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3D printing as an enabling technology to implement maritime plastic Circular Economy

J. Garrido[a,*], J. Sáez[a], J.I. Armesto[a], A.M. Espada[a], D. Silva[a], J. Goikoetxea[b], A. Arrillaga[b], B. Lekube[b]

[a]*Automation and System Engineering Department, School of Industrial Engineering, University of Vigo, Campus Lagoas-Marcosende, Vigo 36310, Spain*
[b]*Department of Industrial Engineering, Leartiker, Xemein Etorbidea 12A-1º, Markina-Xemein 48270, Spain*

Abstract

CircularSeas European Project, as part of the European Union Circular Economy [1], aims at promoting the Green Economy by encouraging the development of green products, parts and components by Maritime Industries. The strategy is a combination of Circular Economy principles, with the use of ocean plastic waste for developing new greener materials, and the uptake of advanced manufacturing technology, 3D printing, flexible enough to adapt to the manufacturing conditions for new eco-innovative small and medium parts and components. The paper presents the ongoing research in the project about strategies to introduce Circular Economy in the maritime sector from plastic wastes. This first prospective phase is focused on a series of interviews with each node stakeholders. The paper presents the survey results, together with the challenges to be faced for the implementation of Circular Economy in that specific scenario, despite the -apriori- short term low-profit disadvantages.

Keywords: 3D Printing; Circular Economy; Maritime Industries; Ocean Plastic Waste; Additive Manufacturing

1. Introduction

Turning waste into a resource is one key to a Circular Economy (CE) [2]. United Nations Sustainable Development Goals (SDGs) are a priority for Europe, and for that reason, the European Commission adopted an ambitious CE package [3], including the Plastic Strategy [4, 5] and, among other targets, "a strategy on plastics to address issues of recyclability, biodegradability, hazardous substances, and the Sustainable Development Goals to significantly reduce marine litter".

Circular Economy main principles are broadly accepted and worldwide shared, although definitions may slightly differ from one author to another in academia [6, 7], and from one stakeholder to another in industry. These differences in CE definitions appear to derive from the fact that the concept is employed by many different scenarios and it is of interest to many groups: academia, industry, and policymakers [8]. CE is not a new concept, and in the last decades, it has been taken from different points of view. Circular approaches go from more classical 3R of "Reduce, Reuse and Recycle", up to 9Rs: "Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle and Recover" [9, 10].

Despite the definitions, the main goal of the Circular Economy is to reduce the environmental impact of human activity. There are many CE approaches and implementation strategies [11, 12]. They go from a global approach, both in terms of geographic area and industry sectors [13], to more specific application fields such as in fisheries and aquaculture areas [14] or Circular Economy in Shipbuilding [15], up to even more specific CE approaches for geographic areas as well as sectors such as: Scandinavian maritime sector [16] or Chinese one [17].

Circular Economy around plastic is one of the main application targets around the world [18, 19] and, the more specific CE application scenario about marine plastic, is one of the biggest topics [20, 21]. There is a need to keep plastic and its value in the economy [22] and out of the oceans. Plastics also tend to accumulate in ports [23, 24], and CE is taking the focus in this water, oceanic, ports and cost environments.

* Corresponding author. Tel.: +34-986-812-610.
E-mail address: jgarri@uvigo.es (J. Garrido).

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Concerning the practical methodology to implement CE principles, growing attention has been paid to the CE and Industry 4.0 (I4.0) enabling technologies, but largely through independent and separate research of both fields [25, 26]. I4.0 is being applied as an enabler for CE [27], and the CircularSeas project explores 3D printing -an Industry 4.0 enabled technology [28] -as a new CE implementation strategy. Within I4.0, additive manufacturing is identified as Key Enabling Technology (KET) in the context of the European Horizon 2020 Industrial Technologies Programme (NMP) [29].

Despite the wide acceptance of 3D printing as one of the most promising technologies, it is still far from mass production, although very near to mass customization. Its profitability in the maritime scenario relies on the identification of products to be produced or repaired using these technologies, or with new and adapted versions of it. To address this, the following research question is proposed in this paper:

"From an economic point of view, how much impact would it have introducing 3D printing technology as a way of recycling plastic to support port industry needs?", and "does this impact justify 3D printing production cost?".

To answer these questions, a more specific one has to be solved:

"How much of the plastic from the ocean industry/port, which is not already being recycled, could be used as raw material for 3D printing of products for the ocean industry/port activities?".

This is one of the questions that CircularSeas project intends to answer. To do that, it has been performed an analysis of the amount of plastic generated in port activities that may be economically revalorized if used as recycled plastic for 3D printing, and an analysis of the number of pieces and products that could be manufactured using 3D printing in the port economic environment.

As part of these analyses, this paper presents the results of the survey and the ongoing research in the project about strategies to introduce Circular Economy in the maritime sector for plastic wastes. Section 2 is an introduction of CircularSeas project, while section 3 describes the methodology for the first project stage of information search. Also in section 3, the main results of the surveys carried out in the port of Vigo (Spain) and in other ports involved in the project are presented. The paper ends with conclusions and future work.

2. CircularSeas Project

CircularSeas is an Interreg Atlantic Area Project [30]. It aims at the promotion of the Green Economy in the Atlantic Area, as a means to adapt and diversify economic activities fully tapping Green Growth potential and to reduce the environmental impact in the ocean.

Overall Objective is to promote the development of eco-innovative or green products, parts and components by 3 Maritime Industries, by the combination of 3D Printing (3DP) technology and the use of recycled ocean plastic waste and new biodegradable, renewable and high-performance polymers. Target Maritime industries are fishing, auxiliary fishing and aquaculture; shipyard and port management; and nautical sports.

The strategy is a combination of Circular Economy principles, with the use of ocean plastic waste for developing new greener materials, and the uptake of advanced manufacturing technology, 3D printing, flexible enough to adapt to the manufacturing conditions for new eco-innovative small and medium parts and components.

The project, co-financed by the FEDER through the Interreg Atlantic Area Program, has 8 partners: Leartiker, Azaro Fundazioa and the University of Vigo in Spain, Université de La-Rochelle and Communauté d'Agglomération from La Rochelle in France, University of Plymouth (UK), Cork Institute of Technology (Ireland) and Leiria Polytechnic Institute in Portugal. All of them are grouped around six nodes, each one associated with a port (Ondarroa, Vigo, LaRochelle, Cork, Plymouth and Leiria).

CircularSeas represents a specific application of CE in Maritime Industries, looking for the replacement of plastic-based polymers gear and products by greener materials and the valorization of ocean plastic waste. The shift to greener products will rely on the potential of a disruptive KET (Key Enabling Technology), Additive Manufacturing or 3D Printing (3DP by material extrusion and jetting). The small investment and size of this equipment are optimal for its use on isolated places (boats, sea platforms) and the rapid manufacturing of spear parts for ships, auxiliary fishing gear, rigs and tools, customized components for nautical sports, etc.

Expected impacts of CircularSeas project are: the increase on the recollection and the valorization of the ocean plastic waste for its recycling and use on the development of new materials; the reduction on the use of plastic-based parts in the Maritime Industries, reducing the spillover of plastic into the Atlantic Ocean; and the diversification of the economic activities linked to Green Growth by Maritime Industries by the introduction of 3DP and new materials, bringing new market opportunities and jobs.

3. CircularSeas Project Methodology

CircularSeas project approach is very specific, focusing on one technology, 3D printing, and three sectors: fishing, auxiliary fishing and aquaculture; shipyard and port management; and nautical sports. First, and key activity of the project, is to perform a diagnosis on circular plastic waste in maritime industries. As a result, it is expected a proposal for closing the loop on the use of plastic by maritime industries, by the means of using 3DP for manufacturing parts with recycled and greener materials.

Therefore, the project has two main phases. The first, presented in this paper, is the survey for the identification of business cases in port Nodes, and the viability assessment of associated Business Cases. And the second, to set up technology to implement the resulting business cases: materials, hardware, software, etc.

This first prospective phase is carried out through a collection of information based on a series of interviews to each node stakeholders: representatives from maritime industries and clusters; research on new materials plastic industry and 3DP; port authorities; innovation and entrepreneurship support services. These interviews are presented next.

3.1. Stakeholders interviews

The interview plan [31] is structured in six main sections: general information, generated plastic waste, replaceable plastic products with recycled plastic, non-plastic products replaceable with recycled plastic, 3D printing in business and general interests. Figure 1 represents the interview flow.

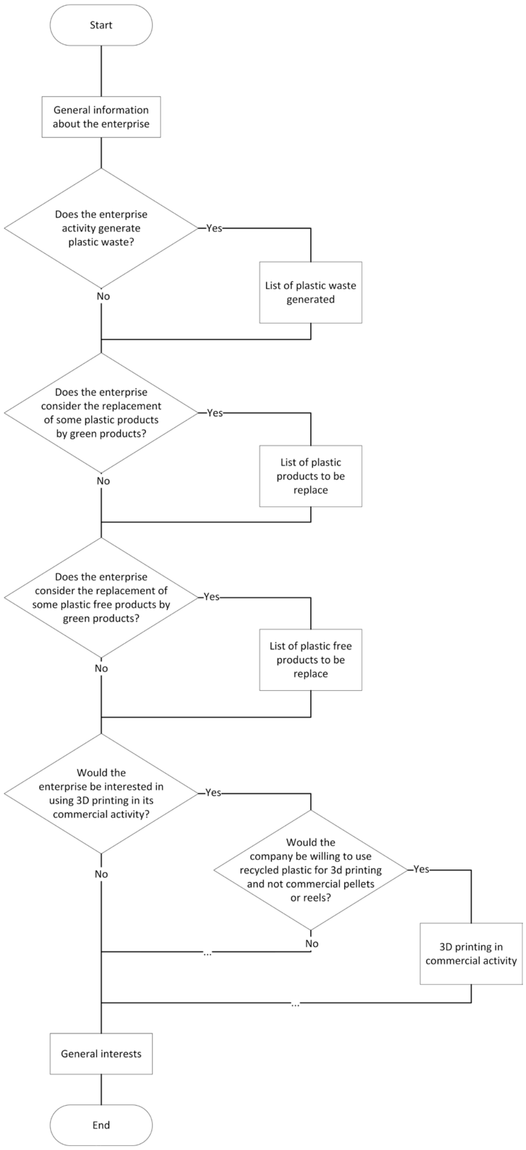

Fig. 1. Survey flowchart.

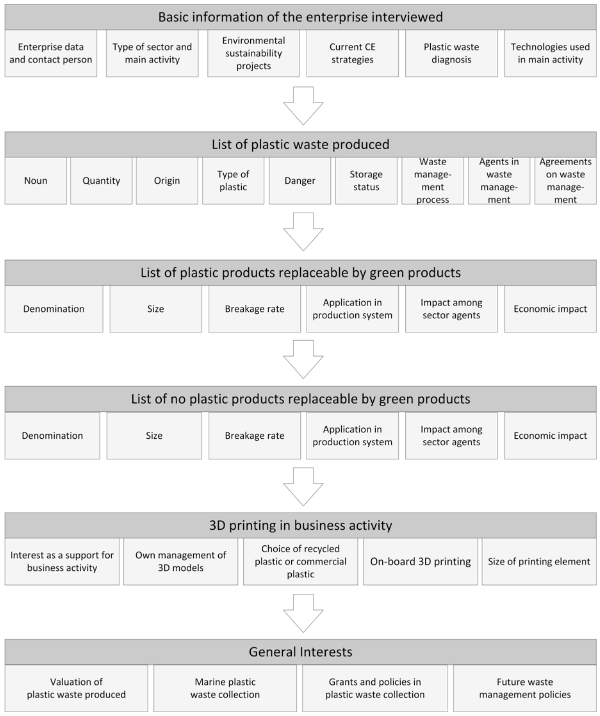

Fig. 2. Stakeholders interview schematic view.

Figure 2 is a schematic view of the interview. First, general information is obtained from the stakeholder. This general information will facilitate the identification of business cases and provides relevant information on current company policies on sustainability, Circular Economy and waste management.

The next part of the survey tries to identify and quantify the plastic waste. Finally, the interview focuses on the parts or products used by the company that can be replaced by green plastic products. Two situations are analyzed: Plastic products to be replaced by a green product, and other non-plastic products to be replaced by green products.

Finally, in the fifth section of the interview, the present or future use of 3D printing as a manufacturing technology for each stakeholder is explored. Furthermore, the conditions under which the company would be willing to use recycled plastic instead of regular non-commercial commercial plastic for 3D printing are explored.

3.2. Survey results: one project port results

The surveys provide significant results. They allow to verify the types of plastic waste generated by each target maritime industry and to estimate how much could be reintroduced into the maritime port circle, as products produced by 3D printing and as products or parts processed by other technologies. Next, conclusions from one of the biggest ports involved in the projects are presented (Vigo-Spain port). Also, a similar analysis has been performed in each of the project ports. Main results are jointly presented in the next 3.3 section.

Table 1. Vigo Port Authority survey main results.

Waste name	Quantity (Tn/year)	Origin	Plastic typology	Waste management method
Plastic	236.88	Various plastics, strapping, scrap boxes and plastic pallets, film bags	-	Collection by the port Authority
Net	71.34	Disused nets from fishing vessels	Others	Collection by the port Authority
Container, bottle	56.44	Food packaging	PET	Yellow container
Expanded polystyrene	31.28	Fish containers	Polystyrene	Collection by the port Authority

Vigo port is one of the biggest European ones regarding fishing activities and the related industry-such as freezing-, both oceanic fishing activity (deep and big fish fishing), as costal fishing [32].

Vigo port Authority, by itself, generates a large amount of plastic waste, since one of its functions is the management of waste from port activities: fishing, commerce, cruises, etc. The selective recycling of plastic with respect to other types of waste is already within the services provided by the port authority, and is one of its environmental priorities, although a more selective plastic separation could be performed. However, at present, plastic recycling is not done from a “port circular” point of view. Therefore, other port plastic consumers, principally fisheries, have to introduce it from outside the port area. The following table (Table 1) summarizes the most significant results from the Port Authority.

Another important activity, in terms of the volume of plastic waste within the target maritime industries, are the small and medium (SME) fisheries that include fishing, freeze fishing onboard, and processing on land. Both, because of the fishing activity itself (it is well known the huge amount of plastic waste from the nets), but especially because of its processing activity on-land.

The packaging is an activity that generates a large number of plastic wastes, although the project concerns those as a result of the industrial process, not the others once the commercial products left the port circle. In fact, over a third of produced plastic is used to make packaging, which is often quickly discarded [33].

The number of fisheries changes greatly between ports. The fishing activity of the port of Vigo, both due coast fishing and oceanic one, is one of the largest in Europe. Three representative fisheries are chosen for this first analysis, to extrapolate results and normalize them.

The data in tons, in the case of the three fisheries, can be seen in the following table (Table 2). From the data, fisheries are recycling more than 45.80%. The analyzed fisheries are recycling more than 45.80%, so 56.20% could still enter the Port recycling circle.

Table 2. Total plastic waste tons/year in fisheries activity.

Input Tons	Output Tons	Total Tons
150.80 Tn	117.51 Tn	268.31 Tn
56.20%	45.80%	100%

Table 3 shows the detail of the main types of plastic waste identified. Plastic that is not recycled may be reintroduced into the circle for the manufacture of the new green plastic products. As presented in the survey, two situations are analyzed: Plastic products to be replaced by a green product, and other non-plastic products to be replaced by green products. The following table (Table 4) represents the first of the situations.

The volume of plastic that could be used with 3D printing technology has been differentiated from other plastic to be used in other technologies such as injection. This classification has been carried out taking into account the characteristics of the products to be manufactured and taking into account the characteristics of current 3D printing technology. For large-scale or mass-produced products, manufacturing technology closer to injection than 3D printing would be required.

Table 3. Main plastic waste from fisheries.

Waste denomination	Quantity (Tn/year)	Plastic typology	Waste management method	Circular
Containers and plastic cutouts	320.00	PET, PEAD, LDPE, PP, PS	Authorized waste manager	Yes
Dirty LDPE and bags	117.00	LDPE	Compacted and management as MSW (no cost to the plastics recycling company before 2018)	No
Film packaging	84.00	LDPE	Authorized waste manager	Yes
Discarded containers	66.51	HDPE	Sale to plastic recycling company	No
Film packaging	51.73	LDPE	Sale to plastic recycling company	No
Strapping tape	29.56	PP	Sale to plastic recycling company	No
Clean LDPE	11.00	LDPE	Compacted and management as MSW	Yes
Rigid plastic containers	4.40	HDPE	Authorized waste manager	Yes

Table 4. Tons/year of plastic products to be replaced by a green product.

3D processing Tons	Injection processing Tons	Total Tons
1.21 Tn 1.90%	62.44 Tn 98.10%	63.65 Tn 100%

However, these percentages could change as 3D printing technology advances and customize to specific scenarios. Table 5 shows the second type of products: currently non-plastic products that could be replaced by plastic ones.

Table 5. Tons/year of non-plastic products to be replaced by green products.

3D processing Tons	Injection processing Tons	Total Tons
5.06 Tn 5.33%	89.88 Tn 94.77%	94.94 Tn 100%

The same distinction is made in the table as in the previous table for the two possible technologies: 3D printing and injection. The percentage of recycled plastic to be used is substantially higher in these types of products, although perhaps the 3D printing technology would have to be greatly customized. One of the non-plastic products to be replaced by equivalent plastic made ones identified in the survey are wooden pallets. The development of 3DP or 3D-injection mixed technology would be required for its manufacture.

Finally, combining both results, it is obtained that 3.96% of the recycled plastic could be used with 3D printing technology (Table 6). Figure 3 summarizes the results.

Table 6. Tons/year of recycled plastic produce green product.

3D processing Tons	Injection processing Tons	Total Tons
6.27 Tn 3.96%	152.32 Tn 96.04%	158.59 Tn 100%

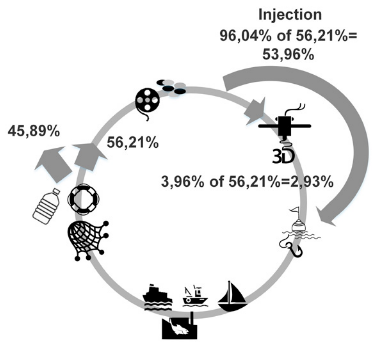

Fig. 3. Fisheries results.

3.3. Survey results: results of the project ports

Taking into account other port results, different from Vigo, a more general view picture may be taken.

Each port has its specificities about the importance and size of each of the three target industries that the project analyzes: fishing, port and shipyards and nautical.

Several different promising parts have been identified to be made using 3D printing technology. Table 7 summarizes some of these identified parts, and Figure 4 graphically represents the parts and the proposed recycled plastic material to be made with 3D printing technology from all project ports.

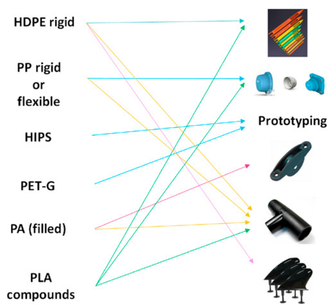

Fig. 4. Relation between recycled plastic and 3D printable products.

Table 7. Products to be printed with recycled plastic.

Product	Actual material	To be replaced by	Dimensions (mm)	Industry
Fishing net mending needle	PA	Recylced material: Rigid PP, PE, PLA	140x11x3	Fisheries
Oyster spat collectors	PP with coating	Bioplastics or recycled plastic	120x120x30	Aquaculture
End and lateral covers of ball bearings	PP or TPU	Recycled PP, PLA	140x140x65	Fisheries (boats), ship yards
Sheave boxes for yatchs	PA	Recycled PP, PLA	120x40x20	Nautical
Paddle handles	PA	Recycled PA	104x70x25	Nautical
Soft board fins	HDPE	Recycled HDPE	160x120x60	Nautical
Jetty modular parts	HDPE	Recycled HDPE	48x48x36	Nautical
Spare parts	Any	Any	Any	Nautical
Prototyping parts	Any	Any	Any	Fisheries (maintenance), shipyards, nautical

Table 8. Product to be made by injection moulding from recycled plastic.

Product	Actual material	To be replaced by	Dimension mm	Industry
Pallets	Wood	Recycled PE	1200x800x145	Fisheries
Jetty	Wood	Recycled PE	1000x80x6	Nautical
Containers (boxes)	Any plastic	Recycled PE	Many	Fisheries
Kayak paddle blades	PVC, rubber, reinforced composites	Recycled PP, PLA	140x370x70	Nautical

However, from the survey have been identified some products which, either due to their dimensions or, above all, due to the high number of single units used in the target industries, injection moulding is a most suitable manufacturing technology than 3D printing. Table 8 summarizes some of these products.

Also, one of the main research issues of the project is about the configuration of the value chain into the port environment and the search for new economic scenarios around 3D printing with recycled plastic. It is many times unclear, though, if such value chain reconfigurations can realistically enable a more circular use of resources, and under which circumstances they are truly beneficial, both from a sustainability viewpoint and from an economical one. This, as it is suggested in [34] and [35], requires a better understanding of the information flows and the relationships between stakeholders along with the product and material life cycles.

However, data from the survey performed in all project ports highlights, from one side, that there is enough plastic waste suitable for recycling in all ports, regardless of the main port activity. And from the other side, there are a large number of products suitable to be made using 3D printing technology. The remaining question is whether the manufacturing-through 3D printing or through injection moulding- of these products would be profitable by using recycled plastic instead of regular plastic. That would be the case, as some of the project industry stakeholders have already suggested if an additional value is added to the products because of that. For instance, in terms of marketing or in terms of becoming easier to fulfil any kind of legislation.

4. Conclusions and future work

This paper has presented the results of the research survey about strategies to introduce a Circular Economy in the maritime sector for plastic wastes. The survey has brought empiric evidence about the economic, technical and environmental viability 3DP technology in the manufacturing of parts using green materials.

From the results, it can be concluded that the amount of plastic that could be recycled through 3d printing, within a port CE, is much smaller than the total amount of plastic waste. Despite this, the amount of plastic to be recycled with this technology is significant.

Therefore, 3D printing with green plastic materials seems reasonable as a service to be provided by green ports. The volume of work and products, which could be manufactured through 3D printing in a medium port, seems enough to support that economic activity.

As new 3D printers specializing in specific products, such as pallets, customized boxes, etc., are developed, the amount of recycled plastic used with this technology could be drastically increased. The search for specific product-oriented 3D printers and, especially the search for mixed injection and 3D printer for manufacture and maintain specific products becomes the next step.

Acknowledgements

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