Valorisation of different wastes: a sustainable approach in the design of new products

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ABSTRACT: In 2014, 2,503 million of tons of waste were generated in EU-28 by all economic activities and households, and it is forecasted that this number is not going to be reduced. So, it is a society obligation to search for solutions for this problem, and the designers have an increased responsibility to change this reality. Different wastes were valued through design and engineering, seeking the creation of materials to be applied in the development of new products. The different proposals involved the use of fishing ropes and nets debris, almond by-product residues, coffee waste and Portuguese pine resin as an underexploited resource.

1 INTRODUCTION

According to Eurostat (Statistical Office of the European Union), Portugal generated in 2014, 14,586,917 tons of waste (Eurostat, 2017). On the other hand, Europe (28 Countries) ended the same year with 2,502,890,000 tons and, in 2012, in the United States, 624,700 tons of solid waste are daily generated and the forecast made by The World Bank Organization through the document "What a Waste" (Bhadda-Tata, 2012) is that by 2025 it will be 701,709 tons.

Facing this situation, efforts should be made to develop more environmentally friendly solutions, intervening, for example, in using materials that can be reused or recycled. In 2015, under the Community Service Engineering European program, it was proposed a project We-Won'tWasteYOU for the students of the Master Program in Product and Industrial Design, in the scope of the Project Design course, in a partnership with the City Council of Matosinhos. The students were asked to develop products using wastes and/or residues of the industries of the city of Matosinhos that could be produced with low-tech tools, so that a small group of unemployed people were able to start a small production. After ending this unit course, the project motivated some students to continue exploring the use of wastes during their thesis. Below are presented four research works of four students which explored the use of fishing ropes and nets debris, almond by-products residues, coffee waste and Portuguese pine resin as an underexploited resource, that were applied as raw material for new products.

2 RESEARCH FOR USING WASTES IN NEW APPLICATIONS

2.1 *Design as a vehicle for using fishing waste to create new products*

The world's oceans are full of discarded debris that degrade and sink or drift ashore which have a very negative impact in the marine environment. Ghost nets, which are deliberately or accidentally lost in the oceans, usually by fishermen, are responsible of the entrapment and killing of many animals and they also may damage and destroy coral reefs through marine currents (World Ocean Review). According to United Nations Environment Programme, it is estimated that there are 640,000 tons of ghost nets worldwide (Shea, 2014).

Through this research, it was intended to study the potential of waste from fishing activities and the best way to transform them into raw material for new products. According to literature review, two companies deserve to be highlighted since they claim to use only recycled material in the creation of their products. Firstly, Aquafil Group, a global leader in the synthetic fibres industry, created the ECONYL[®], a Nylon 6 100% regenerated yarn from fishing ropes and nets (FRN), carpets and cloths (Econyl). Secondly, Bureo conceives innovative solutions to the growing problem of plastic pollution in the oceans by developing products with sustainable design, as for example, skateboards and sunglasses (Bureo).

Followed by the literature review, it was proceeded to the collection of FRN debris at Do-caPesca, in Matosinhos, to start the experimental work. Before starting with the experimentation of the transformation of FRN debris, it was important to identify their polymers. Bearing this in mind, a procedure (Monteiro, 2016) of identification of thermoplastics was used for four types of residues that consisted in immersion of the polymers in water and ethyl acetate, scratch them with the fingernail, exposure to the flame and smell of the smoke after being extinguished. The results showed that three of the samples correspond to a High-Density Polyethylene (HDPE), while the other is a Polyamide (PA).

The first transformation experiments were conducted in a vertical injection moulding machine using the debris. The materials were previously cut into small pieces to fill the cylinder of the machine and, then, injected into a small mould. With these experiments, it was verified that the recycled HDPE had a high viscosity, inhibiting the flow of the material through the sprue bushing, having never filled the mould. For last experiments, it was used a silicon mould of a cup where melted material was cast and manually pressed. These experiments showed that a good combination of parameters allows the filling of the mould. However, this moulding method has proved to be unsuitable due to the high viscosity of the material.

Considering the results obtained, a different approach was tried; the direct use of the recycled material. The product has the intention to keep the connection of the FRN debris to where they came from – the ocean and beach. Taking this into consideration, a “bag backboard”, made of 100% recycled material from FRN, which allows the user to enjoy two functionalities in a single product was designed (Figure 1). This product will use the FRN in its natural state, fabric made of nylon and injected HDPE, so the bag component will be made using fishing net in its natural state allowing the sand that is always accumulated in towels and objects, such as toys, to fall off. Inside this component, there will be a small pocket made of nylon, so that the user can place smaller belongings with more value to ensure their safety.

Although the performed experiments with 100% recycled HDPE from FRN haven't been positive neither conclusive, the literature review indicated that using 100% recycled FRN and others is a reliable option, depending on the application. With this project, it can be concluded that using recycled materials, as for example, FRN, can be an excellent alternative in product design, creating more sustainable and still aesthetically pleasing solutions, avoiding the extraction of resources from nature.

Figure 1. Product designed based on the raw material from FRN debris.

2.2 Application of almond nuts by-products in a biocomposite

This project focused on finding a solution through design for the problem of almond nuts industry residues which are by-products of the almond nuts, such as hulls, shells and skins. Through a literature review regarding the agro-industry, it was found that about one third of edible food produced for human consumption is wasted (European). In 2013, the almond industry produced 1,823,180 tons of residues (Faostat, International Nut and Dried Fruit Council Foundation, 2015).

These, as well as other agricultural wastes, have not received enough attention, ending up being incinerated or used as biomass fuel to produce heat or generate electricity or dumped or used as animal feedstock. Besides these final uses, researchers have already studied the possibility of using the almond by-products in different applications with positive results such as, reinforcement in a polypropylene matrix and a wood based composite using urea-formaldehyde resin, absorbent of heavy metals and dyes, growing media for soilless culture and for preparing activated carbons.

According to the information from the previous paragraph, it was pretended with this project to study the possibility of employing the almond by-products in new products, by using them as a reinforcement of a polymer, thus creating a mouldable composite material. It is well known that oil-based plastic materials have unique and innumerable properties which have a big interest for manufacturers but it is also well known that they are one of the biggest pollutants on Earth. Concerning this, it was decided to use in the experimental work a PLA manufactured by Nature-Works® with the brand name of Ingeo™, which is a biodegradable biobased polymer, so a more environment friendly solution concerning its health.

Bearing this purpose in mind, by blending both materials, PLA and almond by-products, a biocomposite was obtained, which is a material 100% originated from renewable resources. For the experimental work, the almond by-products were grinded and milled in small particles. After this, the particles were sieved using a vibratory sieve shaker with the following sieves: 630, 400, 315, 125, 90 and 53 µm. Regarding the nature of these natural fillers, before proceeding to any blend, the particles were dried in an oven to remove the majority of its moisture. Plates were successfully created by blending 10% to 50% of reinforcement of different particle sizes. However, in all particle-sizes mixtures, it is notable the increasing of the roughness and brittleness with the amount of reinforcement. Besides, increasing the particle size changes the product aesthetics, since it is possible to clearly observe the particles in the PLA mixture. It is important to refer that there isn't an ideal blending composition since this will vary depending on the intended end use for the material.

After finishing the blending experimentation, a composite material mixture with 20% of reinforcement and particle-size range from 53µm to 125µm was manually pressed in a silicon mould of a cup. The result achieved was very interesting, with great aesthetics, but the material still needs to be characterized in order to know its properties.

After achieving the main goal of this research, the design project was the creation of a laptop stand, which was intended to be low weight, adjustable, small size, and, if possible, multifunctional or adaptable to tablets or smartphones. This product can be used as a vertical support for smartphones and tablets, with two adjustable positions in height and maximum dimensions of 5x7x2 cm (length x width x height) (Figure 2). In order to be small and easy to pack, this product uses two separated laptop-stands. Considering the sizes of tablets, it may be necessary to use the two laptop stands together to hold the equipment.

This experimental work, using the almond by-products, presented positive results with room for improvement and more research. The composite can be produced with different reinforcement percentages and particle-size distribution, being also possible to combine bigger particles with very small particles. After characterization, it will be possible to know its potential applications.

Figure 2. Concept design of the laptop stand using the composite PLA + almond by-products.

2.3 Coffee waste reused as a composite material

Based on data provided by the International Coffee Organization, it is estimated that its overall consumption in 2014 was 149,8 million bags of 60 kg (Organization, 2015a). In the case of Por-

tugal, in the same year, 823,000 bags of 60 kg were consumed, which represent a per capita consumption of around 4,7 kg (Organization, 2015b). According to the same source, the annual coffee demand from 2011 to 2014 increased by 2,4%. It is further noted that this increase is gradual, being registered every year. It is therefore plausible to deduce that this tendency will continue.

The research developed (Canavarro, 2016) aims to present a production method for reuse coffee ground leftovers. The main goal is to obtain a mouldable material, composed by coffee grounds and a suitable binder. It is also intended that the created material is durable and washable, with prospects of extending the realities in which it can be used. The composite material developed within this mixture can be used in a variety of products, from simple vases, coffee table tops, to light emitting objects with original effects. The options are vast and abundant.

The base material used in the experiments was coffee grounds, obtained domestically and the only treatment given was, in some cases, heating it in an oven at 100 °C for 24 hours, in order to eliminate its humidity. In all other cases, it was used as is. So, in conclusion, it is obvious that the experimental work was fundamental in obtaining and developing this material. The epoxy resin experiment was valid in order to determine that coffee waste can, in fact, be mixed with other substances to achieve a composite material. It didn't work however, because it is not safe for food contact and is not biodegradable. Starch showed some promising results at the beginning, but with time it revealed great negative characteristics, with the appearance of mould on all samples. It also couldn't withstand contact with cold water, being therefore discarded. Pine resin displayed very weak results, because it couldn't be homogenized with coffee waste, not even with the addition of wax. PLA exceeded the initial expectations. It is biodegradable and the experiments showed very good results, with different formulas, permitting its use in different areas of interest. It is also FDA approved for food contact. The final material is not, however, perfect or completely developed. It does not withstand high temperatures like hot beverages (coffee). There is, for that reason, room for improvement.

The main design project is a tray with capacity for 6 cups. The cups are made out of our composite (preferably 40% coffee grounds waste), as well as the two side bases/handles. The tray platform is made out of light wood to introduce some contrast to the set. The cups may then be used for all kinds of cold beverages, desserts, condiments, spices, jams. The list is vast, as long as it's nothing hot (temperature wise) (Figure 3). The two side legs/handles are simple structural pieces with an orifice to facilitate handling. These were made to try to demonstrate other uses for the created material, with a higher thickness. The wooden tray has 6 holes for the cups and some geometric cuts at each end to make the joinery with the legs/handles.

Because the experimental work presented such positive results in terms of formulas between coffee waste and PLA, with so many different visual and physical effects, other design possibilities (besides the main project) were thought of, trying to embrace the different potentials offered by the material. Some include the contact with food, others the good relation between coffee waste and plants, and even the effect that some samples have when placed against a light source.

Figure 3. Group of products created with the PLA+coffee waste mixture.

2.4 Bio-valorisation potential of the Portuguese pine resin as matrix of sustainable composites

This project focused on the creation of proposals for revitalize the use of pine resin, a resource with high potential that is currently underexploited in Portugal. The idea is to take advantage of this natural resource as an opportunity to integrate matrices of sustainable composites of flax natural fibres, to apply in an ecological product line to promote the Portuguese Design. Due to the fragility characteristic of this resin, experiments were carried out with other materials, so that they can be used as additives to increase rosin plasticity. In this sense, materials from natural and synthetic waste were used, namely: cork powder, rubber granulate, wax, among others.

The traditional pine-tapping is the most common process for obtaining rosin, in which the resin appears naturally in the pine tree to protect and cover the wounds caused by the incisions, being collected and stored in plastic bags or vases (Abad Viñas et al., 2016). The potential for the production of rosin in Portugal is immense, since the pine tree (*Pinus pinaster*) represented in 2010 about 22% of the forest area in the national territory, corresponding to 714,000 hectares (ICNF, 2013). In Portugal, warm temperatures allow each pine to produce, on average, 3 to 4 kg of resin per year (Anastácio and Carvalho, 2008). However, the annual production of resin in Portugal in 2005 was about 5,000 tons, and there is currently installed capacity to increase this value considerably, to 20,000 tons (Anastácio and Carvalho, 2008). The applications of the pine resin derivatives are very broad and are mainly used by the processing industries as raw material present in industrial products, pharmaceuticals, and adhesives.

The research (Ruben, 2016) began with the preparation of several samples of rosin with each waste individually, varying the proportion of additive between 10% and 50%. Four different additives were considered: cork powder as a waste of natural origin; granulated rubber (particle size < 0.8mm) and wax as wastes of synthetic origin; and EVA (ethylene vinyl acetate) in granules as a virgin material of synthetic origin. In terms of physical resistance, it was possible to see that the combination of pine resin and cork powder was brittle, since more voids were created that contribute to the fragilization of the samples. On the opposite side, the wax waste, when mixed with the pine resin, promoted an increase on samples ductility. However, the use of this feature modifies the original visual appearance of the resin, making it greenish. The processing of rubber granules led to the emission of fumes and odours, proving to be a dangerous and flammable additive. The results with this material were not very positive since the rubber waste granulate did not completely melt with the resin and the original appearance of the rosin changes completely, making the samples black and opaque. The virgin EVA presented itself as the most promising additive, showing complete compatibility with the pine resin, giving more flexibility, especially in the proportion of 30%, without significantly altering their original aspect.

After the research of the material for the composite matrix, pieces of furniture and lighting were designed (Figure 4). The concept consists of semi-structural composite pieces produced in a pine resin matrix with 30% EVA, reinforced by flax fibres. The composite pieces appear attached to complementary pieces produced in cork. The hollow composite part allows for some storage space for objects or a spotlight, so that the bench can be used as a lighting element.

With this work, it was possible to realize that the untapped potential of the Portuguese pine resin can also be considered a waste. The fragility of this natural resource can be improved with the use of natural and synthetic additives and the waste can have great potential as an alternative of less environmental impact. Moreover, since EVA was the only non-waste material, it is possible to carry out future experiments with EVA from shoe soles.

Figure 4. Composition of the concept products idealized to apply the composite material.

3 CONCLUSIONS

From these experiences, it was concluded that waste in general is growing and there are no predictions for this growth to slow down. Although there are already waste treatment strategies in place, if it could be reused, this problem might not exist in a near future. Also, the use of most wastage materials allows for a low-cost approach, making this an unrivalled advantage. For this reason, it becomes apparent that waste really is a good choice for substances to be reused as a material on the creation of design products. It is also obvious that its abundance will continue to exist and designers should see this as an opportunity.

4 FUTURE DEVELOPMENTS OF THE PROJECT

The accomplishment of these research works with positive and promising results, raised a wave of motivation and interest for the use of wastes, entrepreneurially. Thus, in the near future, it is intended to continue the WeWon'tWasteYOU project by creating a social workshop - OFICINA design: School of Social Entrepreneurship – in which teams of designers and engineers will work together with groups of unemployed people. The necessary infrastructures are going to be prepared for this project for the creation of products based on the wastes generated by the local industry. Besides, training courses are going to be made for workers. With this initiative, it is expected to create products in a more sustainable way and appeal to the environment awareness of the society as well as creating more job opportunities for a vulnerable social group.

5 ACKNOWLEDGEMENTS

Funding of Project NORTE-01-0145-FEDER-000022 - SciTech - Science and Technology for Competitive and Sustainable Industries, cofinanced by Programa Operacional Regional do Norte (NORTE2020), through Fundo Europeu de Desenvolvimento Regional (FEDER), and Community Service Engineering European Project (LLP - 539642 - Community Service Engineering).

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