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3D Printing Applications for Creating Products Made From Reclaimed Fishing Nets

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In pursuit of innovative and sustainable solutions for marine plastic waste, the Circular Ocean project seeks to inspire enterprises and entrepreneurs to realise the hidden opportunities of discarded fishing nets and ropes in the Northern Periphery & Arctic (NPA) region.

As increasing levels of marine litter is particularly pertinent to the NPA region, the Circular Ocean project will act as a catalyst to motivate and empower remote communities to develop sustainable and green business opportunities that will enhance income generation and retention within local regions.

Through transnational collaboration and eco-innovation, Circular Ocean will develop, share and test new sustainable solutions to incentivise the collection and reprocessing of discarded fishing nets and assist the movement towards a more circular economy.

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3D Printing Applications for Creating Products Made From Reclaimed Fishing Nets

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Abstract

Waste fishing gear or 'ghost nets' present not only significant environmental issues, but also represent a missed opportunity for local coastal communities to harness the value of these high-quality polymers. Fused Filament Fabrication (FFF) 3D printers have risen in popularity, availability and affordability in recent years and therefore provide a potentially accessible route for distributed manufacture. This paper examines the potential of (FFF) 3D printing as a method of converting waste fishing gear polymers into saleable products on a localised scale through the completion of a pilot study. This includes a qualitative assessment of the available fishing gear polymers, their composition, construction, condition and level of contamination as well as an evaluation of their potential suitability as source material for (FFF) 3D printing filament. The viability of both the direct 3D printing of fishing gear and the indirect use of (FFF) 3D printing as a facilitator in the conversion of fishing gear into saleable products are discussed.

1. Introduction

1.1 The Problem of Discarded Fishing Gear

Fishing nets and ropes may be found drifting in the ocean for a number of reasons, from storm events to snagging, illegal dumping and abandonment (Macfayden et al., 2009). Prior to the introduction of synthetic polymers in the mid to late 20th Century, fishing gear were made from natural fibres, such as hemp and cotton, and would therefore simply biodegrade (Martinussen, 2006). Today, however, synthetic fishing gear lost at sea, otherwise known as 'ghost nets', persist in the marine environment causing significant harm to aquatic life (Macfadyen & Brown, 2007). As they are circulated by ocean currents, ghost nets continue to unintentionally catch both target and non-target species, exacerbating the dwindling of fish stocks, and causing entanglement of other marine wildlife, including birds and mammals. Adding to existing levels of plastic pollution in the ocean, fragments of fishing nets and other plastic wastes are also often mistaken for food and ingested by aquatic organisms (Moore, 2008). This leads not only to starvation and nutritional deficiency, but also the introduction of contaminants into the food chain, including plastic components and by-products, as well as various chemical pollutants present in the ocean, which are known to sorb[1] onto polymers (Engler, 2012). The prevention and retrieval of ghost nets is therefore in the interests of fishing communities, whose livelihoods rely on the sustained health and supply of fish stocks. However, presently there exists a lack of infrastructure and direct incentives to support their widespread return and recovery (World Animal Protection, 2014).

1.2 The Material Value in Waste Fishing Gear

Fishing gear also represents a substantial capital investment, the value of which is lost when nets become badly torn, tangled or lost at sea (Large et al., 2009). The high price is largely

[1] Sorb: To take up and hold by either adsorption or absorption (Merriam-Webster Dictionary, 2016)

due to the need for fishing gear to be made from high quality polymers that are able to withstand the stresses of daily fishing activities (Storm, 2015). As such, polymers used to manufacture fishing gear exhibit desirable properties, including strength, flexibility, light and chemical stability and resistance to abrasion and microbial activity, which are either inherent in the materials themselves or achieved through the addition of chemical stabilizers and additives (Kim, 2009; Oxvig & Jansen, 2007). The polymers, which include polyamide, polyethylene, polyester and polypropylene, are also thermoplastics and are therefore able to be melted and re-shaped through the application of heat (Ramos, 1999). As such, waste polymer fishing nets and ropes are promising candidates for mechanical recycling, as their high quality should withstand the small amount of inevitable thermal degradation that occurs during melting to produce a relatively high quality end product (Storm, 2015). Whilst industrial plastic recycling provides an environmentally sound alternative to dumping or abandoning waste fishing gear at sea, the material value held in the fishing gear will be removed from the local community. Additionally, the high quality polymers that make up fishing gear may be diluted when mixed with the waste streams of other industries during recycling. One solution to this is distributed recycling, a concept that has been gathering interest since the popularisation of (FFF) 3D printing (Baechler et al., 2013; Kreiger et al., 2014; Hunt et al., 2015).

1.3 Distributed Recycling with Fused Filament Fabrication (FFF) 3D Printing

Unlike selective laser sintering (SLS) and stereolithography (SLA), which require specialty fine powders and UV-curable resins respectively, the fused filament fabrication (FFF)[2] method of 3D printing uses extruded filaments typically made from low-cost and widely available thermoplastics (Lim & Cassidy, 2014). The affordability and compact size of FFF 3D printers has also helped the technology's popularity to grow, with markets expanding to include home and office applications. As transporting waste plastics from their point of disposal to a processing facility is one of the key challenges in waste plastics recycling (Krieger et al., 2014; Hopewell et al., 2009), (FFF) 3D printing's ability to facilitate cost-effective, distributed manufacture close to the point of waste generation is an important development (Ihl & Piller, 2016). Further, desktop shredders, such as the FilaBot Reclaimer, and extruders, including the RecycleBot, Strooder and Noztek Pro, have been developed to complement the (FFF) 3D printing process to provide a complete desktop recycling solution (Chong et al., 2015). It is for these reasons that (FFF) 3D printing holds significant potential for the localised recycling of waste fishing gear.

2. Methodology

An initial scoping study was completed by the authors within the EC funded Circular Ocean project www.circualrocean.eu focused on the potential applications of 3D Printing (3DP) in the recycling of Fishing Nets & Ropes (FNR's) (Hunt & Charter, 2016). This research provided important learning that fed into further research that is highlighted in this paper.

A project to assess the suitability of waste fishing gear for use in (FFF) 3D printing applications was carried out within the constraints of a 14-week timeframe (6th July - 10th October 2016), without budget or funding and with no access to specialist facilities, tools and equipment. The first step in the process was to establish the types of polymers typically used in fishing gear, the properties of those polymers and their current use within (FFF) 3D printing applications, which was achieved through a desk-based review of the literature. This research provided a good indication of whether or not the materials contained within waste fishing gear had the potential to be processed using (FFF) 3D printing technology. Following this, it was then necessary to consider the additional challenges associated with sourcing these polymers in the form of used fishing gear. In order to explore some of the common issues, a representative selection of waste fishing gear samples (approximately 20-50g per sample)

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2 Fused Filament Fabrication: *"…a filament of material is fed into a machine via a pinch roller mechanism. The feedstock is melted in a heated liquefier with the solid portion of the filament acting as a piston to push the melt through a print nozzle. A gantry moves the print nozzle in the horizontal x–y plane as the material is deposited on a build surface that can be moved in the vertical z direction. This enables complex 3D objects to be produced as the melted bead leaving the nozzle solidifies"* (Turner et al., 2014, pp.192)

were obtained from MCB Seafoods,[3] Newhaven UK. A visual assessment was then carried out in order to estimate the composition, construction, condition and contamination of the materials and their potential suitability for reprocessing into (FFF) 3D printing filament.

2.1 Composition

Determining the polymer composition of the fishing gear samples was identified as an important step as the melting points of different polymers vary. Knowledge of polymer type is therefore necessary for the selection of appropriate extrusion and printing temperatures and the prevention of uneven, poor quality extrusions and potential blockages during printing caused by heterogenous material inputs.

Whilst scientifically accurate methods of identifying different polymers from mixed waste streams were available, including laboratory testing and hand-held near-infrared (NIR) spectroscopy tools (Huth-Fehre et al., 1995), typically costing between £500 to £50,000 and £18,000 respectively, these methods exceeded budget constraints and were deemed prohibitive for any local entrepreneurs looking to recycle the polymers from the nets into saleable products. Working with 'zero' budget, the fishing gear samples obtained from MCB Seafoods were instead visually assessed and matched to descriptions published in the '*All About Nets Identification Guide*' made available by Ghost Nets Australia (Gunn, 2015).

2.2 Construction

In addition to polymer type, separating waste fishing gear by colour was also identified as something that would provide greater control over the look of final recycled products. As such, the ease of disassembly and separation of each samples' component materials by polymer type and colour was estimated through a visual assessment.

2.3 Condition

It was also acknowledged that, whilst fishing gear is made from high quality polymers in order to withstand the physical stresses of fishing activities (Storm, 2015), abrasion, water conditions and ultraviolet (UV) light can cause the materials to degrade whilst in the ocean (Macfayden et al., 2009). Laboratory analysis was identified as an accurate method of assessing polymer quality and the presence of any UV or thermal stabilizers, which are commonly added to fishing gear polymers in order to prevent degradation and maintain a high quality (UNEP, 2015). However, due to the limitations of the study this was not possible and a visual assessment was instead carried out for each sample in an attempt to spot any obvious signs of degradation or disintegration.

2.4 Contamination

As the process of 3D printing requires forcing a thin and consistent stream of melted polymer through a nozzle (Turner et al., 2014), the potential for 'macro' contaminants (e.g. sand) to cause blockages, resulting in a failed print and damage to the printer itself, has been highlighted as a possible issue. A visual assessment was carried out to assess the presence of sand and salt for each sample. As other contaminants, such as fish oils and seacraft fuels may also affect the colour, consistency and quality of the polymer as it's printed, discolouration and odour were also included as part of the analysis (Storm, 2015).

2.5 Fishing Gear Extrusion Testing

The results of the literature review and visual assessment of the net samples from MCB Seafoods as described above, enabled the identification of the types of fishing gear most viable for use in (FFF) 3D printing filament. A further 700g of these particular types of fishing gear were then sourced from MCB Seafoods for further experimentation. The materials were first cleaned in fresh water, dried and, without access to a shredding device, cut by hand into <10mm segments. This method was used out of necessity rather than preference as manual cutting of the nets proved a very time-consuming process. If further tests are completed in the future, it is recommended that mechanical or electronic shredding devices be sourced. Once cut, the fishing gear materials were sent to recycled (FFF) 3D printing filament producer,

[3] MCB Seafoods, Newhaven UK, were identified as a potential source of fishing gear samples as they had previously set up a take-back programme for sending nets to Circular Ocean partner Plastix Global, Denmark.

Object Form UK, for trial extrusion testing. Whilst a technical programme of polymer testing was recommended in order to provide definitive results in relation to the material's viability as a filament, this involved 3rd party costs and was therefore not possible within the budget constraints of this study. Instead, a trial extrusion was carried out using an in-house desktop extruder at Object Form UK and a visual estimate of the quality of the filament produced was made.

2.5 Assessment of (FFF) 3D Printing Applications for the Recycling of Fishing Gear

The findings of this study were then consolidated and used to evaluate the feasibility of four potential methods of localised fishing gear recycling involving the application of (FFF) 3D printing technology:

- Production and sale of recycled fishing gear (FFF) 3D printing filament
- Localised production and sale of products printed using recycled fishing gear (FFF) 3D printing filament
- Rapid prototyping with (FFF) 3D printing to mould products using fishing gear polymers
- (FFF) 3D printing of components to facilitate the assembly fishing gear into products

3. Results

3.1 Literature Review: Waste Fishing Gear Polymers

Polymers typically found in waste fishing gear include polyamide (nylon), polyethylene, polypropylene and polyester (Ramos, 1999; Oxvig & Jansen, 2007; Storm, 2015). Whilst polylactic acid (PLA) and acrylonitrile butadiene styrene (ABS) filaments currently dominate the (FFF) 3D printing market, filaments made from other polymers, such as those found in fishing gear, are becoming increasingly available (Hunt et al., 2015). Table 1 lists the properties of common fishing gear polymers and explores the current use of these materials within an (FFF) 3D printing context.

Polymer	Polyethylene (PE)	Polypropylene (PP)	Polyester (PET)	Polyamide (PA)
Advantageous Properties	▪ Moisture, chemical and oxygen resistance[1] ▪ Good impact resistance[1]	▪ Moisture and chemical resistance[1] ▪ Low density[1] ▪ Suitable for high temperature end uses (100°C)[1] ▪ Good fatigue resistance[1]	▪ Moisture and chemical resistance[1] ▪ Excellent UV resistance[1] ▪ Excellent wear resistance and durability[1]	▪ Tough[1] ▪ Good impact and abrasion resistance[1] ▪ Chemical resistance[1] ▪ High tensile strength[1] ▪ Creep resistance[1]
Limiting Properties	▪ Poor UV and weathering resistance[1] ▪ Subject to stress cracking[1] ▪ Difficult to bond[1] ▪ Suitable for low temp end uses[1]	▪ Poor UV resistance[1] ▪ Difficult to bond[1] ▪ Several metals known to accelerate oxidative degrading[1]	▪ Differential cooling rates can lead to warpage[1]	▪ High moisture pick-up (physical distortion and changed mechanical properties)[1] ▪ Requires UV stabilisation[1]
Filament Availability	• Experiments using HDPE post-consumer plastic have been carried out with some success[2] • Filacycle planning release of HDPE filament in the near future[3]	• Experiments using waste food containers have been carried out with limited success[4] • German RepRap GmBH has released first PP filament available only in black 1.75mm[5]	• Available as filament in 1.75mm & 3mm diameters[6]	• Available as filament in 1.75mm & 3mm diameters[6]
3D Printing Temperature	▪ Print bed: Unknown ▪ Extruder: 110°C[7]	▪ Print bed: Unknown ▪ Extruder: Unknown	▪ Print bed: 55-70°C[6] ▪ Extruder: 230-255°C[6]	▪ Print bed: 60-80°C[6] ▪ Extruder: 235-270°C[6]
3D Printing Performance	HDPE: ▪ Poor layer adhesion[7] ▪ Subject to warping during printing[7] ▪ Requires PVA-based glue print bed[7] LDPE: ▪ Starts to breakdown and burn above 80°C[7]	▪ Currently in experimental stage[4] ▪ Very limited filament options[4] ▪ Subject to significant shrinkage and warping during printing [4]	▪ Produces strong parts[6] ▪ Resistant to warpage[6] ▪ High clarity[6] ▪ No odours or fumes produced during printing[6] ▪ Requires blue tape print bed[6]	▪ Produces strong and durable parts[6] ▪ High interlayer adhesion[6] ▪ Can be dyed with acid-based clothing dyes[6] ▪ Requires PVA-based glue print bed[6] ▪ Requires drying prior to printing[6] ▪ Some curling during printing[8]

Table 1. Properties of Fishing Gear Polymers within an (FFF) 3D printing Context

Adapted from: 1. Campo, 2008; 2. Baechler et al., 2013; 3. Taylor, 2014; 4 Billing et al., 2014; 5 German RepRap GmbH, 2016; 6 Matterhackers, 2016; 7 RepRap Wiki 2016; 8 Chong et al., 2015.

Whilst it may be possible to extrude the polymers found in waste fishing gear into filament for (FFF) 3D printing applications, Table 1 shows that print quality is likely to be a limiting factor. Polyamide and polyester show the most promise, with favourable mechanical properties and a market having already been established for their use as 3D printing filaments. It has been suggested that polyamide prints, with their high flexibility, strength and tear resistance, may even outperform those made from market leaders, ABS and PLA, despite polyamide being a more difficult filament to work with (Chong et al., 2015). For polypropylene and polyethylene, however, warping and distortion are a key issue, along with poor layer adhesion in the case of polyethylene. It is these issues that present a significant obstacle to their use as 3D printing filaments. Nevertheless, it should be noted that there has been some progress in this area with at least one commercial polypropylene filament having entered the market and a polyethylene filament currently in development.

3.2 Visual Assessment: Fishing Gear Samples (MCB Seafoods)

3.2.1 Composition

The eight samples analysed (Appendix 1) comprised a total of four different polymers, with one identified as polyamide 6.6 purse seine net, two as polyamide 6 monofilament gillnet, two as polyethylene rope, one as polyfoam and polyethylene floatline and one as a combination of polyamide 6.6 stitched to polyethylene rope. The polymers varied in colour to include white, cream, pale green, blue, yellow, orange, red and black as well as green and colourless translucent materials.

3.2.2 Construction

Five of the samples were homogenous in both material and colour composition, therefore requiring no manual separation. Those comprising different colours in a twisted rope configuration proved relatively easy to unravel manually and separate by colour (Figure 1), although in some instances this required the prior removal of additional elements, such as adhesive tapes (Figure 2) and other materials that had been sewn on (Figure 3).

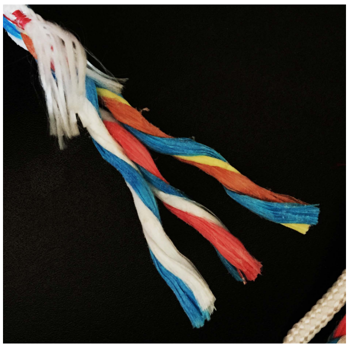

Figure 1.

Adhesive tape securing the end of twisted polyethylene rope.

Figure 2.

Adhesive tape securing the end of twisted polyethylene rope.

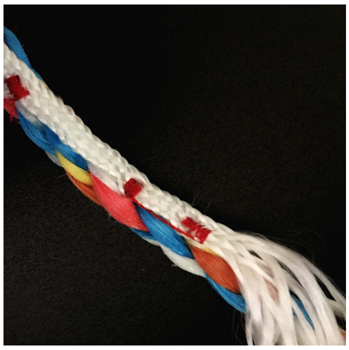

Figure 3.

Braided polyamide rope stitched into a twisted polyethylene rope.

The combination of different materials in the floatline required the additional removal of the polyfoam core (Figure 4). Whilst this could be cut away, unraveling and detangling the remaining black and pale green polyethylene proved a more time-consuming process due to the fine filaments and tightly braided structure.

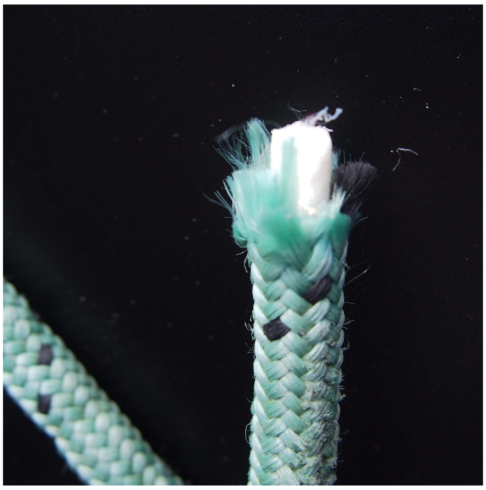

Figure 4.

Floatline in pale green and black PE filaments braided around a polyfoam core.

As any manual separation of waste fishing gear, whether by polymer type or colour, will add labour time and therefore cost to the recycling process, those fishing nets comprising a single material and colour may be considered the most cost effective input for (FFF) 3D printing applications.

3.2.3 Condition

Of the samples analysed, all but the monofilament nets showed signs of abrasion. It was not possible to determine the level of ultraviolet (UV) or chemical degradation by visual appraisal; however, there were no obvious signs of disintegration.

3.2.4 Contamination

Five of the eight samples analysed were visibly contaminated with sand and salt. The twisted polyethylene ropes were observed as having the highest levels of sand and salt contamination (Figure 5), whilst the braided polyethylene ropes appeared to have slightly lower levels. Sand and salt contamination was not visibly evident on either the braided polyamide 6.6 purse seine net or the polyamide 6 monofilament gillnets. The observed differences in visible sand and salt contamination could have been due to a variety of reasons, including the duration of use, the location and method of fishing and the kinds of maintenance and storage practices employed. However, it should be noted that the samples with the least sand and salt contamination tended to be those with smoother surfaces and narrow diameters. In addition to sand and salt, other contaminants were observed during the visible assessment of the samples and this included signs of possible rust (Figure 6) and biofouling (Figure 7). Strong odours indicating other contaminants, such as ammonia in the case of fish oils, were not observed for any of the samples.

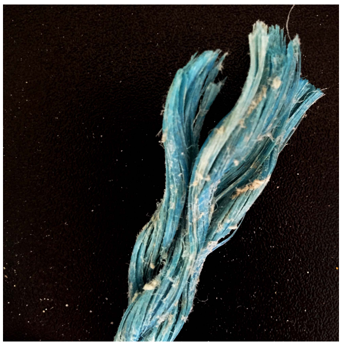

Figure 5.

Salt and sand contamination on twisted polyethylene rope.

Figure 6.

Suspected rust contamination on twisted polyethylene rope.

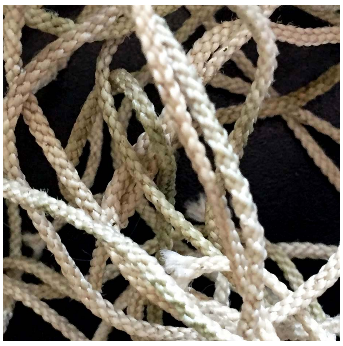

Figure 7.

Suspected biofouling on lengths of polyamide 6.6 purse seine nets.

3.3 Filament Extrusion Trials with Object Form UK

Prior to commencing filament extrusion trials, it was important to select the fishing gear polymer/s most likely to produce a high quality end product. The results of the initial literature review found that, whilst all of the most common fishing gear polymers are thermoplastics, that are able to be reshaped through the application of heat, their suitability for extrusion and (FFF) 3D printing varies. Further analysis of each polymer's properties found that, as polypropylene and polyethylene are both prone to significant warping, polyester and polyamide were likely to produce superior results.

The visual assessment of fishing gear samples also suggested that the polyamide monofilament gillnets would be the least labour intensive fishing gear to process as they were found to be homogenous in both colour and material composition and therefore did not require any further disassembly or separation. They also appeared to be the least contaminated with sand and salt, likely due to the monofilament's smooth surface compared to gear made up of narrower fibres that have been twisted or braided. For these reasons, polyamide monofilament gillnets were deemed the most suitable for extrusion and (FFF) 3D printing and a larger quantity (700g) were obtained from MCB Seafoods (Figure 8 & 9) in order to carry out extrusion trials with recycled filament producer, Object Form UK.

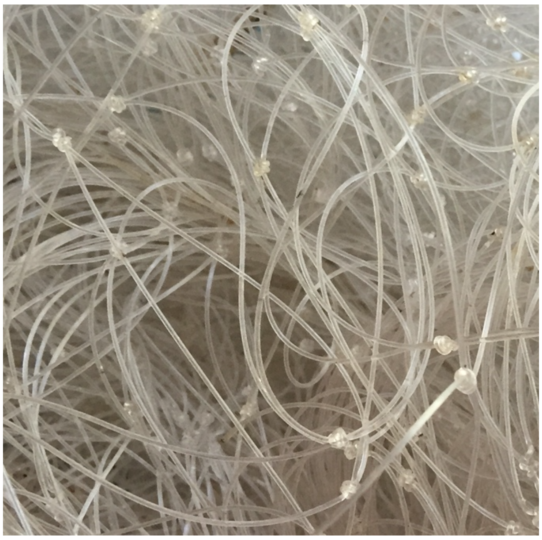

Figure 8.
Polyamide monofilament gillnets sourced from MCB Seafoods.

Figure 9.
Hand-cut (shredded) polyamide monofilament gillnets.

The Object Form UK trials produced several filament samples from the shredded polyamide monofilament gillnets, demonstrating that extrusion is possible and providing proof of concept (Figure 10). The trials also confirmed a number of important suspected issues associated with sourcing polyamide from waste fishing gear. The first was that the material contained a significant amount of water as a result of polyamide's high moisture pick-up (Table 1) and the gear's constant contact with the sea. This caused unwanted bubbling during extrusion, as evidenced by the opaque appearance of the filament shown in Figure 10. An industrial drying process was therefore recommended by Object Form UK, going forward.

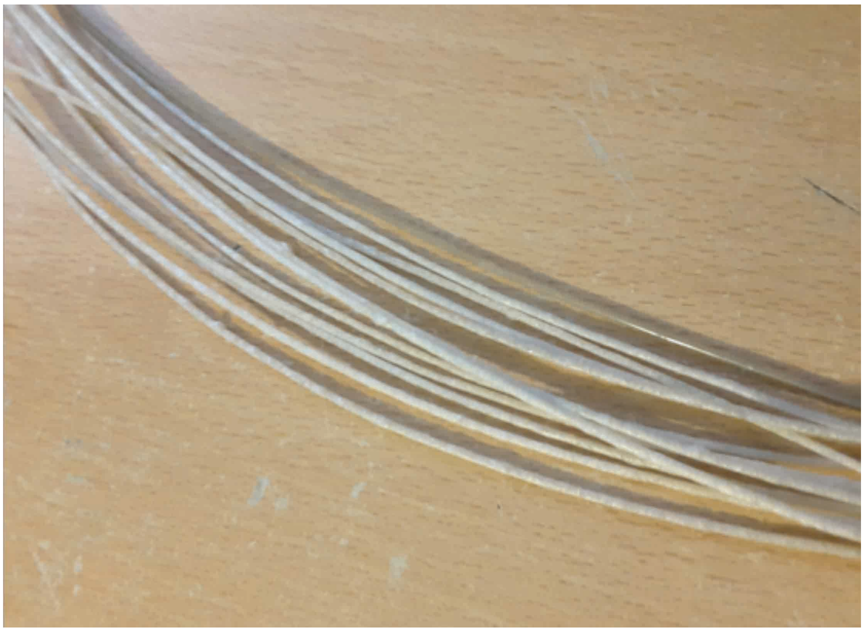

Figure 10.
Filament samples extruded from shredded polyamide monofilament gillnets by Object Form UK

Secondly, a salty odour was detected during extrusion, suggesting salt contamination. As such, it was recommended by Object Form UK that further scientific testing be carried out in order to determine the level of contamination and its impact on filament and print quality.

Despite the challenges identified, it was concluded that with the correct industrial processes and further testing, recycled polyamide fishing gear could prove to be a viable source of material for producing (FFF) 3D printing filament.

4. Discussion

The key motivations behind this project are the need to prevent the discarding of fishing gear at sea and to retain the material value of fishing gear within local coastal communities. Therefore, successful solutions need to provide an incentive for the return of fishing gear to port and facilitate the localised processing of as much fishing gear material as possible into either value-added products for sale or objects that are of use to the local community.

4.1 Production and Sale of Recycled Fishing Gear (FFF) 3D Printing Filament

The results from the extrusion trials with Object Form UK suggest that producing (FFF) 3D printing filament from *some* fishing gear polymers is a possibility, although further testing and industrial processing would be required to achieve the quality necessary for selling the filament commercially. Although this would involve initial investment in machinery, the process could be scaled up to process and extrude large volumes of fishing gear into filament. Whilst other methods of 3D printing may produce higher quality prints compared with fused filament fabrication, the affordability of FFF 3D printers has seen their popularity grow amongst hobbyists and the general public, creating a global market for filament. The key limitation of this option is the narrow requirement for clean and dry polyamide, and possibly also polyester, fishing gear, leaving behind that which does not meet the requirements.

4.2 Localised Production and Sale of Products Printed Using Recycled Fishing Gear (FFF) 3D Printing Filament

With filament made from waste fishing gear a possibility, there exists the potential to (FFF) 3D print saleable products and useful objects locally using the filament. Although this provides local entrepreneurs with the option of adding value to fishing gear materials through creativity and design, there exist a number of limitations. Firstly, the quality of (FFF) 3D prints is relatively low compared to other manufacturing processes, such as injection moulding, and other forms of additive manufacture (e.g. SLA). The appeal of (FFF) 3D printing is its ability to facilitate distributed manufacture of custom products, rather than the physical quality of the products produced. Therefore, it may be difficult to establish a market for the sale of ready-made (FFF) 3D printed products. Additionally, the maximum print size achievable using (FFF) 3D printers tends to be limited by the size of the print bed and also the considerable time that it takes to print larger objects. As such, it is unlikely that significant volumes of fishing gear could be processed locally using (FFF) 3D printers.

4.3 Rapid Prototyping with (FFF) 3D Printing to Mould Products Using Fishing Gear Polymers

Whilst the direct extrusion and printing of fishing gear may be limited by polymer type, condition and contamination level, there may be other ways in which (FFF) 3D printing can be used to convert fishing gear into saleable products. Rapid prototyping is a promising option as it allows various product designs to be developed and created without expensive re-tooling. Prototypes could be manufactured using off-the-shelf filament and then cast to make a mould. With affordable desktop injection moulding equipment becoming available (e.g. Many-Maker), fishing gear polymers could then be used as the material feed for injection moulding multiples for sale. This process would make the most of the advantages of (FFF) 3D printing, whilst rapidly processing significant volumes of fishing gear into saleable goods. As the fishing gear themselves are not going through an extruder or print nozzle, it may also be possible to utilise a wider range of fishing gear.

4.4 (FFF) 3D Printing Components to Facilitate the Assembly of Fishing Gear into Products

Where the mechanical reprocessing of fishing gear through the application of heat is not viable, due to polymer type, condition or contamination level, (FFF) 3D printing may still offer an option for converting fishing gear into saleable products, through the production of custom-components. The components, such as frames, clips or mechanisms, could be printed using high quality, off-the-shelf filaments, which would then allow the fishing gear materials to be assembled into large-scale products.

5. Conclusion

In conclusion, (FFF) 3D printing offers numerous options for the reprocessing and repurposing of fishing gear polymers into valuable products. Whilst the direct extrusion and subsequent printing of fishing gear polymers may be limited to select polymer types and those materials with the lowest levels of contamination, there exists a growing market for (FFF) 3D printing filament. This would not only utilise a high volume of fishing gear material, but also generate profits for the local community. The most problematic option appears to be the direct printing of saleable goods using filament made from fishing gear polymers, due to the limitations of (FFF) 3D printing technology, including print quality, speed and size, which reduce both the economic viability and the volume of fishing gear material able to be processed. For the fishing gear polymers unsuitable for direct (FFF) 3D printing and extrusion into filament, alternatives using injection moulding to reproduce 3D printed prototypes or 3D printers to make components that facilitate the assembly of fishing gear into valuable products, hold significant potential. Prior to any of these options being implemented, however, it is important that further testing and trials are carried out.

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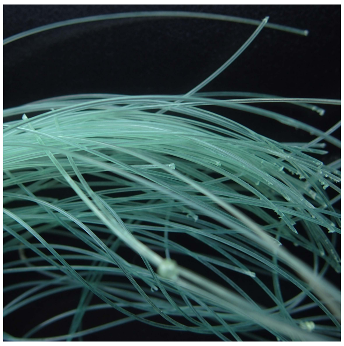
Appendix 1. Fishing Gear Samples from MCB Seafoods, Newhaven UK.

Sample 1.	
Suspected Composition:	Polyamide 6.6
Construction:	(Purse seine net) single, braided, cut lengths
Diametre:	2mm
Fibre Diametre:	~10µm
Colour/s:	Cream
Odour:	Negligable
Visible Signs of Contamination:	Areas of dark green discolouration, (possibly biofouling)
Visible Signs of Degradation:	Slight freying of fibres throughout indicating abrasion

Sample 2.	
Suspected Composition:	Polyamide 6
Construction:	(Gillnet) monofilament, knotted, 10cm (full mesh gauge)
Diametre:	0.5mm
Fibre Diametre:	0.5mm
Colour/s:	Translucent
Odour:	Negligable
Visible Signs of Contamination:	None
Visible Signs of Degradation:	Some scratches and imperfections indicating abrasion

Sample 3.	
Suspected Composition:	Polyamide 6
Construction:	(Gillnet) monofilament, knotted, cut lengths
Diametre:	1mm
Fibre Diametre:	1mm
Colour/s:	Translucent, pale green
Odour:	Negligable
Visible Signs of Contamination:	None
Visible Signs of Degradation:	None



Sample 4.	
Suspected Composition:	Polyethylene
Construction:	(Rope) single, twisted
Diametre:	8mm
Fibre Diametre:	~20µm
Colour/s:	Pale blue
Odour:	Negligable
Visible Signs of Contamination:	Areas of orange discolouration (possibly rust), significant sand and salt
Visible Signs of Degradation:	Some freying of fibres throughout indicating abrasion

Sample 5.	
Suspected Composition:	Polyethylene
Construction:	(Rope) single, braided
Diametre:	10mm
Fibre Diametre:	~20µm
Colour/s:	Blue
Odour:	Negligable
Visible Signs of Contamination:	Some sand and salt
Visible Signs of Degradation:	Slight freying of fibres throughout indicating abrasion

Sample 6.	
Suspected Composition:	Polyfoam & polyethylene
Construction:	(Float line) polyfoam core, braided
Diametre:	10mm
Fibre Diametre:	~10µm
Colour/s:	White (polyfoam core), pale green & black
Odour:	Negligable
Visible Signs of Contamination:	Slight discolouration, some sand and salt
Visible Signs of Degradation:	Significant freying of fibres throughout indicating abrasion

Sample 7.	
Suspected Composition:	Polyethylene and polyamide 6.6
Construction:	(Rope) single, twisted with a second (rope) single, braided stitched along one side
Diametre:	10mm
Fibre Diametre:	~20µm
Colour/s:	White, blue, red, orange, yellow & white (red stitching)
Odour:	Negligable
Visible Signs of Contamination:	Sand and salt present
Visible Signs of Degradation:	Slight freying of fibres throughout indicating abrasion

Sample 8.	
Suspected Composition:	Polyethylene
Construction:	(Rope) single, twisted
Diametre:	7mm
Fibre Diametre:	~20µm
Colour/s:	White, orange, blue, black
Odour:	Negligable
Visible Signs of Contamination:	Sand and salt present
Visible Signs of Degradation:	Slight freying of fibres throughout indicating abrasion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