3D PRINTING FASHION WITH RECYCLED POLYESTER: A SUSTAINABLE JOURNEY

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ABSTRACT

Textile waste is a global problem and one in which we all must tackle together to minimize. In the UK alone 350,000 tonnes of textile waste goes to landfill each year. In order to foster pro environmental behaviors in the household and for it to become part of our culture, recycling awareness must be converted into practice.

Bringing together sustainability and innovative technology, the focus of this enquiry, aims to examine, design and manufacturing possibilities using recycled Polyester filament to 3D print fashion garments. This explorative journey will determine whether it is feasible to use this material to create wearable or sculptural fashion pieces, through design, development, sampling and testing whilst using an entirely sustainable material.

Recycled PET has been used for many years by outdoors clothing companies such as Patagonia who have been the pioneers of using old polyester clothing and recycling it back into new yarn to make more clothing. Working with Teijin a Japanese high-performance material developer since 2005 they have been able to advance their environmental responsibilities further into more of their products. In this study, the use of rPET will be explored.

Since 2010 3D printing has emerged as a new method of manufacture for clothing. This is mainly evident in experimental sculptural forms for women as seen by Iris van Herpen. Likening the development and commercialization of 3D printing in fashion to that of the desktop computer. In the beginning, few could afford or know how to use a PC, in time many improvements made it more affordable, smaller and more commercial. We are at the beginning of this journey with 3D printing in fashion but like the PC, before too long it will be commonplace to all.

Key Words: Polyester, 3D Printing, Future Fashion, Sustainable, Closed loop

1. INTRODUCTION

The purpose of this paper is to outline the theory of 3D printing fashion from recycled polyester and testing the possibilities and methods involved. The idea of recycling polyester into fashion has been around for decades and in 1993 Patagonia was one of the first outdoor clothing retailers to do so. However, in comparison 3D printing in fashion is in its infancy, it only materialized in 2010 in Iris Van Herpen's Crystallization work and has gradually continued to gain steady momentum ever since. This study brings multiple ideas together to minimize waste in this new emerging industry, further exploring and linking sustainability, fashion and technology throughout. By gathering information on an area of such limited research, the author is attempting to close the gap between this technology and the recycling area of sustainability, moving towards advancing the knowledge in that field and increasing

sustainable practices in 3D printing in fashion. This would allow the research to be driven by the requirements of the practice and outcomes resulting from a combination of a qualitative, naturalistic and reflective enquiry (Gray & Malins, 2004) .
The material rPET (recycled polyethylene terephthalate) is the most notable recycled filament to 3D print from and as it is derived from polyester, the same material used in clothing, the link to fashion is clear. It is currently made from recycled plastic bottles and now exists in 100% recycled PET from REFIL who state "Why continue to use new plastics, when there's so much old plastic we can reuse?" (Refil, 2015) Although there is predictions of more future 3d printing recyclable options, this study will concentrate on this filament alone.

This study aims to gather information from 3 areas: 3D Printing, Recycled Polyester and Fashion (Fig.1), to argue that 3D printing fashion from sustainable polyester is possible.

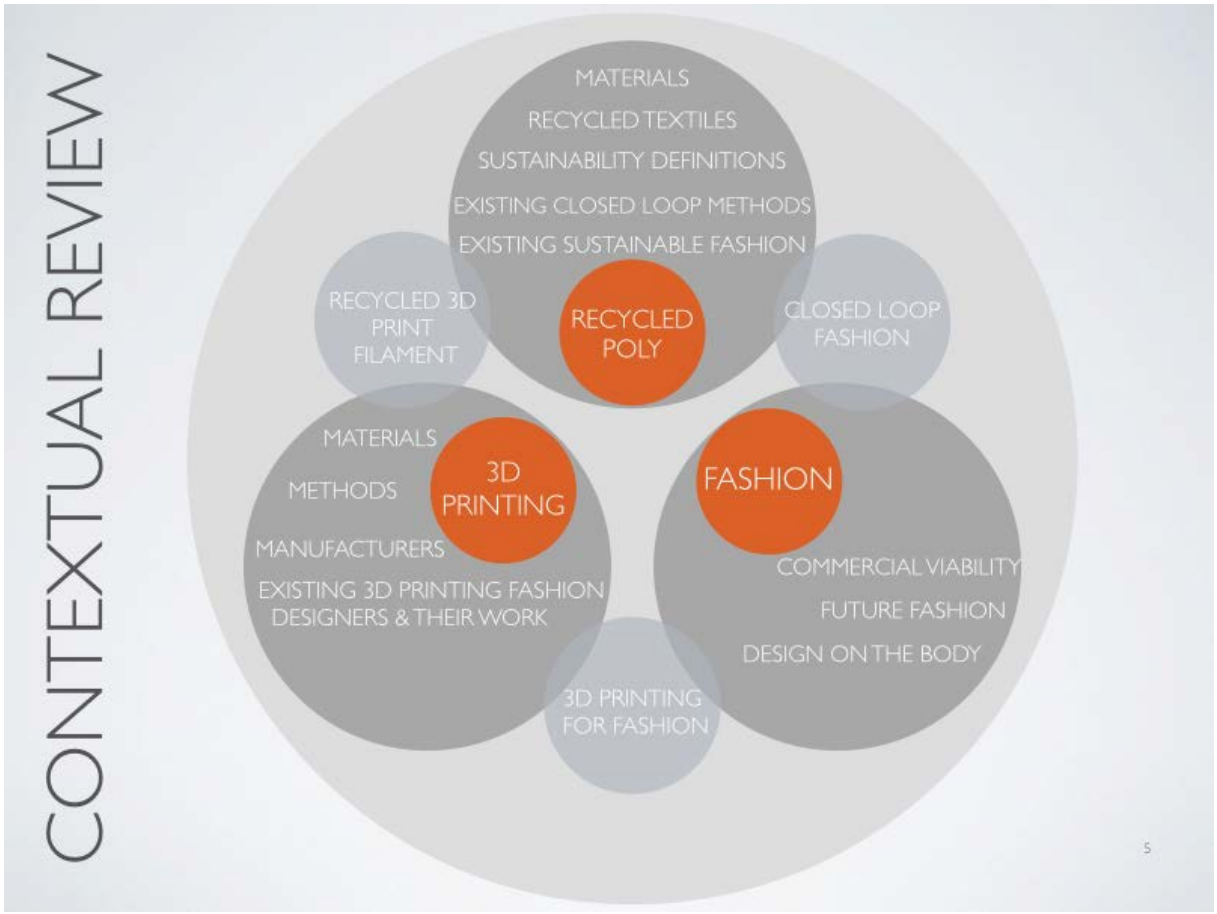

Fig. 1 - Contextual Review, Grain, E 2015

In the 2 way Closed Loop Apparel Cycle (Fig.2) Grain has theorised that by recycling all PET products, whether it is bottles, clothing or 3D prints, the existing recycling process of clothing and bottles into textiles can be mirrored but into 3D printing filament and visa versa. This stands to reason through exploring the methods existing polyester recyclers use and noting the early stages up to the pellets stage is identical to that of recycling into printing filament.

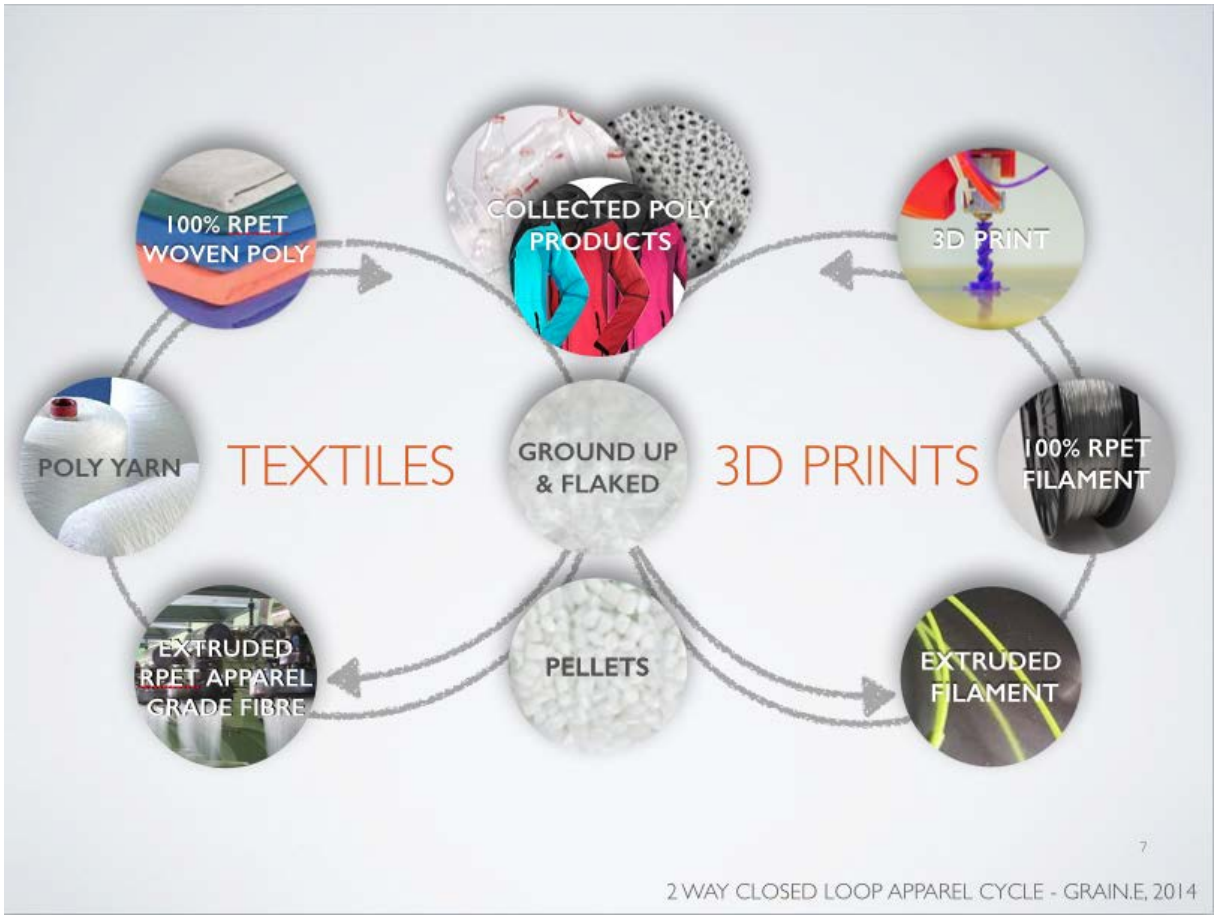

Fig. 2 - 2 Way Closed Loop Apparel Cycle - Grain, E 2014

2. SUSTAINABLE POLYESTER EARLY ADOPTERS- CASE STUDIES

Polyester is made from petroleum a nonrenewable resource that creates damaging environmental impacts during the extraction process (TED Research, 2013) It has been identified by many brands as a material that can be recycled but you must have the right resources and manufacturing system in place. Recycling existing polyester garments into new

polyester fiber for use in future garments has a less negative impact on the environment than producing virgin polyester. (Hayes, 2010)

2.1 PATAGONIA – USA

The pioneer of using recycled polyester on a great scale is Outdoor sports brand Patagonia. "They began making recycled polyester from plastic soda bottles in 1993 (Fig.3) the first outdoor clothing manufacturer to transform trash into fleece' (Patagonia, 2012). Since then they have built up a large following and have promoted their sustainable methods widely.

Patagonia was founded with a triple mission to "build the best products, do no unnecessary harm and to use business to inspire solutions to the environmental crisis"(The Daily Telegraph, 2015). They continue on this basis to innovate in this area and do more than make great clothes.

Using recycled polyester lowers the need for petroleum as a source of raw materials. It slows down the need to discard clothing as soon, thereby prolonging life away from the landfill and reducing toxic emissions from incinerators. Compared to using non recycled polyester it causes less air, water and soil contamination. Other sustainable initiatives that Patagonia run include:

2.1.1 Yerdle

Recently collaborating with US startup Yerdle on an anti black friday event, Patagonia promotes a sharing environment that enables the consumer to either share or swap their old Patagonia items with other lovers of the brands on the Yerdle app or at a swapping event held in store. Patagonia promoted this event by saying (Fig.4) "This Black Friday, investing in the things we already own"(Patagonia Works, 2014). If the consumer happens not to find anything they like, they can trade in their item for Yerdle dollars to use at a later date (Yerdle, 2014).

2.1.2 Worn and wear

The worn and wear campaign takes this thought one step further by "celebrating the repair and extension of life of existing products" (Patagonia, 2014) The company will undertake 40,000 repairs this year in their North American garment repair facility and have linked up with ifixit to create 40 online repair guides to support the customers with their threadbare garments.

2.1.3 Reuse and recycle

This involves the consumer bringing back their old Patagonia clothing, however old and passing it over to be recycled and used again into another part of a new line of clothing. Unwanted clothing can be posted in or dropped off in store, since 2005 they have recycled 82 tonnes of clothing by using this strategy and Common Threads garment recycling Program (Patagonia, 2014)

2.1.4 Do not buy this jacket

Patagonia Launched its most high profile ad yet in 2011 a full page in the New York Times stating “don't buy this Jacket”(The Daily Telegraph, 2015) It was almost and inti advert, telling people to use what they have and don't buy new things they don't need, however it still managed to increase sales from the publicity.

Patagonia now recycle garments into several different fabrics ranging from hemp to organic cotton and recycled wool to technical fabrics such as Lyocell, Nylon, Polyester used throughout their entire range. Their research and development and technologies that they have evolved are second to none and continues to lead the way in sustainable fashion. They understand that by extending the life of clothing by an extra nine months of active use would reduce carbon, waste and water footprints by around 20-30% each and cut resource costs by 20% (£5 billion) (WRAP, 2012) .

Fig.3

Fig.4

www.patagonia.com

2.2 THE NORTH FACE- USA

The North Face® fundamental mission remains unchanged since 1966:
Provide the best gear for our athletes and the modern day explorer, support the preservation of the outdoors, and inspire a global movement of exploration. (The North Face, 2014a)

2.2.1 Clothes the loop

Is an innovative recycling programme ran by The North Face and has been running since 2013, piloted across 10 stores in the US and in early 2014 pushed to 27 stores allowing customers to drop off any clothing to be recycled (Fig.5). These items are then sorted into

over 400 categories to be repurposed into new products and garments. To help promote the program, participants earn a coupon towards their next purchase and all program proceeds benefit the Conservation Alliance, which funds community-based campaigns to protect the shared wilderness and recreation areas.In 2015 the scheme was ran out to all stores in the US (The North Face, 2013).

In a video made by The North Face, sustainability manager James Rodgers discusses how " People are expecting more of the organisation and the companies where they are buying their products so we have to get more involved looking at our supply chain and looking at issues like climate change and how they affect work around us" (The North Face, 2014c).

2.2.2 Behind the Seams

In the Behind the seams video, The North Face shows how fleece innovation and recycled PET, less water, scrap take back all amount to a fleece innovation that they are proud of. Every 10 jackets worth of scrap fabric makes 4 more whole jackets.

2.2.3 Backyard Project Collection

In 2014 this idea was to make a collection of jersey products from seed to garment within a 150 mile radius of their head office in california. In collaboration with Fox Fibre, Fibre Shed, and Sustainable Cotton Project.

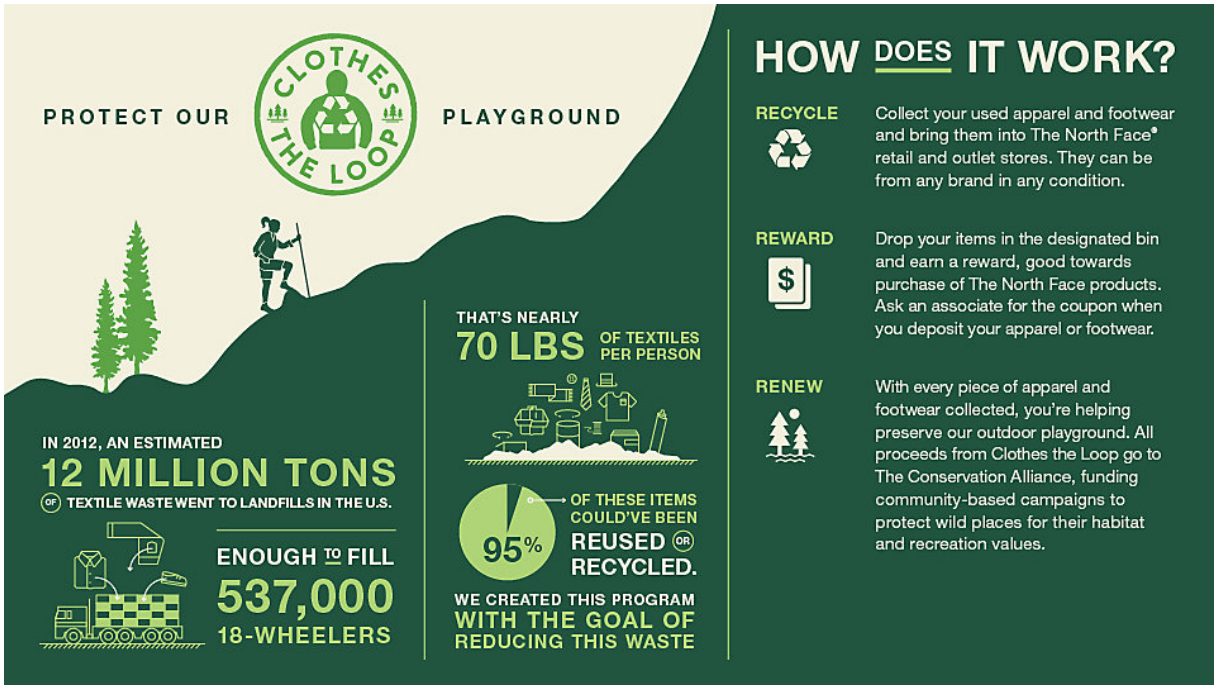

Fig.5

2.3 TEIJIN - Japan

Teijin's mission statement is "Human Chemistry, Human Solutions" , to respond to various global issues and needs, focusing on technological innovation in their strengths of high-performance materials (Teijin, 2014). They are the global leader in chemical recycling of materials into fabric including polyester.

The current global annual production of major fibers is approximately 78.11 million tons. Synthetic fibers account for more than half of this amount, approximately 45 million tons, of which approximately 80% is polyester (Teijin, 2014)

The two main materials which Teijin have developed from post consumer pet or polyester products are as follows:

2.3.1 Eco PET

A mechanically recycled polyester fabric which is made from 100% recycled PET bottles called which was first established in 1995 after Teijin had already been manufacturing recycled Pet bottles into new bottles so this was naturally the next step.

2.3.2 Eco Circle

Alternatively in 1999 ECO CIRCLE™ utilizes Teijin Fibers' innovative chemical recycling technology for polyester products. Its unique recycling technology is a world first in this field (Fig.6). The technology enables decomposition of used polyester products using chemical recycling, followed by reproduction of new polyester fibers. This process can be repeated multiple times (Japan for Sustainability, 2009). This method can produce fabrics that are so purified through this process that the quality is equivalent to that of freshly produced polyester from petroleum (Teijin, 2014). This method is popular with both Patagonia and The North Face and allow a totally closed loop cycle.

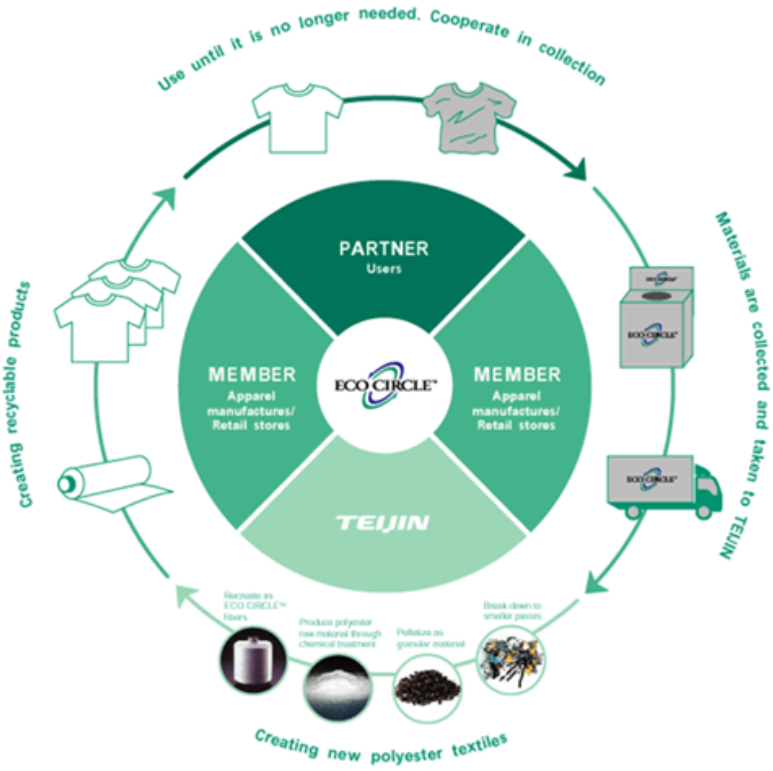

Fig.6 www.teijin.com

2.4 Repreve by Unifil – USA

Repreve by Unifil an American based leading producer and processor of multi-filament polyester and nylon textured yarns. Providing innovative, global textile solutions and unique branded yarns for customers at every level of the supply chain. (Repreve & Unifil, 2009)

Under the Repreve label 2 types of recycled polyester are produced, Repreve filament fibers and Repreve staple fibers. The latter is further processed to produce the physical properties required of a spun yarn and the former is in the form of yarn.

Both these types of Repreve polyester are used by brands such as The North Face, Quicksilver, Patagonia, Timberland, New Balance to name a few. These top brands are safe in the hands of a certified sustainable fiber manufacturer and can rely on 100% traceability in their products composition.

2.5 Ekocycle – Will.i.am and Coca Cola

In a wholly collaborative move towards sustainable fashion, Will.i.am has teamed up with Coca-Cola to make new things in part from recyled materials (Ekocycle, 2015). This high profile colab has brought together some of the biggest names in fashion and retail to make this possible and the products range from clothing by Adidas and Ecoalf to lifestyle products by Globe Trotter and footwear by Keds all sold online and in the prestigious Harrods of London.

The products are all made from partly recycled materials mainly including a percentage of PET bottles and this information is clearly displayed on their website adding transparency to the brand's impressive attributes.
In an interview with GQ Will.i.am discussed that the project will continue to launch new products throughout the year, from everyday pieces to luxury items, with will.i.am at the helm as creative director - producing the type of recycled clothing we can actually get on board with (Conner, 2015). The quest for making sustainable living cool does not stop with clothing, but reaches over into 3D printing. Using an average of 3 post consumer PET bottles per printing cartridge this enables the consumer to use their 3D Systems Ekocycle Cube printer for home use with sustainability in mind. Will.i.am explained that the goal is to

> Partner with the most influential brands around the world and use technology, art, style and inspiration to change an entire culture. We will make it cool to recycle, and we will make it cool to make products using recycled materials. This is the beginning of a *more* sustainable 3D-printed lifestyle. Waste is only waste if we waste it. (3D Systems, 2014)

3. MANUFACTURING METHODS OF RECYCLING POLYESTER

Both mechanical and chemical methods (Fig.7) are used in producing recycled polyester filaments/yarns and fibers. The process can be described in a linear form or circular depending on which company is manufacturing it and what the quality of the original PET is.

Polyester/Pet Products are granulated or flaked then through a chemical process of polymerisation the are turned into pellets then the pellets are extruded into a fine filament/thread before being spun onto bobbins and re woven or knitted into polyester fabrics.

(Fig.7) www.Teijin.com

4. 3D PRINTING MANUFACTURING PROCESSES IN FASHION

4.1 Selective laser Sintering

This additive manufacturing/3D printing process uses a high-powered laser to fuse small particles of powder together layer by layer, layer by layer, to print a part in successive cross-sections. (Laser sintering | materialise.2014) This process allows very fine detailed designs to

be visualised and come to life through this method. Many materials can be used as long as they can be powdered. Currently there are not recycled SLS materials to use for printing in this way but B-Pet plan to change this. B-PET will launch a recycled PET-based powder for laser sintering processes in 2015 and has even made plans to launch their own SLS 3D printer by 2016. Then the P2P (PET to PET) cycle can truly be complete. (B-Pet, 2015)

4.2 Fused Deposition Moulding

Fused Deposition Modeling (FDM) is an Additive manufacturing process that constructs objects by means of a temperature-controlled head that extrudes thermoplastic material layer by layer. Similar to how a glue gun extrudes the melted glue. One layer at a time the model is built up to create the 3D design from the computer screen. Multiple materials are available for these machines including 100% recycled PET filaments, further to this this type of printer is widely available for use in the home. Companies such as B-PET and REFIL both offer 100% recycled PET filament to use in this type of printer, however its full potential is not known due to its newness in the market.

4.3 Multi Material

This process allows multiple materials, colours and flexibilities to be used all in one item, in one print. The possibilities of this type of 3D printing are endless but it is one of the most expensive ways to 3D print. Wearable tems by Neri Oxman of MIT university have been printed this way. With more advanced systems, software combines two or three materials in specified concentrations and microstructures to produce digital materials with varying translucency, rigidity, thermal resistance or color. (Stratasys, 2015) Currently there are no recyclable materials available for this machine.

4.4 Stereo Lithography

Stereo lithography is a 3D printing process that involves a part being built slice by slice from bottom to top in a vessel of liquid resin that hardens when struck by a UV laser
(Laser sintering | materialise.2014) This method is used in any industry requiring quick detailed prototypes but it can be costly and the look and material is limited. No colour or variant in properties are yet available as yet.

4.5 Others – Electrospinning, Spray on

A few other methods have recently been categorised into the 3D printing area but it is debateable. Both Electrospinning and Spray on techniques displayed by Cosyflex are non woven materials applied additively to an existing mold/die. The electrospinning process, dubbed Field Guided Fabrication, makes it possible for anyone with a small bit of CAD ability to design and create seamless fabric items on demand (Electroloom, 2015).

5. CURRENT PRACTICE IN 3D PRINTED FASHION

Iris Van Herpen

For her Autumn Winter 15/16 Hacking Infinity Collection Iris van Herpen continues her interdisciplinary collaborations with Niccolo Cassas an Italian Architect and together created an Crystal-esque dress. 3D Systems helped the two define the possibilities surrounding size, texture, and complexity of their 3D printable Accura Clearvue (SLA) material. This material was selected by van Herpen because of its ability to create a high level of detail, delicate refinement, and translucent quality. (Eddie Krassenstein , 2015) it took over 200 hours to print but compared to haute couture methods this is still much quicker.

Fig.8,9&10. Hacking Infinity SLA Dress 2015 www.irisvanherpen.com

Van Herpen mainly chooses SLA and SLS processes when 3D printing because of their ability to create great details. In Van Herpens 2013 Collection Voltage she chose the Selective Laser Sintering method for one of the dresses made by Materialise using the new flexible material TPU 92A-1. This method and material created a fine detailed design with flexible properties allowing it to move more naturally with the body compared to other 3D prints. Both the samples were printed in sections and put together after printing, this is part of the post production that 3d printed fashion needs an in this case included dying.

Fig.11 & 12 Voltage SLS Dress in TPU 2013 www.materialise.com

Francis Bitonti an architect turned designer whose most notable 3D printed fashion design was the floor length black dress worn by Dita von Teese made using Selective Laser Sintering and finished with 13,000 Swarovski crystals in a collaboration with Michael Schmidt and Shapeways (Fig). Taking over 400 hours to print, the dress was made of 3,000 unique articulated moving components and doesn't rely on a continuous repetitive structure. And unlike a normal dress, that would lie flat, the dress was fully flexible and similar to chainmail.(Wired.co.uk, 2015)

His fashion pieces made using 3D printers, all use SLS to achieve the detail and show the design off to the best possible standard. He has used, nylon, metals and gold plated materials in his work. Bitonti openly sees computational design methodologies and additive manufacturing processes as opportunities to create new aesthetic languages (3d Printing Industry, 2015).

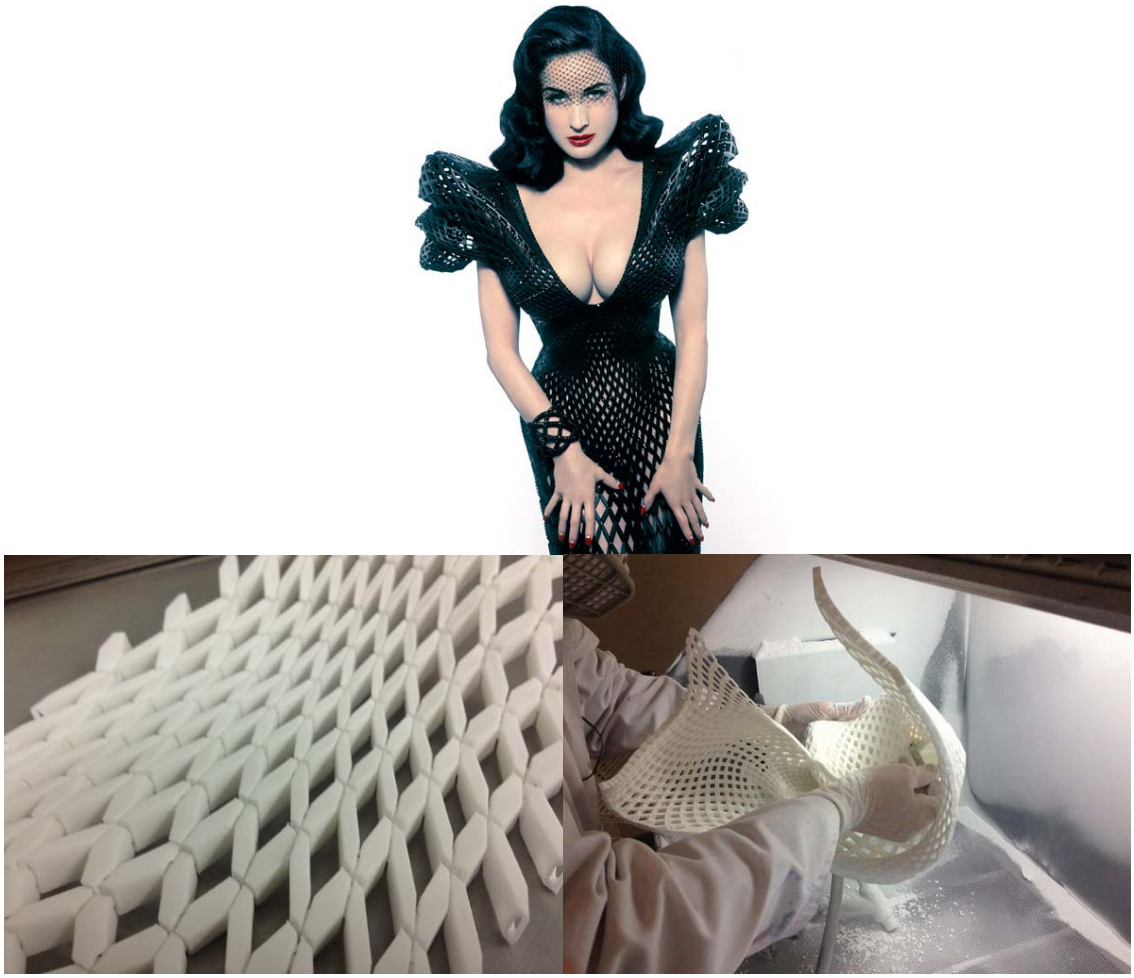

Fig.13, Fig.14 & Fig.15 www.shapeways.com

Nervous Systems is a design studio that combines research into science, art and technology and the use of digital fabrication focusing on 3D printing and have made a number of items from art to fashion and jewellery. Their most notable fashion piece to date is the Kinematics dress (Fig .16), which is made up from 100's of hinged pieces which allow the dress to flow in a fabric like manner (Fig .17). Nervous systems said

> Bodies are 3-dimensional but clothing is traditionally made from flat material that is cut and painstakingly pieced together. In contrast, Kinematics garments are created in 3D, directly from body scans and require absolutely no assembly. (Nervous System, 2013)

Nervous systems work has evolved the methods in which 3D printing in fashion is designed and used a particular computer simulation process which allowed the designed garment to be digitally folded to fit into the printer dimensions then unfolded when finished (Fig.18).

The hinge mechanisms that are designed into the garment work straight out of the machine and offer up many design developments as it is modular in construction. nervous systems explained that

The design was printed in a flattened form, produced by our Kinematics folding software. The bodice was wearable straight out of the printer: no pieces were manually assembled and no fasteners were added. The back of the bodice features integrated 3D-printed snaps for fastening the garment. (Nervous System, 2013)

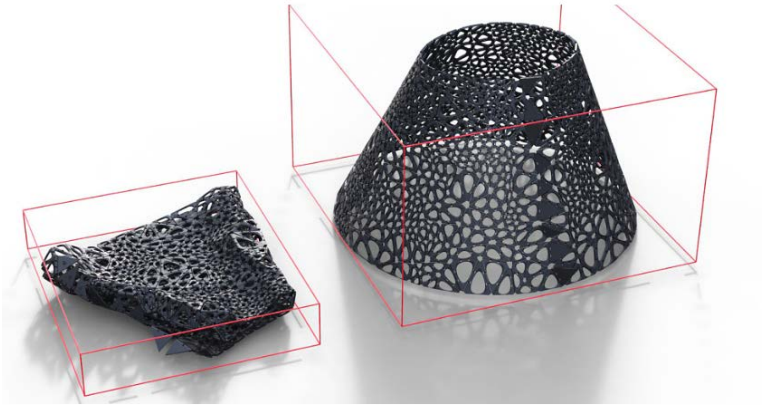

Fig.16 Fig.17 & Fig.18

In 2015 Shankar College Israel student **Danit Peleg** was the first person to print her entire final collection on home FDM 3D printers (Fig 19). Peleg wanted to check if it would be possible to create and entire garment using technology accessible to anyone. She tested various materials on various printers and chose Filaflex on the Witbot printer which gave the flexible properties of real fabric when printed. Her collection took 2000 hours to print and comprised of designs drawn on 3D software Blender. Also by using some of Andreas Bastian's Mesostructured cellular materials (Fig 20) downloaded from thingyverse.com an open source website (Danit Peleg, 2015)

Fig.19 Danit Peleg graduate collection 2015, www.danitpeleg.com

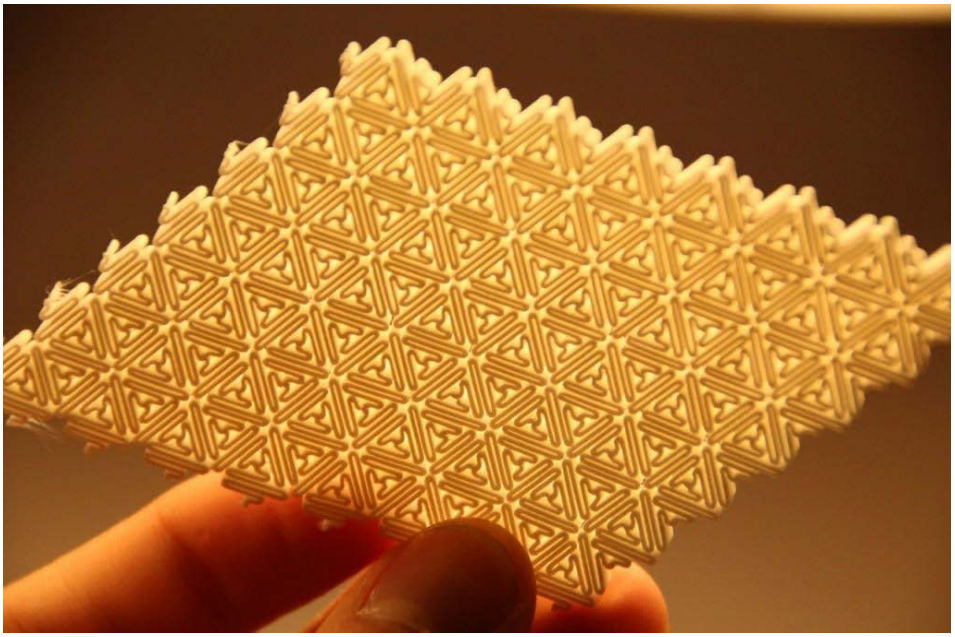

Fig. 20 Andreas Bastian's Mesostructured cellular materials, www.thingyverse.com

Other notable 3D print creatives making fashion pieces include **Neri Oxman** of MIT university and founder of the Mediated Matter group who collaborated with Iris van Herpen to produce the Anthozoa Cape and Skirt in 2012 on a multi material printer. **Richard Beckett** an Architect, Lecturer and designer in 2014 worked with Pringle to produce some 3D designs integrated into the ready to wear pieces of knitwear and outerwear for both the men's and womenswear collections all produced by SLS. It has become quite common for collaborations to involve designers from backgrounds such as architecture due to the digital aspect lending itself to the 3D fashion printing.

6. DESIGN OBSTACLES

Learning how to use 3D software to enable you to 3Dprint your designs is no mean feat. There are many tools and techniques you need to learn in this virtual studio before you can show your ideas in 3D. One of the reason the designers that 3D print fashion always collaborate with other industries is because there are so many technicalities involved in the process and it allows them to share resources and pool innovative ideas.

Some things to be considered when designing for 3D printing are:

Material guidelines: There will be specific guidelines depending on what material you want to print in.

Printing Technology: Different printing technologies have different capabilities as with materials so you must know what that specific technology can do before designing for it.

Whether its SLS or SLA or FDM they would all react differently to the same design, one may need more support while the other may need the design to be made thicker or not interlinking.

Wall Thickness: Taking this into consideration means the print is less likely to fail. Creating a wall thickness that is too thin thus leaving a weak part or too thick so the desired flexibility is not achieved, this is one of the most common mistakes people make.

File Resolution: This will determine how pixilated your print will look. The high the resolution the design you send to print, the more detail and smoother it will be.

Software Guidelines: Depending on which software you use, different settings may need to be altered before you are able to print from your design, this may include, wall thickness or hollowing out. (I Materialise, 2015)

7. CONCLUSIONS AND FUTURE WORK

In a world where technology is part of everyday life and 3D printing is gaining in popularity, acting responsibly with the waste that is produced from it, sits inline with other waste initiatives we have adopted in our culture. In the near future there will be 3D print containers at recycling centres, specifically for sending your unwanted or ill printed 3D prints to be recycled, either into reformed filament to print with again or new items, including clothing.

Recycling post consumer PET bottles is widespread across the world but a greater awareness is needed within communities so it is not left up to these recycling companies to filter these items out for their use. But have consumers bring the bottles and clothes to them, few have managed to do this, but again Patagonia and NorthFace lead the way by already adopting this into their strategies.

The ultimate goal is to bring together 2 companies who can a) recycle post consumer polyester clothing and b) turn the PET pellets into 3D printing filament, in which I can use to print fashion items from. Thus combining 2 of the most innovative sustainable polyester recycling methods that exist but crossing them over to work with the fashion industry and into the future of 3D printing fashion items in a sustainable manner.

The researchers current and future work concentrates on Closed Loop 3D Printing for Menswear and brings together through analogue and digital design, a body of practical work that will be created and will support a written thesis. Exploring the design possibilities using 3D CAD software and the male form to work on digitally, creating new and unusual shapes and forms. The design is inspired by the formation of skin cells and the mapped hexagonal pattern that occurs. This is mimicked throughout the designs which allows and rigid material bend and curve across and shaped form using living hinges throughout the designs.

Currently there is only FDM filament available in recycled PET but already set for later in 2015 is powdered PET from B-PET which can be used in SLS machines. For this reason the

authors work will include designs for 3 types of 3D printing machines on the basis that they will all have recycled materials available to them in the near future.

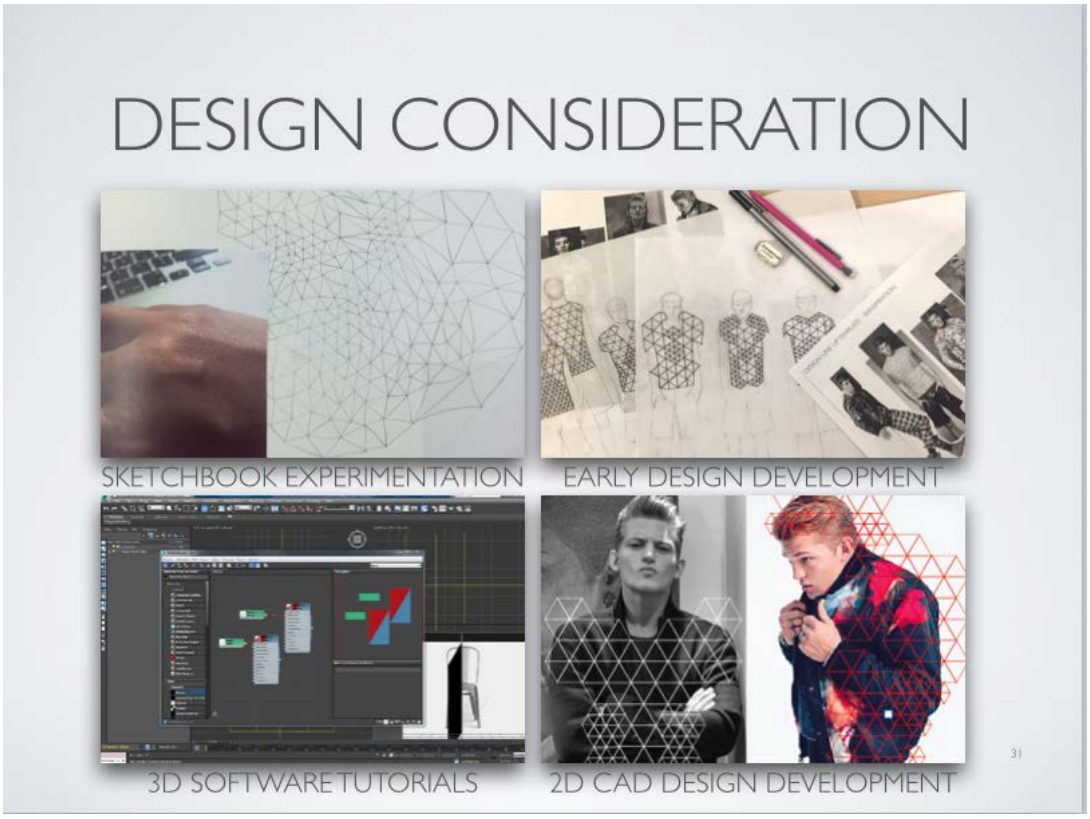

Fig. 21 Grain,E 2015

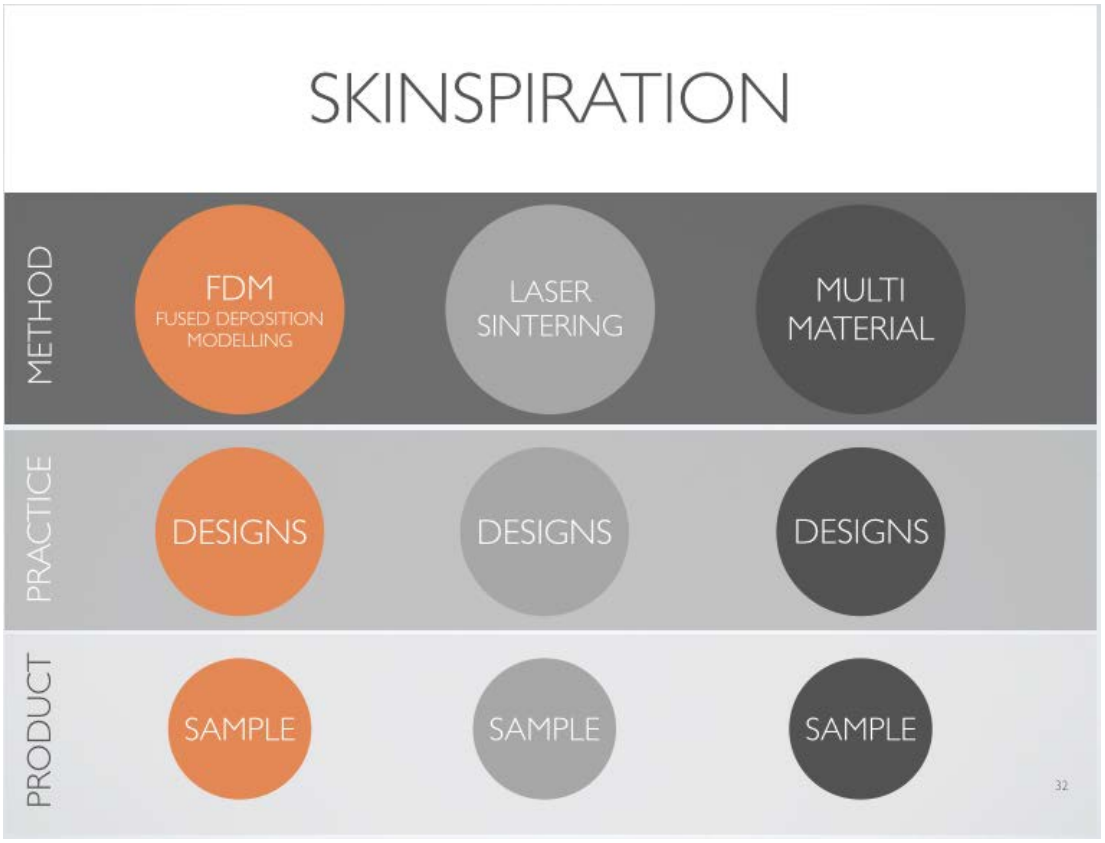

Fig. 22 Grain,E

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