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Business support – Case study 3DPW Limited

Redesigning products with recycled plastic feedstock

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As part of the TRANSFORM-CE project, several case studies will be done to assess the conditions that foster the uptake of recycled plastic feedstock in (new) products. This document covers the results of the case study at 3DPW Limited, based in Bradford, UK. A total of 20 case studies will be done, each representing one product to be (re)designed with recycled plastic. In depth support will be given to five cases per country (The Netherlands, Germany, Belgium, and the United Kingdom).

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Deliverable	WPT3 D3.4	Redesigned products with AM
	WPT3 D3.5	Redesigned products with IEM
	WPT3 D3.7	Redefining Circular Economy business models

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Table of contents

1. Introduction and method

1.1 Goal of case study

TRANSFORM-CE is an international research project about the uptake of recycled single use plastic (SUP) feedstock. A core part of this project is to provide in-depth business support to businesses willing to use recycled plastic materials in (new) products. The uptake of SUPs implies that companies in the plastic industry must make a major transformation. In order to gain a better understanding of the support required for the wider uptake of recycled plastics (such as SUP) by companies, 20 different case studies will be completed, documenting the conditions that foster the uptake of recycled feedstock. In line with the technologies of the pilot plants from the TRANSFORM-CE project, cases will represent either IEM[1] technology or AM[2] technology.

Thus, the aim of these case studies is twofold; 1) to support the case study company with their specific request to help foster the uptake of recycled plastic feedstock into one of the company's products, and 2) to gather insights into the conditions necessary to support the wider uptake of recycled plastics by using IEM and AM technologies. The case studies also present a unique opportunity to study the technical requirements for (re)designing products with IEM and AM. The learnings of the various cases and (re)designed products could serve as a proof of concept that provides the entire value chain with the insight and confidence to uptake recycled feedstock, creating circular economy opportunities for all stakeholders.

1.2 Case study process

The case studies are being carried out between September 2021 and December 2022. The case study process is structured in four steps[3], with an iterative approach at the end of each step. The first step (*initial diagnostic*) aims to establish a starting point and describes the challenge to be addressed. The second step (*circular product development*) captures basic information about the product (re)design and describes prototyping and testing leveraging IEM and/or AM technologies. The third step (*circular product management*) covers how to commercialise the new (or redesigned) product and describes the product's relevance for business and environment, creating a successful circular business model. The last step involves a wrap-up of the results and concludes with

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[1] IEM: Intrusion-Extrusion Moulding (for low(er) value recycled material), a combination of two techniques to produce plastic products/components. With extrusion the polymer is being melted, thereafter the polymer is being forced into a shape (by using a mould).

[2] AM: Additive Manufacturing (for high(er) value recycled material), method of creating objects layer by layer according to a digital design.

[3] This work uses insights derived from other activities of TRANSFORM-CE, in particular the case study method of WPT3 D2.1: *Case study methodology - Researching good practices of circular economy business models.*

strengths of the redefined business model, an overview of the barriers and enablers for circularity, and learned lessons from the case study. The final result is a case study report, covering the previously established information.

The total case study can be seen as a package of business support (all steps). Yet, a specific type of 'in-depth support', chosen from the menu-card[4], will be done for each case study. This support differs from company to company and will be selected based on a first analysis of the case. Examples of in-depth support include material testing, prototyping and production trials, implementation of technology and use of recycled filament.

An overview of the case study analysis process is shown in figure 1 on the next page. In order to obtain the results, a 'collaborative/participative' assessment is used to collect further information, which gives insights in the overall innovation process. At the end of the case study, an iteration will be done to validate the results. The reported results will be sent to the contact person by email, so this person can validate the results and check if something is still missing or if information has been misinterpreted. Any comments will be processed, and the results will be adjusted accordingly. Table 1 gives an overview of the people that have been interviewed during the case study.

Table 1: *Overview of interviewed people*

	Interviewed person	**Function**
Step 1: Initial diagnostic	Narinder Kumar	Director
Step 2: Circular product development	Narinder Kumar	Director
Step 3: Circular product management	Narinder Kumar	Director

[4] An extensive list of the support possibilities is presented in a separate document '*Transform-CE support Summary*', describing the menu-card.

Step 1. Initial Diagnostic

- First assessment of company
- Establish starting point
- Describe challenge to be addressed
- State project goal

Step 2. Circular Product Development

- Describe product to be (re)designed
- Assess context in which product will be produced, used and marketed
- Design product
- Describe product’s relevance for business and environment
- Create successful circular business model
- Prototyping and testing leveraging IEM and/or AM technologies

Step 3. Conclusion

- Wrap-up of results
- Strengths of redefined business model
- Summarise barriers and enablers for circularity
- Describe learned lessons

Report

- Succinct, yet informative case study report
- Excellent exposure opportunities for business

Figure 1: *Overview of case study process*

2. Step 1 – Initial diagnostic

The first step focusses on an initial diagnostic of the case study, which includes outlining the company profile, its wishes and the project goal.

2.1 Company profile

3DPW Limited is a start-up SME based in Bradford, UK, who offer a waste collection and recycling service to organisations that operate fused filament fabrication (FFF) 3D printers on their premises. A short overview of 3DPW Limited is given in table 2.**Error! Reference source not found.**

Table 2: *Overview of company*

Topic	Information
Company name	3DPW Limited
Website	https://3dprintingwaste.co.uk/
Country	UK
Size of company (0-10, 10-200, 200-500, 500+ employees)	0-10
Mission/vision	3DPW Limited offers viable end-of-life solutions for 3D-printed waste that is not currently recycled or reused, thus preventing further plastic pollution of land and marine environments. 3DPW Limited seek to disrupt existing manufacturing waste management by curating a scalable Circular Economy business model which will design out waste and utilise previously non-recycled resources as high-value input material for various industries and markets, giving plastic waste a new life.
Value proposition	3DPW Limited offer an affordable and convenient waste collection and recycling service to organisations that operate fused filament fabrication (FFF) 3D printers on their premises.
Main activity	3DPW Limited enlists the services of several 3rd party companies for the distribution, recycling, and manufacturing aspects of their business model. As such, its key activity is the coordination of waste collection from its customers and distribution of these materials to 3rd party companies, as well as material testing.

2.2 Current situation & challenge

3DPW Limited provides a tailored service that collects and recycles FFF (fused filament fabrication) waste that is generated through the use of 3D printers. 3DPW Limited acknowledge that 3D printing is a double-edged sword. Whilst fundamentally additive, the use of plastic as a feedstock could exacerbate the plastic problem without efficient resource recovery.

The company collects the waste from various customers ranging from dedicated 3D printing service providers to schools, universities, and other organisations. The resultant recycled granulated material is then sold onto manufacturers and injection moulding firms as a sustainable feedstock, which will be turned into a variety of products and sold onto end users.

In addition, 3DPW Limited also commission the injection moulding of a range of in-house products, such as plant pots and hanging baskets, which they sell onto retailers (B2B) and directly to end users (B2C).

Whilst 3DPW Limited acknowledge that the use of the recycled granulated material does improve the circularity of manufacturing system that takes it up as feedstock, it does not contribute to closing the loop on the initial 3D printing system. Indeed, 3D printing is often reliant on sourcing input materials (i.e., filament) from other value chains.

To close the loop, 3DPW Limited wanted to explore the idea of turning the 3D printed waste back into 3D printing filament, thus potentially recirculating the materials within the same system. 3DPW Limited also wanted to explore the expansion of their service beyond just PLA, to also include ABS and PETg. This poses several challenges with regards to recycling efficiency (the ease at which the waste can be turned into filament), printing efficiency (how well the recycled filament prints), and number of possible cycles (how many times the material can be recycled in this way).

Description of support

The support provided centred around a feasibility study. Answering the question; could the collected 3D-printed waste (PLA, ABS and PETg) be processed in a way that produces usable recycled 3D printing filament.

Utilising AM technology, samples of granulated waste received from 3DPW Limited were processed (including drying, shredding, and blending) and then extruded to make new filament (with no formula changes). The recycled filaments were then subjected to test prints (in combination with FFF 3D Printers) to assess printing efficiency.

3. Step 2 – Circular product development

After creating a first analysis of the company and project, a more detailed assessment of the (re)designed product is made. This includes basic information about the product and an assessment of the context in which the product will be produced and used, as well as an analysis of the circularity of the product. Moreover, a more detailed design of the product is created, which goes hand in hand with prototyping & testing.

3.1 Circular product canvas

The new (or redesigned) product is investigated by using a circular product canvas (CPC). This model is created for the purpose of this study and covers the main aspects to consider in circular product design. The CPC of 3DPW Limited is visible in figure 2 and a description of each element is given below.

RESOURCES & MATERIALS

- Waste 3D printing filament (PLA, ABS & PETg)
- Sourced from existing customers.
- Collection and transport via 3rd party companies.

CIRCULARITY OF PRODUCT

- Recycled materials
- Maintains the original value of waste materials rather than downcycling.
- Renewable materials

PRODUCT

- Recycled 3D printing filament (rPLA, rABS, & rPEtg)
- Can be used in FFF 3D printing.
- Presented on a reusable paperboard spool
- No additives or formula changes.

BUSINESS & PRODUCT VALUE

- Closing the loop.
- Utilising waste materials.
- Maintains the value of the material.
- Replaces virgin material use.
- Short supply chains, less transportation required.

TOOLS & TECHNOLOGY

- Final product will be made and utilised using AM technology.
- Shredder
- Extruder
- 3D printer (FFF)

REQUIREMENTS

- Use waste 3D printing filament.
- No formula changes
- Withstand the shredding and extrusion processes.

REGULATIONS & COMPLIANCE

- Final product will adhere with requirements to achieve CE / UKCA marking
- ‘Key Enabling Technology’

Figure 2: *CPC of recycled filament for 3D printing for 3DPW Limited*

Product
The final product will be a range of recycled 3D printing filament. 3D printing, also referred to as 'additive manufacturing', is a process whereby objects are created through the gradual layering of material, one after another. This is in contrast to subtractive manufacturing, where an object is cut, carved, or milled from a solid block of material.

One particular form of 3D printing, fused filament fabrication (FFF), involves heating a long strand of thermoplastic or 'filament' through a nozzle. The nozzle then traces each layer of an object, dispensing the melted thermoplastic, which becomes solid as it cools. This allows each layer to be laid one on top of another, as the printing bed is gradually lowered. As such the recycled filament should be shown to effectively and consistency provide a good quality print.

A variety of thermoplastic filaments are used in FFF 3D printing. The most common of these tend to be PLA (polylactic acid) and ABS (acrylonitrile butadiene styrene), as they are easy to print with and produce reliable and consistent results. Additional materials include PETg (polyethylene terephthalate glycol), PC (polycarbonate), PA (nylon) and ASA (acrylonitrile styrene acrylate). Currently, 3DPW Limited focuses on the collection and recycling of PLA. This exploratory study focuses on the recycling of PLA, ABS and PETg.

Demonstrators of the recycled filament produced through this project will be presented on cardboard spools, which are durable and can be reused many times.

Resources & materials
The final product will make use of the 3D-printed waste generated by existing clients of 3DPW Limited. Clients include organisations that operate FFF 3D printers on their premises, ranging from dedicated 3D printing service providers to schools, universities, and other organisations.

The waste material collected include 3D-printed ABS, PETg and PLA filament from failed prints, off-prints, and other discarded parts (such as supports).

While 3DPW Limited coordinate the collection of the 3D-printed waste from its clients, it also enlists the services of several 3rd party companies for the distribution, recycling, and manufacturing aspects of their business model.

Tools & technology
The final product will be produced using AM technologies. In the feasibility study, tools used to produce and test the recycled filaments included shredders, extruders and FFF 3D printers.

To launch the final product, 3DPW Limited will have to invest in the technology to complete these stages in-house or enlist the services of a 3rd party company.

To increase circularity, mechanisms should be explored that give the generators of the original 3D-prionted waste could access to the new recycled filament, e.g., loyalty club, priority access, etc.

Circularity of the product

3DPW Limited provide a mechanism in which 3D-printed waste is collected from the companies that generate it, and then transported to 3rd party companies for processing. The collected waste materials are sorted, granulated, and sold to companies that would then use the recycled material as a feedstock in their own product manufacturing processes. 3DPW Limited also commission the use of the recycled material in product manufacture, which includes a range of in-house products, such as plant pots and hanging baskets, which are injected moulded by 3rd party suppliers then sold onto retailers (B2B) and directly to end users (B2C).

This study has explored the feasibility of recycling the 3D-printed waste back into 3D print filament, which could then be used by the clients that generated the waste in the first place, closing the loop by maintain the value of the material and reducing the amount of filament needed that is sourced from other production system and may well contain virgin and/or non-renewable resources.

3DPW Limited currently focuses on the collection and processing of waste PLA. PLA is a particularly popular material used in FFF 3D printing, it is a bioplastic derived from starch (renewable material) which is recyclable and will biodegrade under certain conditions (industrially compostable under specific humidity, temperature, and microbial conditions). Collection and industrial composting infrastructure in the UK is currently limited and therefore the quantity of PLA waste industrially composted is low. By providing a system where waste PLA can be collected, processed, and recycled, 3DPW Limited has created an efficient disposal route for PLA and in processing and granulating the material will also increase its lifespan.

Requirements

The final product must be suitable for use as a 3D printing filament, where it would be use in conjunction with a FFF 3D printer to create prints of a suitable quality. FFF 3D printing involves heating a long strand of filament through a nozzle. The nozzle then traces each layer of an object, dispensing the melted thermoplastic, which becomes solid as it cools. This allows each layer to be laid one on top of another, as the printing bed is gradually lowered. As such the recycled filament should be shown to effectively and consistency provide a good quality print. No specialist knowledge is required for users, although experience of using 3D printing would be advantageous.

To create and test the filaments, AM technology has been used, namely an extruder and FFF 3D printer. The feedstock used to create the test filaments were high-quality recyclates, PLA, ABS and PEtg (made available from granulated 3D printed waste). No formula changes or additives will be added to the recycled material.

Business and product value

The final product will take 3D printed waste (PLA, ABS or PETg) collected from various customers, ranging from dedicated 3D printing service providers to schools, universities, and other organisations, and process the material back into 3D printing filament for utilisation by the same customers. This would improve circularity by maintaining the value of the waste material (rather than downcycling the material for use as feedstock in injection moulding production systems) and also provide a recycled product for the customers to use. Any waste generated by this second round of printing can again be put back through the recycling process to gain another lifecycle.

The company could generate revenue through this, either by selling the recycled filament separately or by including the returned filament within an upgraded service plan provided to its customers.

Regulations and compliance

Currently any product sold in the UK and Europe must adhere with UKCA / CE requirements, respectively. In technical terms, the differences between the requirements for CE marking and for UKCA marking are slight. Products which meet the technical requirements for one will mostly meet the requirements for the other for the foreseeable future. Most of the differences between the two systems are administrative in nature and reflect the fact that the UKCA mark only applies in Great Britain (England, Scotland, and Wales only, products sold in Northern Ireland must conform with CE marking).

Additive manufacturing (including 3D printing) is known as a 'Key Enabling Technology' for research and innovation by the European Commission. Strategies such as the 'Re-Finding industry: Defining innovation' are keen to make sure that the uptake of AM optimises processes so that products have no defects, waste is avoided, and industrial pollution, material consumption and energy use are all reduced (European Commission, 2018). As such, it is likely that the uptake of AM technologies will increase in the future and with it the generation of 3D printed waste and the need for sustainable 3D printing filament.

3.2 Design, prototyping & testing

3DPW Limited met with representatives from MMU PrintCity to discuss ways in which their operation could be made more circular. One option that 3DPW Limited were keen to explore was the possibility of producing recycled 3D printing filament from the 3D printing waste, rather than granulating the waste for use in IEM production systems (effectively downcycling the material). It was agreed that using the AM technology available at the R&D centre (PrintCity), MMU would test the possibility of recycling the 3D printing waste into new filament.

MMU received samples of granulated waste from 3DPW Limited, which included of PLA (red and white), ABS (blue and white) and PETg (white).

Upon receipt of the sample materials, pre-processing steps included drying the materials to remove moisture and improve consistency (length of time and temperature for each waste stream given in Table 3), shredding the materials to achieve uniform size and shape, and where appropriate, blending a mix of materials, for example, blue and white ABS was mixed to create the final-coloured spool. Observations made during the drying, shredding, and blending process are noted in Table 3.

Next, the shredded material was extruded to produce the new filament (length of time and temperature for each waste stream given in Table 3). It is noted at this point that no formula changes or additives were included during the processing steps, as such the final filament contained only what had been included in the clean sample provided and should exhibit the same characteristics and properties of the original material. Observations made during the extrusion process are noted in Table 3.

Table 3: *Observations made during the processing (drying, shredding, blending and extrusion) of granulated 3D printing waste.*

	rPLA (White)	rPLA (Red)	rABS (Blue)	rPETg (White)
Condition of material received.	Parts sometimes a bit too big for the shredder.	Fairly uniform in colour	Mixed blue and white ABS – combined well to create a large, finished spool.	All white.
Drying or other pre-processing				
	2.5 hours @ 85°C	2.5 hours @ 85°C	1 hour @ 100°C	2.5 hours @ 85°C
	Smallest amounts of deterioration detected. Use weight to determine how much moisture has been removed.			Amorphous material. Softens before it melts. Extrudes before fully melted, don't want it too runny for filament.
Shredding / Blending				
			1-3 mm sized pieces mixed together. Poured into tray and then into hopper to help blend.	
Extrusion				
	Approx. 2 hours @ 195°C	195°C	210°C	235°C
	100% infill not used on print settings – hollow / light pieces can be problematic for the hopper on extruder.			
	Attention required to prevent bridging in the hopper -> less time for checking diameter.	-	-	-
	Some industrial extruders have vibrating hoppers to enable constant extrusion. Quite a slow extruder (1-3kg/hr). No additional heat applied.			

The extruded recycled filament was then collected on spools (Figure 3). In this instance, reusable paperboard spools were used.

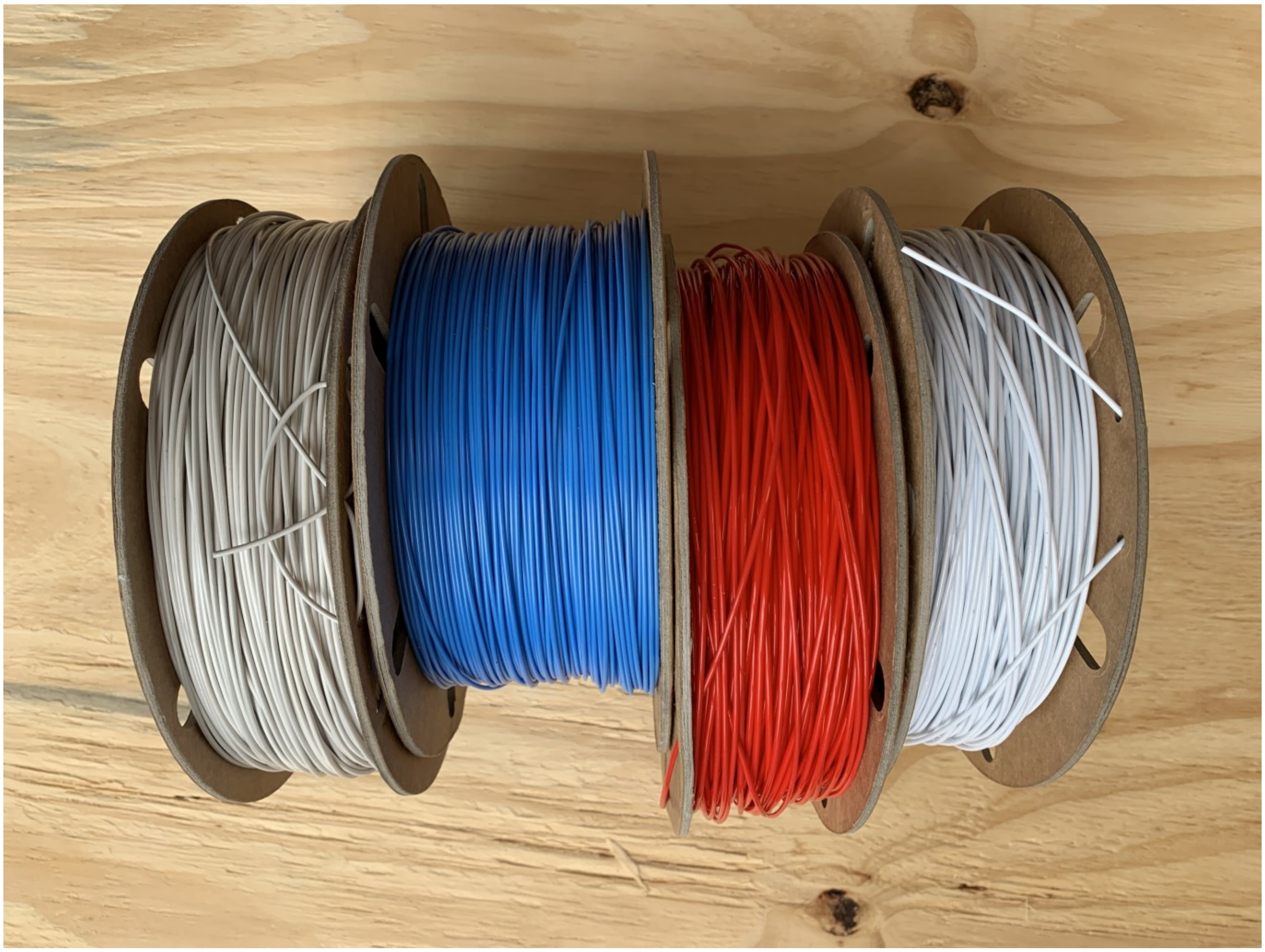

Figure 3: *Spools of recycled 3D printing filament made via extrusion processes using 3D printing waste.*

To ensure that the recycled filaments were suitable as filaments for 3D printing, they were then subjected to test prints to assess printing efficiency. To test the accuracy of the filament, a 3D computer model of a highland cow was used as a basis for the test prints (open access file available at: https://www.thingiverse.com/thing:5417799). When used in conjunction with the FFF 3D printers available at PrintCity, the recycled filaments were shown to print successfully (as shown in Figure 4), with no issues reported by the technicians.

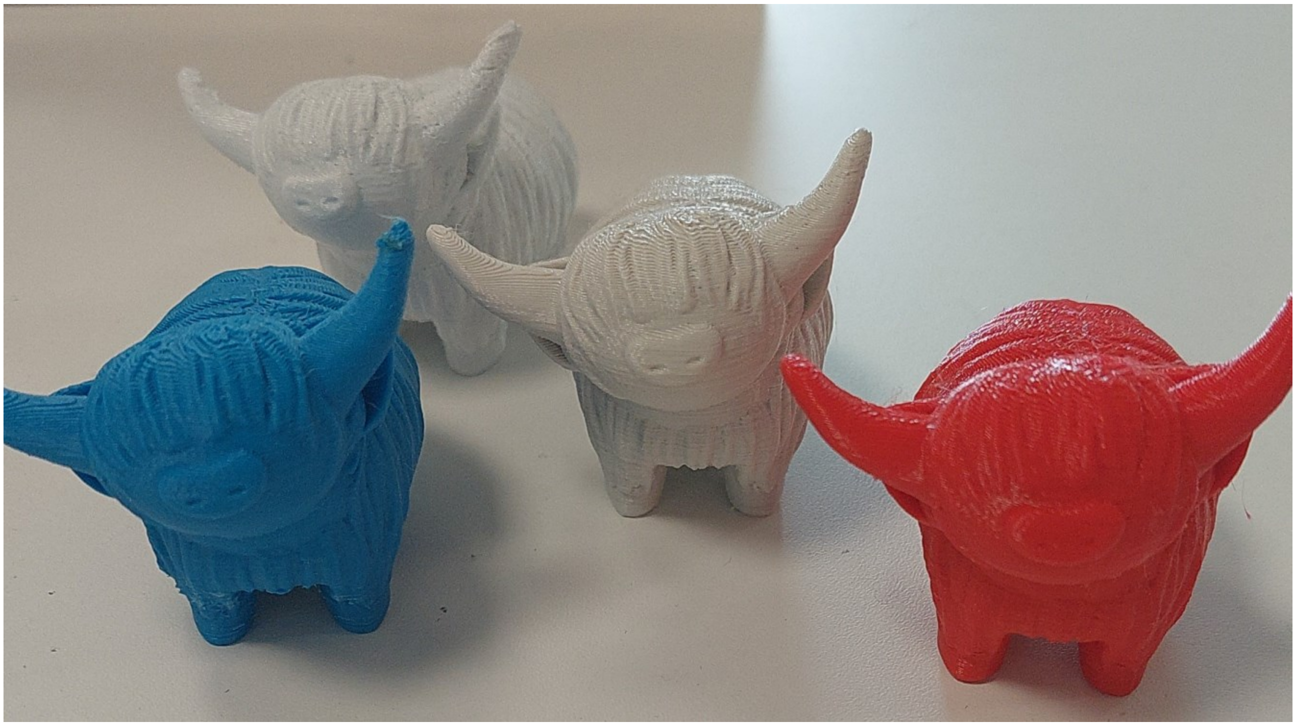

Figure 4: *Test prints using recycled 3D printing filament.*

4. Step 3 – Conclusion and recommendations

After going through the previously described steps, a wrap-up is presented in this chapter. This includes identifying the strengths of the redefined business model in regard to circularity, describing the learned lessons from the case study project and providing recommendations for the next steps.

4.1 Strengths of the redefined business model

Circularity of the product

3DPW Limited provide a mechanism in which 3D-printed waste is collected from the companies that generate it, and then transported via 3rd party companies for processing. The collected waste materials are sorted, granulated, and sold to companies that would then use the recycled material as a feedstock in their own product manufacturing processes.

This study has explored the feasibility of recycling the 3D-printed waste back into 3D print filament, which could then be used by the clients that generated the waste in the first place. This would act to close the loop by maintain the value of the material and reducing the amount of filament that is sourced from other production system and may contain virgin and/or non-renewable resources.

3DPW Limited currently focuses on the collection and processing of waste PLA. PLA is a particularly popular material used in FFF 3D printing, it is a bioplastic derived from starch (renewable material) which is recyclable and will biodegrade under certain conditions (industrially compostable under specific humidity, temperature, and microbial conditions). Collection and industrial composting infrastructure in the UK is currently limited and therefore the quantity of PLA waste that is industrially composted is low. By providing a system where waste PLA can be collected, processed, and recycled, 3DPW Limited has created an efficient disposal route for PLA and in processing and granulating the material will also increase its lifespan.

Product (re)design, testing and/or prototyping
The support provided centred around a feasibility study. Answering the question; could the collected 3D-printed waste (PLA, ABS and PETg) be processed in a way that produces usable recycled 3D printing filament. Utilising AM technology, samples of granulated waste received from 3DPW Limited were processed (including drying, shredding, and blending) and then extruded to make new filament (with no formula changes). The recycled filaments were then subjected to test prints (in combination with FFF 3D Printers) to assess printing efficiency.

4.2 Lessons learned
This case study highlights opportunities for companies such as 3DPW Limited to close the loop within the 3D printing sector. Rather than down-cycling waste filament through injection moulding, this case study has shown that waste collected from customers can be turned back into 3D printing filament.

4.3 What's next
3DPW Limited have big plans for the future but acknowledge that there are a few logistical and financial hurdles to overcome first. 3DPW Limited are already working on educational videos on how the processes work and they are open to further opportunities to expand their outreach and educational activities. The company is also keen to explore the establishment of formal (product) return scheme, especially as the business scales and the market grows.

References

European Commission, Directorate-General for Research and Innovation, *Re-finding industry: defining innovation*, Publications Office, 2018, https://data.europa.eu/doi/10.2777/927953

About the project

The problems associated with plastic waste and in particular its adverse impacts on the environment are gaining importance and attention in politics, economics, science and the media. Although plastic is widely used and millions of plastic products are manufactured each year, only 30% of total plastic waste is collected for recycling. Since demand for plastic is expected to increase in the coming years, whilst resources are further depleted, it is important to utilise plastic waste in a resourceful way.

TRANSFORM-CE aims to convert single-use plastic waste into valuable new products. The project intends to divert an estimated 2,580 tonnes of plastic between 2020 and 2023. Two innovative technologies – intrusion-extrusion moulding (IEM) and additive manufacturing (AM) – will be used to turn plastic waste into recycled feedstock and new products. To support this, an R&D Centre (UK) and Prototyping Unit (BE) have been set up to develop and scale the production of recycled filaments for AM, whilst an Intrusion-Extrusion Moulding Facility, the Green Plastic Factory, has been established in the NL to expand the range of products manufactured using IEM.

Moreover, the project will help to increase the adoption of technology and uptake of recycled feedstock by businesses. This will be promoted through research into the current and future supply of single-use plastic waste from municipal sources, technical information on the materials and recycling processes, and circular business models. In-depth support will also be provided to a range of businesses across North-West Europe, whilst the insights generated through TRANSFORM-CE will be consolidated into an EU Plastic Circular Economy Roadmap to provide wider businesses with the 'know-how' necessary to replicate and up-scale the developed solutions.

Lead partner organisation
Manchester Metropolitan University

Partner organisations
Materia Nova
Social Environmental and Economic Solutions (SOENECS) Ltd
Gemeente Almere
Save Plastics
Technische Universiteit Delft
Hogeschool Utrecht
Hochschule Trier Umwelt-Campus Birkenfeld Institut für angewandtes Stoffstrommanagement (IfaS)
bCircular GmbH

Countries
UK | BE | NL | DE

Timeline
2019-2023

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