Transformimg waste in industrial design products for social vulnerable groups

Teaching industrial design based on real projects, a Project Based Learning experience in Faculty of Engineering of University of Porto

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***Abstract*—The University of Porto, Portugal, started in the academic year 2013/2014 a Master Program in Product and Industrial Design, which is a partnership between the Faculty of Engineering and Faculty of Fine Arts. This new program that replaced a previous Master Program in Industrial Design from Faculty of Engineering, was conceived with a different philosophy, seeking to join designers and engineers in a multi-disciplinary methodology. The syllabus was sought to "transfer" know-how between those two backgrounds and develop projects, supported in project-based learning principles, in the two main courses; Project Design and Project in Industrial Design.**

This work explains the main operation principles of the course and presents the results of a project settled in partnership with the Municipality of Matosinhos, in Porto, Portugal, which was developed to design artifacts based on recycling the waste produced by activities of that city. The goal was also to create low cost products in an attempt to generate profit for the poorest communities in the region.

Keywords—design; recycling; waste; PBL; master program

I. INTRODUCTION

The Master Program in Product and Industrial Design (MDIP) of University of Porto (U.Porto) is a Project Based Learning (PBL) course. The training is based on unifying Courses of Project, where students, under the workshop frame (extended stay in school that can go up to 40h/week, between tutorial hours and individual work) successively develop several products, process in which other teachers from converging courses also participate, reflecting the aspects that relate to their subjects. The evaluation of these courses takes into account a portion resulting from the application of knowledge acquired to the projects developed [1].

Each project has the cooperation of a partner company or other external entity that launches, monitors and validates the results obtained, without participating in the assessment, which is sole responsibility of the Faculties.

This commitment stems from the understanding that the design of new products, from capital goods to consumption ones, the so-called tradable goods, is a cooperative project-oriented business that must emerge from the intersection of three cultures: Engineering, Design and Management. Fig. 1 shows this cooperative vision of the course [1].

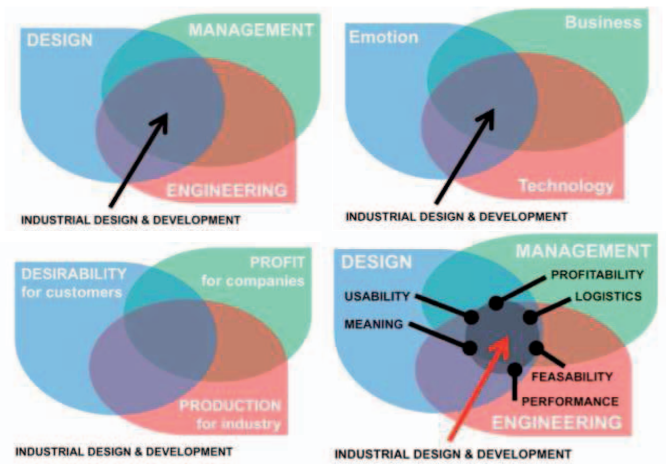

Fig. 1. Overview of cooperative industrial design and development [1].

Students visit companies' facilities and have contact with manufacturing processes and installed capacities. The companies made them acquainted to their market and more relevant needs. During the project, held at Faculty of Engineering (FEUP) and Faculty of Fine Arts (FBAUP) of U.Porto, companies' technicians monitored, twice, the results under development (in the middle of the semester and in the final). At the end of each semester, a public presentation of the work is made using multimedia and prototypes. In some cases, the final presentation is in the partner company.

II. DESIGN WITH WASTE TO BOOST A SMALL SOCIAL BUSINESS

Nowadays, the complex Industry panorama confirms the need for interdisciplinarity, at a professional and scientific level. Efficiency of the production processes and the performance of the products are demanded in all areas of activity. Knowledge is no longer organized in different shelfs, and all disciplines have to contribute to the efficiency of the product. The team is getting larger, besides designers and engineers, end users and industrial technicians are fundamental to optimize all the product development process.

The need to open the academy to the industry reality, has been changing the teaching pedagogy in some courses related with engineering [1-4]. In Civil Engineering course at the U.Porto, this experience has been led with second year students [5]. Bringing this reality to the University has been a priority in MDIP, at FEUP, developing projects in a real context. Learning by doing is a methodology where the participants, students, teachers and "clients" discover new paths to achieve a solution. Introducing specific cases with real "clients", intends to establish a relation between these two worlds, allowing the students to perceive the problems in the "reality" [6]. Students are given the opportunity to communicate directly with companies, understand their production systems and realize the limitations of manufacturing processes. Companies can explore and develop ideas which in the manufacturing daily life is not possible. This direct relation with real problems results in extra motivation and dedication to the possibility of job offers or having the projects implemented in the market. In the past years, different experiences were developed, and some examples should be highlighted: an adaptable school chair for children between 6 to 10 years old [7], developed for a scholar furniture company; a technical glove for protection motorcyclist wrists [8], in partnership with a technical fabrics company and a sports products company; shoes for persons with cerebral palsy in partnership with an association of cerebral palsy, an international shoes manufacturer and other partners [9]; and a trolley to separate used food trays in scholar canteens, for one of the biggest Portuguese companies that operates in the area of restoration.

In 2015, under the Community Engineering Service was proposed a project **WeWon'tWasteYOU**, to be developed with a vulnerable social group in Matosinhos, a city close to Oporto, identified by the City council social department. The students were asked to design products with the industrial waste of the city that could be produced with low-tech technologies, so that a group of unemployed adults from 30 to 50 years old could produce them in a future small social industry.

Matosinhos is a city by the sea, with one of the biggest commercial and fishing ports of Portugal. The waste produced comes from the fishing industry and from the restaurants all around the port. The students, divided in groups, explored different types of waste to design new products. Used bottles were transformed in lamps, bottle caps in beach toys and fishing nets were transformed in fruit rigid bowls, as shown in Fig. 2.

Fig. 2. Products developed under the project **WeWon'tWasteYOU**.

The products were presented to the city council social department twice during the concept design to validate the options and different possibilities. Some of the students continued with the project in their thesis research in the second year of the course [10]. In this period was possible to understand and solve the technological problems involved in their first concepts, with the opportunity to work in the laboratories of the Mechanical Engineering Department and the research Institute of Mechanical Engineering (INEGI). The development details of two cases; coffee powder waste reuse and transformation of fishing nets, are then presented as case study A and B, respectively.

III. CASE STUDY A

A. Introduction

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 [11]. In the case of Portugal, in the same year, were consumed 823,000 kg which represent a per capita consumption of around 4.7 kg [12]. According to the same source, the annual coffee demand from 2011 to 2014 increased by 2.4%. It is noted further that this increase is gradual, being registered every year. It is therefore plausible to deduce that this tendency will continue in the near future.

This theme has emerged as a way to fight this problem through design. The research developed aims to present a production method for reuse ground coffee leftovers. The main goal to be achieved is to obtain a moldable material, composed by coffee grounds and a suitable binder. It is also intended that the material created 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.

This work presents the results of experiments done with the different mixtures, seeking to obtain the desired material. It began with epoxy resin, followed by starch, and in a later stage pine resin, wax and thermoplastics, but the material that showed the best results, for the time being was Polylactic acid (PLA).

As long as the mixture is moldable almost a large variety of objects can be produced by casting it in a mold produced in different materials.

B. State of Art

Coffee grounds waste has been studied for its characteristics in order to be reused in the most various ways and on different areas of interest, such as its transformation into energy [13] or even biodiesel [14].

Regarding the additive manufacturing process, although this technology is relatively new to greater audiences, it is safe to say that there are already attempts to use coffee waste in 3D printing. One of the best examples of this is the Wound-up by 3Dom [15], a filament created with PLA and spent coffee grounds. Nevertheless, this technology is here to stay and it might well be the way for waste reuse in the future.

As for Design applications for this raw material, it was also found that some designers are now looking at this as a reality. Some products are already in the market and others with just concepts. These applications vary from mushroom cultivation [16] to furniture [17].

It can thus be concluded that much has been done in relation to coffee waste reuse in several areas, from agriculture to product design, and even the transformation of raw materials into fuel. However, it is also clear that many of these technologies are at the beginning of their existence and much more can still be done.

C. *Experimental Work*

The experimental work appears as a way to establish the main and most suitable material to add to coffee waste, in creating this composite. The base material used in the experiments was spent coffee, obtained domestically.

Regarding these experiments with coffee waste, the only treatment given to it was, in some cases, by heating it in an oven at 100 ºC for 24 hours, in order to eliminate its humidity. In all other cases, it was used as is.

Concerning the used binders, they all appear with a purpose, not having been chosen at random. The epoxy resin, the first binder to be tested, appears because it was available at (INEGI) and only in an attempt to understand if it would be possible to mix the coffee residue with other materials. The starch was selected because it is a natural and biodegradable polymer and these were fundamental points for this project. The pine resin was used at a time when an ideal binder had not yet been defined and because it was a material whose access was abundant, since other students were using it as base raw material in their own thesis. On the other hand, the wax helped to comprehend if the mixture of pine resin with coffee could be improved, and it was concluded that it would not result. Finally, the choice of PLA arose mainly because of the characteristics that are already recognized. It is a biodegradable thermoplastic, which can be injected and can be used in contact with food. Taking into account the initial objectives of this project (produce coffee cups), PLA has thus proved to be the ideal candidate.

There are several reasons for this material to have been chosen, although the main reason is the perfect symbiosis with the coffee in the creation of a perfectly moldable and inert material in contact with food. In addition, it is also biodegradable and that is a positive thing as it was one of the initial goals for this work.

After the initial impression on this material, many experiments were done in order to try to achieve the best ratio coffee/PLA.

Fig. 3 shows the best results created in this manner. Sample A is composed from 20% spent coffee grounds and 80% PLA, sample B is 30% coffee and C 40%.

It was concluded, therefore, that the greater the proportion of coffee in the blend, the longer will have to be the heating of the two materials in order for them to merge. 40% was the best initial formula for this mixture, with this mold, although this percentage has been increased.

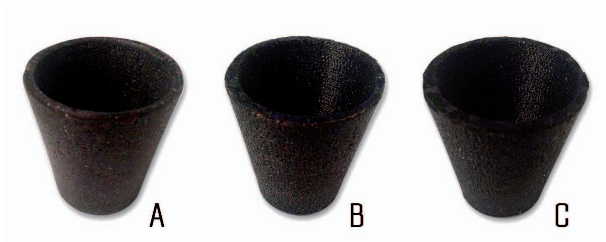

Fig. 3. Best PLA/spent coffee grounds results

This mixture presented however a structural problem, since the part cannot be machine washed, due to the high temperatures to which it would be subjected. In this case, the material undergoes irreparable deformation and gets unusable. The piece has therefore to be washed by hand, preferably with cold water.

Another preoccupation was if the material would withstand hot beverages (coffee) temperatures. The part behaved according to the goal, it even had some insulation, and tolerated the contact with hot coffee, fulfilling part of its function. However, after a couple of minutes it began to show signs of softness, and became wobbly. For this reason, we do not believe the material to be completely tolerant to hot liquids at this stage.

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 mold 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, allowing 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.

D. *Design Proposal*

The first goal of the main design project would be to create a cup with the capacity of withstanding hot coffee temperatures. However, throughout this study, it was realized that this would not be possible at this stage. The project stays the same, but its function adapted to its physical characteristics. It 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 (Fig. 4).

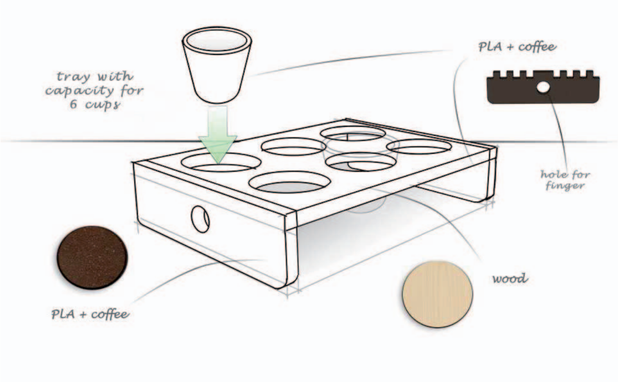

Fig. 4. Explanatory sketch of the main project

As recognized, PLA is an FDA approved material. Therefore, it is safe for food use and is well known as a food packaging material. For this reason, it was decided to maintain the project as it was, because further uses for the cups were seen, other than the capacity to withstand hot liquids.

The cups may, then, be used for all kinds of cold beverages, desserts, condiments, spices, jams. The list goes on and on, as long as it's nothing hot (temperature wise).

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, as can be seen on Fig. 5.

Fig. 5. Representation of the main project

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.

Fig. 6 illustrates the creative process that allowed for the creation of the products present on this section of the chapter. These products try 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 some samples have when placed against a light source.

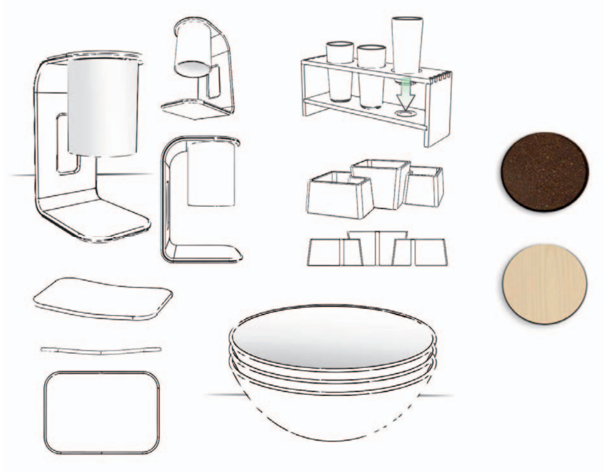

Fig. 6. Other design possibilities: creative sketches

E. Conclusions

From this work, it was concluded that waste in general is growing and there are no predictions for this growth to slow down. And 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 allow for a no cost approach, making this an unrivalled advantage. For this reason, it becomes apparent that coffee waste really is a good choice for a substance 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.

It was also demonstrated that it is safe to recognize that coffee grounds waste is and has been studied for its characteristics in order for it to be reused in the most various ways and on different areas of interest. Moreover, there are already attempts to use coffee waste in additive manufacturing, with some being more successful than others. Additionally, it can be concluded that much has been done in relation to coffee waste reuse in several areas, from agriculture to product design, and even the transformation of raw materials into fuel. However, it is also clear that many of these technologies are at the beginning of their existence and much more can still be done. It also shows that there is already research being done in order to aggregate coffee waste to other substances as a way to turn it into a composite material.

Furthermore, it was concluded that 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, allowing for food contact. The final material is not, however, perfect or completely developed. It does not withstand high temperatures like hot beverages (coffee) or washing machines. There is, for that reason, room for improvement to create an ideal material, but the forecasts are quite positive. Taking into account that it is a moldable material, the creation of shapes is only limited by the imagination.

However, it is certain that the developed composite allows for coffee waste to be reused in the universe of Product and Industrial Design. There is still some way to go to improve this technology, but at this time one can already realize that coffee does not need to be just another piece of trash, it can be turned in to a building material, very efficient and applicable to a large number of areas.

IV. CASE STUDY B

A. Introduction

The world's oceans are full of discarded debris that degrades and sinks or drifts ashore. In 1997, the National Academy of Science, estimated that, per year, about 6.4 million tons of debris are dumped in the oceans [18]. These debris have various origins: sewages, industries, dumpsters and trash left by people on beaches – about 80% of the trash found in the ocean was originated on earth and only 20% derives from marine activities such as fishing [19].

One of the phenomena leading to the entrapment and killing of many animals are ghost nets, which are deliberately or accidentally lost in the oceans [20], usually by fishermen. Besides having a negative impact on the marine fauna, these nets can also damage and destroy coral reefs when being pushed by oceanic currents, affecting all the marine ecosystem [21]. According to United Nations Environment Programme (UNEP), it is estimated that there are 640.000 tons of ghost nets worldwide [22], corresponding up to 10% of the debris in the oceans, which represents a big threat to marine ecosystem [20].

Taking into account the problem of marine pollution and, in particular, the ghost fishing, it is pertinent to intervene with the creation of solutions that encourage the reduction of abandoned fishing gear and raise the awareness of people about the importance of waste as recycled materials, thus acting against the problem of ghost fishing.

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, valuing them by promoting sustainable, ecological and economically viable products. It also aims to raise consumer awareness of the importance of the environment and the value of industrial waste.

After selecting the study subject – reuse fishing ropes and nets (FRN) – it was initiated the collection of information and problem analysis to justify the conduct of the research, followed by the research of applications of the recycled material in market solutions and the collection of the referred waste to proceed to experimentation in the laboratories of the Faculty. After concluding the literature review and experimentation, it was created a product where the fishing waste can be applied.

B. State of the Arte

From the market research, there are two companies which 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 Nylon6 100% regenerated yarn from FRN, carpets and cloths [23]. ECONYL® has two types of yarn: Bulk Continuous Filaments (BCF) that can be used in the production of carpets, upholstery and some automotive coverings; and Nylon Textile Filament (NTF) that can be used in the production of clothing such as underwear, sports clothing, swimwear and socks. There are some companies that already use these yarns for their products, as for example, DESSO, Interface, Koru Swimwear, Adidas, Star Sock, Levi's and BMW [24].

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 [25].

C. Experimental Work

The experimental study started with the collection of fishing waste at *DocaPesca*, in *Matosinhos*, with the collaboration of *Hidurbe Gestão de Resídos S.A* (Fig. 7), followed with a visit to a fishnet factory in order to know the manufacturing process of nets, as well as, the materials used in its products.

Before starting with the experimentation of the transformation of FRN waste, it was important to identify the polymers to be used. Thus, a method of identification of polymers was used to identify four types of residues. The results of this method show that samples A, C and D correspond to a High-Density Polyethylene (HDPE), while sample B corresponds to a Polyamide (PA) (Fig.8).

Fig. 7. FRN collection at *DocaPesca* in *Matosinhos*

Fig. 8. Samples A, B, C and D.

The first transformation experiments were realized in a vertical injection moulding machine using materials A and D. The materials were previously cut into small pieces to fill the cylinder of the machine and, then, injected into a small mould available in the Department of Mechanical Engineering at FEUP. With the performing of these experiments it was verified that recycled HDPE from FRN has a high viscosity, not allowing the flow of the material through the sprue bushing, having never filled the mould. However, with the addition of virgin Polyethylene (PE) – which had much lower viscosity – it was possible to fill the mould with, approximately, 70% of recycled PE (Fig. 9).

Fig. 9. Results of experiments 3, 4 and 5.

Considering the obtained results and the intention to use only FRN recycled material, it was decided to produce a new injection mould with a bushing sprue with a larger diameter - 3 mm. With the new experiments, the material was able to fill the mould but the product presented many irregularities on his shape (Fig. 10).

For last experiments, it was used a silicon mould of a cup where it was placed melted material to give shape using human force as pressure. As can be seen in Fig. 11, the first experiment had lack of material to fill the mould. In the second cup, it already filled the mould. However, this moulding method has proved to be unsuitable due to the high viscosity of the material.

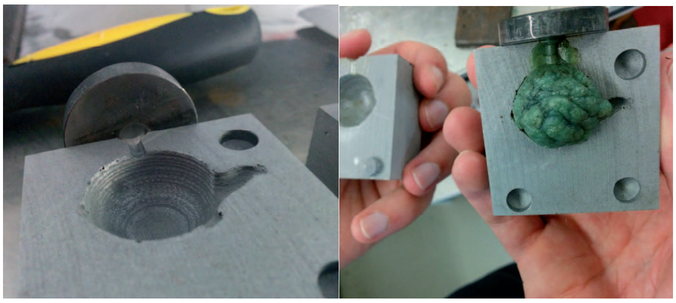

Fig. 10. Resulting product of the new mold.

Fig. 11. Experiments using a silicone mould of a cup.

Although the obtained results were not as expected and little conclusive, the literature review indicates that these materials can be a reliable option for the manufacturing of new products.

D. Design Proposal

The presented product has the intention to keep the connection of the FRN to where they came from – the ocean and beach. Thus, it consists in a “bag backboard”, made of 100% recycled material from FRN, which allows the user to enjoy of two functionalities in a single product. This product will use the FRN in its natural state, fabric made of nylon and injected HDPE (Fig. 12).

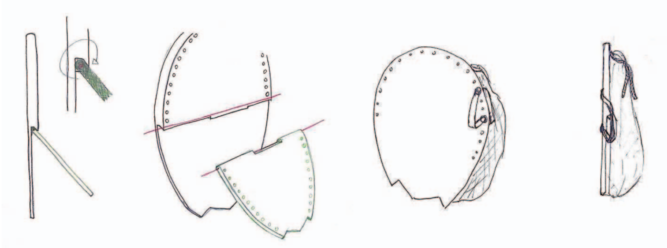

Fig. 12. Sketches of the product.

Thus, the bag component will be made using fishing net in its natural state allowing the sand that is always accumulated in towels and objects, 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. Finally, the backboard prototype will be produced in plywood (Fig. 13).

Fig. 13. “Bag backboard” prototype made of, fishing ropes and nets, non-recycled fabric and plywood.

E. Conclusions

Although the performed experiments with 100% recycled PE from FRN having not been positive neither conclusive, with the literature review it was found that using 100% recycled FRN and others is a reliable option depending on the application.

With this project, it can be concluded that the 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. After the performed experiments in this study, there is a need to go further in order to obtain a better analysis of the ability of the material to be injected.

Finally, it is intended to re-design the presented product in search of the best solution to be manufactured by injection moulding. This requires finding partners with tools and machines to produce a new prototype, close to the final solution, and realize usability tests with users to validate the product.

V. CONCLUSIONS

The case studies presented had the purpose to enhance the importance of project based learning practice in the master’s program of product and industrial design from University of

Porto and the collaboration with different society partners to develop real and feasible products.

Coffee waste can be reused in the universe of Industrial and Product Design. There is still some way to go to improve this technology, but at this time one can already realize that coffee does not need to be just another piece of trash, it can be turned in to a building material, very efficient and applicable in several industrial sectors.

Recycled solutions using fishing nets as new raw material can be an excellent alternative in the design of products, creating more sustainable and still aesthetically pleasing solutions. It was also found that there is a growing concern in cleaning the debris of the oceans and use the possible debris as raw material for new products. After the performed experiments there is still a need to go further in order to obtain a better analysis of the ability of the material to be injected. Taking into account that it is a moldable material, the creation of objects is only limited by the imagination.

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