shaped with jewelry pliers by shaping the earring and the gem support. The second produced piece was a pendant (Fig. 4C), following the fabrication of a silver sheet with the electric rolling mill and then with the shaping of a butterfly pattern by cutting

with a jeweler's saw. Finally, another silver sheet was used to involve the gemstone, which was then coupled with the pendant. Lastly, both earrings and pendant pieces were smoothed using files with different coarseness, sanded with abrasive paper, and polished with natural bristle and muslin buffing wheels.

## 4 Discussion

In countries with a poor recyclability rate of plastic waste, such as Brazil, this type of residue heavily depends on the commercial interest from buyers to acquire them [28, 52]. Despite years of national policies to designate the responsibility for the recovery or the definition of a proper end of life of plastic waste, little efforts have been seen that may contribute to this matter. From capitals to inland cities, the treatment of Urban Solid Waste passes through selection steps from Sorting Units, where low-income workers separate residues according to their type and sell them to third-party companies, who eventually recycle the waste and reinsert it into the production chain [52]. However, this situation is worrying on a sustainable, holistic scale due to several issues. The first one, obviously, is that potential buyers are only going to be interested in a secondary material that could be economically feasible when reused. If the residue cannot offer a minimum level of profit, it is not going to be commercialized. This creates an economical issue given that less revenue is being generated to the Sorting Units, as well as a great amount of secondary material that could be reprocessed and reused ends up being wasted, despite having a great usage potential. The second one regards the destination of the residue that is not sold. Brazilian legislation, in fact, accepts waste to be destined to landfilling when no other recovery choices are feasible. Furthermore, even open dumps are used to dispose of it irregularly in many cities. This directly contributes to a greater environmental impact, particularly when considering the time polymer-based residue takes to decompose and all the contaminants it releases during the process [41, 46]. The third one directly affects the welfare of the workers from the Sorting Units, because their main revenue is sourced from the gains obtained from the selling of waste. By reducing the volume of waste being sold, inevitably their salaries decrease, and since they are largely composed of underprivileged and low-income families, this represents a fair reduction in wages. Therefore, the issue of the recovery and reuse of secondary plastic material affects all spheres in the development of the country, and measures for improving their acceptance in the market are essential for keeping a sustainable consumption of polymer-based products.

There are currently several types of plastic waste that are not commercialized by most Sorting Units, varying from aluminum-metalized, bi-oriented polypropylene (BOPP) films, primarily used in the packaging of snacks, to composite materials, where different sorts of fibers are added to plastic resins for mechanical or aesthetical purposes, also largely used on food packaging, principally in organic products [52]. Despite being considered examples of multi-material products [70], known for being considered difficult to separate into their original materials, these types of residues can



be successfully recovered in some recycling centers. For instance, newer programs of reverse logistics from the private sector are being settled in Brazil for the recovery of BOPP packaging [56], aiming to make this type of waste profitable by means of increasing the volume of reprocessed residues. However, there is one type of polymer waste that has become more difficult to recover due to lack of interest, even though it is consumed on a daily basis. Expanded polystyrene (EPS) is a globally known problematic material regarding its post-use treatment due to several difficulties on recycling. When considering factors like the low density of the secondary material and the low costs of the virgin styrene commodity as well as its manufacturing processes, gathering a significant volume of EPS in order to make its recycling viable leads to major logistic obstacles. In many parts of Brazil, for instance, no near EPS recycling plant can be found, making the process of collecting, storing, and transporting simply too expensive to be feasible. As a result, several major municipalities have no other choice but to landfill a large quantity of EPS residues. In addition, despite national policies forbidding inadequate treatments of several types of waste, in that case, the disposal of EPS waste is even legally supported precisely due to the costs of following more sustainable alternatives. Being one type of waste largely used in many industries, from cushioning of electronics to food packaging, EPS is a common choice. It is worth mentioning that even products that have a “sustainable” approach, such as organics, also widely employ the use of EPS, despite being considered one of the worst options in terms of recyclability [52]. According to the systematics of USW treatment in Brazil, the higher the economic interest of a given type of residue, the higher it is likely to be sold for reprocessing. As in the case of most polymeric residues, the value of the secondary material tends to be low, particularly by comparing it to its virgin equivalent. With the exception of secondary plastics that have a more established recycling process in the country, such as polyethylene terephthalate (PET)—where PET bottles from soft drinks are recycled and extruded as fibers for the manufacturing of brooms—polymeric residues like EPS are almost never used as source material. Therefore, finding alternatives for the recycling of EPS waste, either by means of increasing its intrinsic value or by discovering newer application options is a necessity in the reality of Brazil.

In addition to the already difficult scenario of plastic waste recovery in Brazil, a newer challenge has recently arisen. The consumption of single-use plastics has seen its usage growth in the past year during the COVID-19 pandemic and its consequent social restrictions, which decrease the presence of people in local bars and restaurants. All over Brazil, this led to a considerable growth in delivery services, mainly related to the meals. As a preferred way to package food in takeout meals, thanks to its thermal insulation, low cost, and low density, the use of EPS is set as one of the main types of problematic materials for post-consumer waste treatment. This new escalation of single-use plastics during the COVID-19 pandemic has been a global matter of investigation and concern, given that scientists and environmentalists have been struggling to reduce its consumption for years. It is clear that single-use plastics may present a number of advantages during a pandemic. From the product design point of view, they are cheap, lightweight, easy to manufacture, and mold to any shape, and have sufficient mechanical properties to endure a typical usage, whether

as a package, cup, plate, straw, or cutlery. Adding that to health and safety benefits, people trust a never-before-used utensil as a way to ensure a contaminant-free object, assuming that it is going to be discarded shortly after. As a result, single-use plastics have gained powerful arguments with public opinion to ensure a continued existence, even by finding breaches within the law in several spheres. Silva et al. [63] commented on the priorities that are urged to be assessed due to the COVID-19, such as finding bio-based alternatives to oil-based plastics and improving the recycling systems. Likewise, Parashar and Hait [54] highlighted that plastics would not be seen as a villain material if appropriate recycling procedures in a circular economy are defined, giving the fact that they are contributing to public health safety during COVID-19. The authors also pointed out that using not only mechanical but also chemical recycling for the creation of valuable products is a way to facilitate the obtention of circularity and a more sustainable economy.

As previously seen in the development of contemporary jewelry, the exploration of alternative materials to gold and diamonds is a practice followed since modern industrialization, as an option to circumvent the lack of aesthetic appreciation of the massification of traditional jewelry. Even though containing noble materials, jewelry pieces produced were then mostly copies, in addition to having a lower finish quality. To counterbalance, jewelers started to look for ways to retrieve one of the original characteristics of what defines one object as a jewelry piece, its uniqueness. By this means, employing different materials and manufacturing processes that can support the distinctiveness of a jewel has been a key feature of contemporary jewelry. Within this realm, many materials have been explored, still always being supplemented by what is trending in terms of style, symbolism, culture, and social importance. In a relatively new field, both in product design and in jewelry, is the social awareness related to sustainable approaches from manufacturers, particularly when environmentally found [15]. In this sense, people are more concerned with commercial practices that consider our society on a holistic scale—social, environmental, and economic—notwithstanding the company's size. From small, local jewelers to a large, international diamond producer, in contemporary jewelry, the need for a sustainability-driven and ethical commercial approach is becoming mandatory for it to be well received by the public. In particular, one way that contemporary jewelry could benefit from this demand is by employing materials considered problematic under some circumstances. In this chapter, we exemplified this idea by addressing it toward the reality in Brazil, by presenting the manufacture of parts with materials obtained from disposal and with no apparent market value, as in the case of Urban Solid Waste. By considering the country's current growing supply of valueless EPS waste, mainly derived from packaging and takeaway meals due to the COVID-19, added to the fact that restrictions that once banned this type of single-use plastic in many places are being revoked, this material has never been so problematic. We followed a chemical recycling procedure of EPS waste and its application as an alternative to gemstones in jewelry pieces. By exploring the array of colors these packages can be found in the waste, different shades and gradients can be obtained. The proposed procedure included the manufacturing of a silicone mold, where the dissolved EPS could be shaped for the latter being applied into recovered sterling

silver jewelry pieces. Regarding this method of chemically reprocessing EPS for application in jewelry design, two resulting characteristics are worth underlining. The first one is related to the fact that the EPS pieces contain air bubbles that originated in the solidification process, by the evaporation of acetone. Generally, the clearer the EPS color, *i.e.*, the less color dye the material originally has, the more bubbles it is going to generate after being solidified. It has been noticed that despite the generation of these pores, the shaped pieces retained the mold geometry pretty well, therefore they mostly do not develop in the surfaces that are in contact with the mold. Another issue from this approach is that if the recycled EPS is going to be employed in a product where mechanical properties are of importance, one may consider using a more traditional mechanical recycling method of the thermoplastic resin, *i.e.*, by melting it in the reprocessing procedure. Giving the fact that these pores make the material more fragile, as this procedure would contribute to further densify the material by reducing the number and size of bubbles. On the other hand, by applying it in jewelry, there is no particular need to improve the structural integrity of the gemstone. The second characteristic worth mentioning is intrinsic to EPS, as the material is extremely lightweight. Even by chemically dissolving it with acetone, which manages to reduce its original volume approximately 20 times [51], the resulted piece is still very light. In terms of jewelry applications, this means that larger or more numerous pieces can be produced and applied without the need for excessive concerns regarding their final weight. This is a major issue in jewelry due to ergonomic factors, particularly related to earrings, where excessively heavy pieces can cause tissue damages. Lastly, employing USW-recovered materials into contemporary jewelry, particularly plastics, can be considered a safe alternative regarding ergonomic factors.

## 5 Conclusions

COVID-19 pandemic and the consequent lockdown measures and social distancing restrictions have led to recent growth in the consumption of delivery and takeaway meals, most of them packaged with single-use plastic. In many cities and countries, laws prohibiting this type of plastic have been revoked, once again authorizing their use, under the justification of being safer for public health. However, in countries with incipient Urban Solid Waste (USW) treatment, like Brazil, this also represents a considerable increase in residues that are mostly not going to be recovered. Among the types of single-use plastics normally found in USW that have the lowest recovery rate is expanded polystyrene (EPS), besides being one of the most employed materials for food packaging, particularly for takeaway meals. Therefore, the current situation of EPS waste in Brazil has reached a critical point, and measures for its recovery need to be discussed.

In order to be recovered in Brazil, a certain type of residue must have some economic interest from potential buyers, and the logistics that allow its reprocessing

must be viable. Giving the fact that EPS has numerous disadvantages in this regard—primarily related to its low density and low intrinsic value—gathering, storing, and transporting sufficient quantities to make it profitable when compared to the virgin material is a difficult challenge and needs to be addressed. Many large Brazilian urban centers do not have easy access to EPS recycling plants, thus making its recovery not feasible. Having a residue that has so little economic interest although is so widely used, one way of addressing this matter is by increasing its perceived value via its use as some source material for new applications. One recent field of product design that has shifting paradigms of conventional materials is contemporary jewelry. In this chapter, we proposed an experimental procedure of applying post-consumer EPS waste as a base material for usage as a replacement of gemstones in traditional jewelry. Different colors of the waste material were chemically recycled and shaped into gemstones in fabricated silicone molds. The produced pieces showed an interesting pattern that could be included in the design of pieces made from recovered sterling silver. One of the main advantages of this procedure was the maintaining of EPS with low density despite the significant volume reduction, which contributes to a lightweight jewelry piece obtained.

Governments and local authorities have been facing many difficulties derived from the COVID-19 in Brazil. From public health to the economy, the pandemic forced many people to revise their habits and face new challenges. However, even though some studies have been reporting the implications of the recent growth in plastic waste pollution from personal protective equipment, this research aimed to expose the matter of one type of residue that is silently but alarmingly increasing, despite already being a well-known example of problematic materials. USW treatment in Brazil is a matter that involves several spheres and reaches social, environmental, and economic aspects of the society since low-income workers are responsible for most of the dry waste destinations in the country. EPS waste needs to be dealt with by public policies that incentive the reprocessing and recovery of this residue, either by expanding the network of recycling facilities throughout the country or by offering ways for workers to increase the value of it. In this sense, contemporary jewelry studies should be seen as one important and sustainable way of contributing to finding better solutions for problematic materials.

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