# Material Reality to Materiality: Ocean Plastic and Design Research

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## *Introduction*

With approximately 5 to 13 million tonnes of plastic waste being deposited into the marine environment every year (Jambeck et al., 2015), oceanic plastic pollution is approaching catastrophic levels. This figure is widely used across the news media, although Jambeck et al. also state that, "[…] no rigorous estimates exist of the total amount and origin of plastic debris in the marine environment" (2015, p.768).[1] As large islands of plastic waste such as the Pacific Gyre (more commonly known as the Pacific Garbage Patch) amass through the forces of intercontinental currents (Law et al., 2010) and microscopic plastic particles enter the food chain, serious consequences on the delicate ecosystems of marine life, and ultimately human health are becoming more apparent (Wright et al., 2013). Remote beaches in the pathway of oceanic currents, such as those on the West Coast of Scotland, become repositories for discarded ocean plastic (Barnes and Milner, 2005), with only a small percentage of the total amount being usefully repurposed by locals. The rest is left to photodegenerate, breaking into ever smaller parts and being washed back into the sea or ingested by local wildlife (Seltenrich, 2015). Ocean plastic therefore represents a serious environmental threat as well as an underused material resource freely available to local populations.

In recent years, this problem has received increasing attention from the media and as a consequence has gained wider public recognition. In the UK, this increasingly applied after the broadcasting of the episode "Our Blue Planet" in 2017, which forms the final part of the BBC's popular *Blue Planet II* series (Honeyborne, 2017). Presenter Sir David Attenborough examined the effects of anthropogenic activity on the world's oceans, and reported that plastics, along with rising temperatures, were the biggest concerns currently facing the marine environment. An article featured in *The Guardian* newspaper previously reported estimates of up to 12m tons per year (Gould, 2015). As far back as 2010, an episode of BBC Radio 4's *Costing the Earth* (Roberts, 2010) provided a detailed report on the above mentioned *Pacific Gyre*. This is a mass of plastics floating on or just below the surface that has collected in the north Pacific Ocean, approximately twice the size of France (Callan, 2014), although estimates of its size vary. It is in fact one of five gyres (Cózar et al., 2014). *Costing the Earth* (Roberts,

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[1] Jambeck et al state that reports of ocean plastics started to emerge in the early 1970s with estimates of around 6million in 1975 (p.768). From this we could make a calculated guess exceeding 200million tons in total today. However, this is wildly different to other estimates of surface plastics only are much lower at 7,000 to 35,000 tons (Cozar et al, 2013, p.10239), although they say that plastic that has sunk cannot be accounted for (p.10243).

2010) reported that plastic litter on beaches has doubled since 1994. Today, there are many groups around the world trying to address the problem, with numerous attempts to retrieve plastic from the sea and coastlines, to others at reducing single use plastics and the amount of plastic entering the oceans in the first place. Environmental organisations such as *Parley for the Oceans* aim to foster public awareness and encourage a more meaningful engagement with the ecological implications of ocean plastic on a commercial level by engaging business partners such as G-Star RAW, Adidas and Stella McCartney in collaborative projects (Parley for the Oceans, 2019). While the resulting “special edition” products successfully utilise remanufactured ocean plastic as a composite material, these initiatives are often short-lived and economically unsustainable in the longer term. Individual designers such as Studio Swine, through their projects Sea Chair (Swine, 2012) and Gyrecraft (Swine, 2015) have taken a more experimental approach, by focusing on the process of directly harvesting the raw material from the sea and then devising original in-situ manufacturing approaches to create thought-provoking objects that draw attention to the underlying ecological issues.

There are multiple challenges. Retrieving marine plastic is immensely difficult: much of the plastic (up to 60%) in the ocean consists of particles less than 1mm in size (Roberts, 2010). The National Geographic (Evers, 2014) estimates that up to 70% of the plastic forming the large gyres sinks to the ocean floor: “[…] The seafloor beneath the Great Pacific Garbage Patch may also be an underwater trash heap.” Once retrieved, the plastic needs to be cleaned of salt and micro-organisms that might contaminate recycling, but even then, ocean plastic can be exposed to ultra violet light for many years and photo-degenerates. This, along with continuous contact with salt makes the ocean plastic extraordinarily plastic brittle. To enter it back into the recycling stream it requires to be mixed with other plastics retrieved through waste disposal on land and a certain percentage of virgin plastics. In 2014, trade publication *Packaging News* announced that environmentally conscious detergent brand Ecover had launched bottles made from ocean waste plastic but then states that it “…is made entirely from recycled plastic, with 10% collected from the sea.” (Corbin, 2014). This low percentage of ocean plastics is further elaborated upon by Ecover’s Philip Malmberg in an earlier article published by newspaper *The Guardian*: "It will always depend on the amount and quality of the plastic they [the fishermen] have managed to fish." (Smithers, 2013). Online technology magazine *Wired* reported that soap manufactuer Method had also used bottles made from a blend of 10% ocean plastic and 90% other recycled plastic for their packaging in 2012 (Hurst, 2012), although an earlier report claimed this would be 25% (Guevarra, 2011). Method (Method, 2015) advised that firstly this was due to the short supply of ocean plastic – it is difficult and costly to collect in the reliable quantities needed at this scale of manufacture –

and also confirmed that ocean plastic was of a lesser quality due to a combination of the photo-degeneration and salt (Method, 2015).

Given the enormity of the problem, individual attempts may seem futile, but as part of a combined global effort of activism stimulated by design research in conjunction with targeted public engagement can make an impact. We make no claim for this project to as a solution to the problem – indeed, experiencing the extent of the ocean plastic problem in remote places such as the Outer Hebrides first hand has emphasised to this team of researchers that individuals can only have a relatively limited impact on the conversations that need to be had in order to generate a meaningful solution. It is a small gesture intended to bring further understanding to the wider public.

### *Objectives of the Research*

So far, the difficulties inherent in obtaining and working with ocean plastic have prevented a comprehensive engagement with this material in a larger context. The concept of ocean plastic as a viable material for design, manufacturing, remanufacturing and recycling has not been explored to its fullest degree. Conventional methods of recycling, such as industrial remanufacturing or depolymerisation, are currently unviable both economically and from an environmental point of view, mostly due to the cost of collecting and transporting ocean plastic to centralised industrial facilities and quality issues connected to foreign particle contaminants having entered the plastic during its lifecycle. Ocean plastic therefore represents a serious environmental threat as well as an underused material resource freely available to local populations. Applying a systemic approach to this circular process allows locals to experiment with materials and processes and discover novel ways to repair, repurpose and remake objects from ocean plastic, encouraging skill sharing and community education. As 3D printing is gaining ground both in popularity as well as general availability, exploring strategies for remanufacturing ocean plastic into 3D printing filament suitable for FDM printers was specified as an intended outcome of the project.

At the core of this research was fieldwork involving site visits to locations on the Isle of Harris, where nautical currents have turned local beaches and secluded bays into large ocean plastic 'repositories', spread over a period of six months. More specifically, the coastal areas on the West of the Isle of Harris were targeted for their potential to attract large amounts of ocean plastic predicted by marine surface modelling (Sherman and van Sebille, 2016). The site visits were conducted in August and March, enabling the observation of the effects harsh winter weather has on plastic distribution and accumulation in the chosen locations. The weather during our second trip in March was too inclement to consider a repeat visit to the Islet of Scarp, but data from a previous site visit in 2015 nevertheless provided a basis for comparison.

Each site visit involved scoping and documenting what ocean plastics are available by collecting a range of samples from different locations, including those that are only accessible by boat. Small samples of those plastics identified as viable for remanufacturing were brought back to the Edinburgh Napier University Polymer lab to be analysed and evaluated for quality. This involved exploring how they could be cleaned, pelletised, desiccated and subsequently remanufactured into 3D-printing filament for use in FDM 3D-printers.

At the end of the project, educational workshops held at two local high schools and at the bi-annual Research Through Design Conference served to share the material knowledge developed during this project, providing pathways to feed research findings directly into secondary education and to specialist, informed, audiences.

### *Location of the Research*

Following an initial visit to the Isle of Harris in the outer Hebrides on the West Coast of Scotland by one of the researchers in 2015, the Islet of Scarp was identified by the research team as a location of interest to the project with a very high concentration of plastic waste being washed up on the SouthWest facing beaches of the Islet, particularly the Mol Mor inlet (Figs. 1&2). By consulting the oceanic current models developed by (Maximenko et al., 2012), (Lebreton et al., 2012) and (Sherman and van Sebille, 2016), the team extrapolated that the likelihood of beaches with a West or South-Westerly orientation on the West Side of the island to contain significant accumulations of Ocean

Plastic was greater than of those with a Northern orientation, or those on the East side that face the Scottish mainland. In this respect, the research undertaken by (Neumann et al., 2014), while not directly focusing on the beaches of Scotland, offers an excellent visualisation of the types of oceanic currents that may affect exposed areas situated in the Northern hemisphere. The multitude of small inlets situated along the coastal landscape of the Isle of Harris, some of which culminate in substantial sea lochs, provide a comb-like structure that traps marine debris amongst the rocks of Harris' dramatic coastline. Anecdotal evidence gathered during the two field trips from local populations suggests that many of these marine debris deposits exist in remote and practically inaccessible locations of outstanding natural beauty. It is the peculiar irony of the Anthropocene that geographical areas mostly untouched by human presence are amongst the worst affected by marine debris.

## *Fieldwork and Initial Findings*

After receiving funding from the Carnegie Trust for the Scottish Universities in 2018, a team of researchers travelled to the Isle of Harris in the last week of August 2018 for a seven day field trip (Fig. 3). Documentary filmmaker Dr Diane MacLean accompanied the team on this field trip in order to facilitate interactions with local populations known to her from previous visits to the area that formed part of her extensive doctoral research on the oral histories of the Islet of Scarp (MacLean, 2014). The following objectives were identified by the team prior to commencing the fieldwork:

- Revisiting the Mol Mor on the Islet of Scarp to investigate whether there had been significant change in the accumulation of Ocean Plastic debris since the first visit in 2015.
- Surveying the area around Scarp for further significant accumulations of Ocean Plastic debris. This included gaining access to more remote locations, particularly the sea lochs north of Scarp, by liaising with local farmers and fishermen.
- Surveying several beaches along the South West coast of the Isle of Harris to assess whether Ocean Plastic Debris is present. Beaches that were targeted included those located around Hushinish, Gobhaig, Borve and Rodel.
- Visiting the two secondary schools (Sir E. Scott School in Tarbert on the Isle of Harris, and Mallaig High school on the West Coast) that were previously identified as locations for conducting public engagement workshops.

On visiting the targeted locations, the team decided to collect a representative selection of Ocean Plastic samples to analyse and experiment with in the Polymer Laboratory located at Edinburgh Napier University. The samples collected ranged in size between 2 and 40cm, and included broken parts as well as whole objects. The team aimed to gather as wide a variety of plastics as possible. Despite the existence of the polymer recycling code system, most plastics that have been through the rugged environment of stormy seas and rock-strewn coast lines, were found not to contain such hints to their material origins, so the team used their own judgement in selecting the samples. Another criterion in selecting the samples was to pick those with an attractive array of colours, as the intention to eventually turn them into 3D-printing filament added the consideration of an aesthetic element. The use of photography as a research method was employed extensively, both in recording the location of Ocean Plastic samples, the environmental issues that were witnessed and later as a tool for in depth analysis in the laboratory.

The Islet of Scarp is only accessible by boat, and the team's first attempt to cross the short distance between the pier at Hushinish and the landing on Scarp was foiled by an increasing swell of the sea. Scarp has not been permanently inhabited since the 1970s (MacLean, 2014), and the only human presence on the Islet is contained within a few cottages on the site of the old village during the summer months. There are no footpaths on Scarp, and the Mol Mor beach is only accessible by scaling a steep hill and subsequently descending through marshland towards the rugged coastline. Even as high as halfway up this hill, evidence of marine debris could be detected, possibly deposited there during the stormy winter months. If this debris is left undisturbed, it gradually degenerates, slowly sinking into the fabric of the boggy landscape. This is a phenomenon we witnessed at multiple locations (Figs. 4&5) and is one of the most insidious environmental issues to be tackled. Once the plastic debris is thus embedded in the landscape, it becomes incredibly difficult to remove and needs to be extracted manually, piece by piece. Furthermore, as harsh environmental conditions deposit soil, stones or sand on top of the embedded debris, strata of plastic waste are formed and become a fossilised element in the landscape. We witnessed such stratification on the cove-like beach at the small hamlet of Gobhaig (Fig. 6), where locals had reportedly been observing this process since the 1980s. These direct observations confirm the model of marine plastic pathways proposed by (Critchell and Lambrechts, 2016), and worryingly point to the eventual degradation of these stratified layers into microplastics that finally enter the water table and food chain.

Reaching the Mol Mor beach itself was an eye-opening experience for the team. The beach is completely covered in large quantities of marine plastic debris as far as the eye can see. A recent drive by the local community to gather the ocean plastic was still evidenced by large white bags, filled to the brim with plastic objects and awaiting collection (Figs. 7&8). However, it is currently unclear when such a collection might take place, as the beach is not easily accessible even from the water and needs to be landed on with a dinghy. Despite a tentative agreement having been formed between local pressure groups and the fishing industry to undertake this arduous task, it depends entirely on the goodwill of individual companies. We saw similar large bags of collected ocean plastics in several other beach locations on the Isle of Harris, but as of our last visit in March 2019 they had been untouched. Images of the beaches strewn with larger objects may elicit a more sensational response from viewers, but these are in fact easier to collect. The bigger problem by far are the smaller fragments embedded in the rotting seaweed, sand, earth and under rocks and stones (Fig. 9). These are more difficult to collect and are the types of items inadvertently eaten by sea creatures, through which they enter the human food chain and also kill birds and mammals (Furness, 1985, Moore, 2008). Collecting plastic washed up on beaches is one place to start; however, plastic debris that comes ashore can easily be taken back by the sea during the stormy winter season.

Visiting a location like the Mol Mor really emphasises the scale and materiality of the global ocean plastic problem. The objects we saw included those from a domestic environment (bathroom fixtures, shoes, brushes, broomheads, plastic bottles and bags), as well as those clearly related to the maritime industries (including fish farms) and nautical activities (crates, wellingtons, buoys, packaging materials, parts of fishing implements, different kinds of rope) (Fig.10). The latter category forms the majority of the waste we discovered on the beaches of the Isle of Harris, and suggests that a more holistic approach including close involvement of global maritime and nautical industries and central government is required to even begin addressing the problem of ocean plastic. Some of the plastic objects found intact on these beaches, such as PVC pipes, undamaged fishing nets, tubs, crates, buckets and lengths of rope may be reclaimed by local populations to reuse, but the majority of the plastics we saw was in fragments. One local resident explained that the variety of objects coming ashore on one beach had in fact declined since the mid-1990s. This coincided, she believed, with the time that New York had stopped dumping its rubbish in the sea (MacLean and Lambert, 2015). Nevertheless, there was still a vast array of objects and many different types of plastic were initially identified: PVC, PP, HDPE, LDPE, PET, PS, nylon, rubber, acrylic. Subsequent, more detailed, analysis in the laboratory confirmed these findings, but suggested that the plastics most plentiful in the visited locations were in fact HDPE, PP, Nylon and PS.

### *Material Reality to Materiality*

Following our initial site visits, the plastic samples the team had gathered were taken to the Edinburgh Napier Polymer Laboratory and analysed in detail by a research assistant with a materials science background, using an infrared spectrometer and differential scanning calorimeter to measure melt flow index and thermal behaviours. Utilising the expertise of someone with a scientific background in the context of collaborative design research is a cornerstone of the methodology proposed by (Miodownik, 2003), and later expanded upon in the context of contemporary craft (Vones, 2013, Vones, 2017), as it emphasises the interplay and amalgamation of fundamentally different perspectives on the nature of materiality. In this case, the technical data gathered during the initial analysis provided a basis for comparing variations in the remanufactured filament in terms of strength, printability and melt-flow. After initial discussions, it was also decided that following scientific protocol in recording the samples before remanufacturing them into 3D printing filament would be beneficial for later-stage analysis. Thus, each sample was photographed in a studio environment from above, using a ruler (cm) as an indicator of scale. A full frame 35mm DSLR (Canon 5D MkII) was used in conjunction with two lenses: the Canon EF 50mm F2.5 Macro for small to medium sized samples, and the Canon EF 24-70mm F4 L IS for larger samples. Additionally, some samples were selected to be photographed using a high-magnification macro lens (Canon MP-E Macro 65mm F2.8), which enabled images of the surface textures of the plastic to be taken at a magnification factor of between x3-x5. Each sample examined in this way was photographed using the focus stacking method, to produce an image that provides maximum magnification and depth of field. The resulting close visual examination of the surface qualities of ocean plastic gives a fascinating insight into the material and biological realities encountered in the field. In addition to the expected discolouration and scratch marks left by environmental conditions, the surface of some of the PP samples examined appears to disintegrate into small scales, that trap dirt beneath them and in time crumble away from the surface to become insidious microplastic particles (Biber, 2016) (Figs. 10&11). The HDPE samples on the other hand seemed to attract increasing colonisation with marine organisms, which could point to consequences for the wider ecology in terms of species migration (Barnes and Milner, 2005) (Figs 12&13). This is an area of great interest and warrants further investigation.

In terms of processing the ocean plastic samples for remanufacturing, the observed surface qualities had a similar impact, namely that of making the cleaning process and removal of foreign matter increasingly difficult. Despite concerted efforts by the research assistant to remove as many contaminants as possible, some remained and were inadvertently included as small particles within the finished Ocean Plastic Filament. It is important to note that the finished filament also retained a strong aroma of the sea, despite having been through a high-temperature extrusion process. This points to the inclusion of contaminants at a molecular level, which would be impossible to remove without further elaborate processing. However, during the public engagement activities that were conducted by the team, this smell was generally received positively and served as a reminder of the historical origins of the material. After vigorous cleaning, the samples were granulated and mixed by weight with virgin PLA to different ratios between 50-60% of ocean plastic (HDPE and PP). PLA was chosen as a carrier material as it is a bioplastic and can be composted in industrial facilities (Ebnesajjad, 2013), thus increasing the end-of-life options of the new material. The extrusion process was undertaken with an industrial single-screw extruder, culminating in a water band cooling track and filament winder. The process was subsequently also trialled with a small ‘enthusiast’-level single-screw extruder (Noztek) and filament winder (V1.0), with promising results. This type of equipment might be reasonably found in a well-equipped local maker space, and opensource initiatives such as Precious Plastic even supply plans to build shredders and extruders to adventurous makers (Precious Plastic, 2019). The diameter chosen for the filament was 1.75mm, as it is easier to extrude within tight tolerance than the other commonly used type at 2.85mm. Over the course of four sessions, seven rolls of filament were produced from approximately ten of the samples.

### *Workshops*

Three short workshops were undertaken, two with year 9 and year 10 schoolchildren in group-sizes of around 8 to 10 participants (Sir E. Scott School in Tarbert on the Isle of Harris, and Mallaig High school on the West Coast), and one as part of a research workshop at an academic conference. The two workshops with schools, both in remote locations situated on an affected coastline, served to introduce the children to the idea that the ocean plastic coming ashore locally had potential value as a material that can be reprocessed for making new things. Using an enthusiast-level single screw extruder, they were shown how granulated ocean plastic (PP), when mixed 50:50 with PLA, can be extruded into 3D printing filament, and then used to print a small scale 3D map of the area where they lived (Fig. 14). The children also had the opportunity to play with 3D printing pens to help understand the principles of the process. Each workshop was followed by a public lecture in the evening, attracting surprisingly healthy numbers of local residents despite inclement weather. The Q&A at the end on both evenings gave rise to lively discussions that revealed useful local knowledge and insight into the problem, with many using personal evidence to point the finger at marine industries and particularly fish farms.

The third workshop took place at the 2019 Research Through Design conference at the Delft University of Technology (TU Delft), having been accepted in a competitive peer-reviewed call for pre-conference research workshop proposals. With six participants, including research students and experienced academics, we were able to make use of TU Delft's Makerspace to granulate polypropylene rope, and form extrusions using granulated blue polypropylene and white PLA. The filament emerged with variations in the weighting of colour (Figs. 15&16), probably because of the larger diameter (2.85mm) that was required for the University's 3D printers.

As a group, it was decided to design and print simple rings. The reason for this was, firstly, that these were small and easy objects to design and print, and second, as jewellery they symbolised the value of returning a difficult to retrieve material into the commodity chain. The resulting rings emerged in a semi-translucent colour that had an uncanny resemblance to aquamarine blue, and these were gifted to any delegates throughout the conference. Some of the designs the participants created had symbols of the sea on them (waves, swirls) while other, such as the "26.8kg ring", embedded a more conceptual narrative based on the amount of plastic each person in the world (7.6bn at the time of the workshop) would have to collect in order to retrieve all of the plastic estimated to have entered the ocean in the last 25 years (Fig.17). The key learning outcomes of the workshops came from the physical demonstration of the transformation of materials, the tactility of the resultant objects, as well as the discussion and creative enquiry throughout. For example, to know that approximately half of the material in the rings, printed there and then, had just a few days before been plastic debris on a beach added a new dimension of appreciation, which resonated strongly with sustainable design narratives.

### *Conclusion*

The problem of ocean plastic is enormous. It has to be addressed through combined activism and the passing of strict international laws. Plastic is a very useful material, but the approaching Anthropocene Epoch needs to see a dramatic reduction in its feckless use and reserve it for essential applications. The project has given rise to new insights into the potential and challenges of working with ocean plastic as a material for practice-led design. We have shifted from a position of optimism following early encounters with large amounts of seemingly useable material, to a degree of pessimism as the growing impossibility for humankind and nature to address this challenge unfolds. Furthermore, the process we are exploring is currently limited by the need to mix different plastic types (i.e. PP and PLA). Mixing of materials is taking one step backwards to take two steps forward.

We also acknowledge that 3D printing does not currently afford opportunities to utilise large amounts of the material. When considering economies of scale in terms of the amounts of plastics used by a single process, our efforts could be more effectively deployed in exploring other manufacturing technologies such as DIY off-grid injection moulding (Lambert, 2017).

However, while our contribution as design researchers and makers is a miniscule dent in the problem, but nevertheless allowed us to engage with local communities and fellow researchers to discuss the problem, share knowledge and demonstrate the potential of ocean plastic as a viable material for remanufacturing. This contribution should not be underestimated in terms of reframing the narratives surrounding waste materials and developing novel strategies for stimulating wider, more meaningful, public debate. As a growing number of design researchers focus their efforts in this area, the diversity of public engagement approaches multiplies accordingly. Speaking about her own research of tasking care home residents with remaking plastic and textiles waste into objects of personal significance, Julie Behseta rightly concludes that:

"...the ethics and aesthetics of sustainability must include recycling as a symbolic and poetic statement about the re-evaluation of the role of empathy and relationality. […] The aesthetics of the process of use and reuse are celebrated here as a means to enable us to reconsider the meaning of 'care'. This is no longer a matter of sentimentality […] but is now an essential and integral element of a global and industrial agenda for sustainable manufacture." (Behseta, 2013) p.144

Our changing relationship with the natural environment, in light of current material realities, necessitates assuming increasing ethical and personal responsibilities as both design researchers and human beings who care for this planet in crisis. To promote an ethos of custodianship within affected communities through exploring how the altered materiality of remanufactured ocean plastic can be used to communicate wider environmental issues has been the focal point of this research project.

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