# 3D Printing Technology Revolution in Future Sustainable Fashion

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*Abstract*

*3D printing technology, also known as additive manufacturing, is appearing at an amazing rate. It enables the creation of many products in design. This study focused on how 3D printing technology has developed, how it has been adapted from industry, and how it is applied in different areas. In the meantime, it also illustrated how this technology is used in fashion to engage creatively and the exciting potential values inspiring and extending fashion designers' range of work. Nowadays many 3D printing manufacturers are dedicated to developing environmentally friendly products along with more sustainable strategies. It is shown how developers are keen to create with less waste, minimised and ethically manufacturing processes as well as recycling reusable, new eco-friendly materials.*

*Key words: 3D Printing, Sustainable 3D printing, Sustainable Fashion*

## I. INTRODUCTION

3D printing technology can be compared to the industrial revolution that forever changed the future of manufacturing [7]. It has boundless potential for exercising designers' imagination and for manufacturing any products more economically and environmentally friendly. For fashion, questions of how designers adopt this infinite possibility of 3D printing manufacturing is on the rise, as is the consideration of sustainable manufacturing.

## II. RESEARCH BACKGROUND

### Terminology of 3D printing

3D printing (also called additive manufacturing) is defined as "a process of making a three-dimensional solid object of virtually any shape from a digital computer model" [2]. The origin of 3D printing technology is the first 3D printer (called a sterolitograph) developed by Charles W. Hull in 1986. Carl R. Deckard invented the Selective Laser Sintering (SLS) 3D printer in 1987 [16] and [2]. Unlike 2D printing, which shoots coloured dyes on sheets of paper, 3D printing technology constructs objects by placing one layer on the top of the other following a structured digital template [2]. Ju and Fonda mentioned that the subtractive process which relies on the cutting or drilling of material, is changing into an additive manufacturing which is placing repeated layers [16] and [2]. Ju predicted that manufacturing structures will become a small quantity batch production [16].

### Types of 3D printer

3D printers can be classified into liquid (photopolymer), powder, and solid (polymer wire) base types based on their materials [14]. First, liquid type 3D printers use lasers or strong ultraviolet rays to make liquid types of raw materials stiffen instantaneously for fabricating shapes. In addition, fine plastic powder, sand, or metallic powder is used by heating in combination with glue or lasers. Solid types of thermoplastic materials such as polymer wire or filament is melted down using heat and it is passed through a nozzle and laminated. Thin plastic sheets or film types of materials are also used in 3D printing. Currently the most popular 3D printer type is FDM (Fused Deposition Modelling) because of the expired patent and the low cost and high strength of material [2] and [6]. Thermoplastics such as PLA (Polylactic acid), ABS(Acrylonitrile butadiene styrene) are normally used in FDM and FFF(Fused Filament Fabrication) but the precision of the object made by PLA and ABS are low and the surface after printing is rough [6].

### 3D Printing in Action

The first stage of the 3D printing process is making an idea into a computerised file using a 3D CAD program such as 3D Max, Alias, Catia, Solidwork, and Rhino etc. or getting 3D models from the web (using open sources). They should be saved in the '.stl' file format (see Figure 1, [2]). This digital file is modified and 'sliced' into layers which can be used by the extruder (G code) [2]. Afterwards, a PC and a 3D printer are connected or a file is moved using a memory card. Digital files are printed after setting the temperature or the position of supporters, etc. Then the printed object is taken from the printer and the supporters are removed (see the left on Figure 2, [2]). Additionally, the surfaces of the objects are polished by sandpaper or chemical solutions if a glossy finish is needed (see the right on Figure 2, [2]).

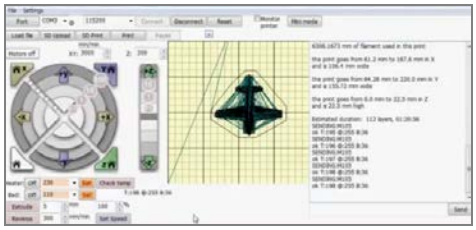

Figure 1 Slicing process at program 'Cura' [6]


Figure 2. Finishing [2]
(supports removal and surface post trestment)

**Benefits of 3D printing**

Park and Nam pointed out that 3D printing technology will bring a manufacturing business evolution at material, design, distribution, and production base points [1]. First, 3D printing uses fewer raw materials than a CNC (computer numerical control) machine because the additive manufacturing process will print only the necessary parts [1]. The components of cars or aircrafts can be produced using specialised net patterns or unfilled fabrication printed by 3D printers with increased strength and less weight [1]. From the point of view of design and mapping, 3D printing can save time and money because a step to make moulds for casting in the previous production process is not required and this helps to be flexible in responding to fast-changing markets [1]. In addition, the distribution evolution of 3D printing will allow any factory to produce the same quality products as long as the raw materials and blueprints are the same. [1]. It boosts local production and saves shipping charges in export trade [1]. Unlike assembling manufacturing, 3D printing can print any shape without assembling labour and it allows companies to reduce production costs [1].

**Application of 3D printer**

3D printers can be adapted everywhere "from pre-production (i.e., rapid prototyping) to full-scale production (i.e., rapid manufacturing). It can also be applied to tooling applications and post-production customization" [2]. 3D printing technology is widely used in many different fields such as design (industrial, architecture, and fashion) construction, engineering, education, health, as well as the arts and entertainment [2]. In medical industries, producing prosthetics at any time and place and printing skin cells directly onto a wound is possible with a 3D printer [2].

## III. 3D PRINTING IN FASHION

Lipson and Kuman mentioned that 3D printing technology allows architects, artists, and designers to create unique and complicated objects without any restrictions. [7]. Fashion design is the best area to optimize 3D printing techniques.

**3D printed fabrication**

The combinations of algorithms and the patterns generated by formulas can create extensive 3 dimensional forms including fractal dimension [7]. The principle of 3D printed fabric is a combination of each unit or digitalised weaving using calculations [7]. 'Pringle of Scotland', the fashion brand, and material scientist, Richard Beckett, collaborated to create a series of 3D printed fabrics using selective laser sintering (SLS) methods [15]. Scrawford created a set of flexible and flat structures using triangular, square, and hexagonal grids (see Figure 3, [15]).

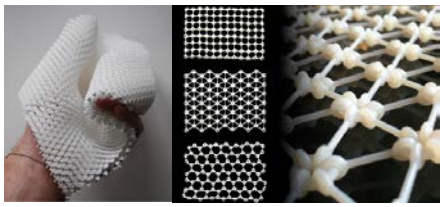

Figure 3 3D printed fabrics, [15]

Huang, who made the first 3D printed N12 bikini, mentioned that the private unit price might be higher but 3D printing technology gives more creativity and a user-friendly varied design [3]. Their bra is supportive, but also flexible, and tiny, semi-porous holes help to keep it dry and not clingy (see the left on Figure 4). Nervous System, a design studio in Massachusetts made each unit fixed but combined them as an extended 3D printed fabric [12]. Their kinematics case study started with a 3D body scan of the targeted person. Afterwards, the design of the dress was decided. It was tessellated with a triaged pattern following the dress's drape and allowing the wearer to move (see the right on Figure 4, [12]).

Figure 4 N12 bikini [3] and The kinematics dress [12]

**3D printed clothing construction**

3D printed clothing can be divided into two types; combination of units and creations of the intended shape based on the designer's ideas and inspirations.

XYZ Workshop developed fully wearable apparel printed out as the unit composition which included two types of shapes: solid and open spheres using flexible PLA. Their two dresses (see the Figure 5) were constructed using each printed unit separately. Each panel was designed onto a 3D scanned torso for a good fit. To represent fabric, floral motif mesh was printed with 0.4mm thickness allowing movement [17].

Catherine Wales mentioned 3D printing gives the possibility to create designs with no limitations [1]. In addition, she pointed out the convenience and accuracy of a 3D tailor-made design for a specific body shape. In the same vein, 3D printing pioneer Iris van Herpen also addressed that “3D prints finally act with the movement of the body” and “Everybody could have their body scanned and order clothes that fit perfectly" [4].

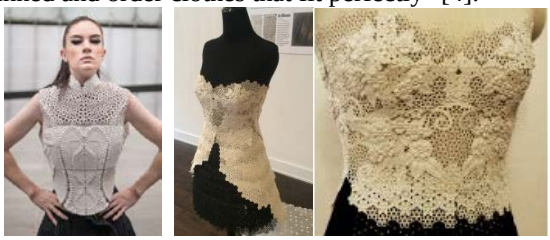

Figure 5 3D printed clothings, [17]

Figure 6 3D printed dress -Catherine Wales (left) and Iris van Herpen (right) (Retrieved from http://www.dezeen.com)

3D printing technology is also used in other fashion items like gadget cases, jewellery, shoes, and eyewear (see Table 2)

| | |
|---|---|
|  | |
| Gadget case / Jewellery | |
|  | |
| Shoes / eyewear | |

Table 2. Fashion Applications of 3D printer [4]

## IV. SUSTAINABLE 3D PRINTING AND FASHION

Faludi made the comparison between 3D printers and the mill using life-cycle assessment (LCA) which included the materials, manufacturing machine, logistics, energy consumption, materials (in final parts and waste), and the abrogation disposal of the machines [9]. 22 different scenarios were tested and measured for ecological impacts. It found that inkjet printers had a considerably worse ecological impact. 3D printers were significantly superior.

**Economical process**

In personal use 3D printing, fewer raw materials are used and 3D printers reduce time in the mock-up process [13]. In addition, personalised 3D printing is more economical because only the designed and required parts are manufactured. 3D printer owners do not need to care about the logistics and can eliminate shipping costs because they can print any product conveniently at home [13].

**Less Waste and Energy**

3D printers which use metal produce less waste than conventional techniques [7]. For example, CSIRO’s titanium 3D-printed fish tags are non-toxic because of extraordinary energy-intensive purification and resistant to the corrosive effects of salt water. CSIRO’s research says using 3D printing helps to save up to 90 percent of waste generation compared to traditional manufacturing processes. [11] In addition, they mentioned it allows for quick designs and manufacturing at different places with no need for making samples. [11] Also reducing printing time is the best way to reduce energy. 3D printing allows printing the object hollowed even though there are support materials that can be printed faster [9].

**Material matters**

One of the most commonly used material for 3D printing is plastic, polylactic acid (PLA). It is a biodegradable corn starch or sugar cane plastic [11] CSIRO senior scientist, Greg Foliente mentioned “If it will print things from waste plastic, before you print you are already in good shape, environmentally.” [11]. 3D printers which reuse plastic from failed print runs, milk bottles and use plastics that can dissolve in water are under development [11] and [8].

However, sometimes 3D printers are more eco-friendly than machine work but 3D printers are not less wasteful because they consume significant electricity [9]. Even though 3D printers contribute to the elimination of product transportation, it is not a considerable matter because transportation is a small part of most environmental impacts [9]. If the intended objects failed during printing, it can also cause pollution.

**Sustainable 3D Printing Fashion**

The trials and efforts to make fashion become more sustainable have been occurring in the marketplace and 3D printing is no exception.

Designer-researchers at ‘Freedom of Creation’ in Amsterdam and Philip Delamore at the London College of Fashion are currently “cranking out seamless, flexible textile structures using software that converts three-dimensional body data into skin-conforming fabric structures. The potential for bespoke clothing, tailored to the specific individual, are as abundant as the patterns that can be created, from interlocking Mobius motifs to tightly woven meshes” [10]. Customisable 3D printed platform high heels by Hoon Chung can be said to be eco-friendly because each component of the shoes are compatible and all removable components do not need glue (see the left of Figure 7, [7]) In addition, ‘Appalatch’, the outdoor apparel company created a custom fit sweater sustainably sourced. Fabric 3D printers were used in the production of the wool and cotton for the sweater. This makes transportation of those

materials unnecessary and allows for perfectly fitted clothes with no waste of fabrics.

Avi N. Reichental, President and CEO of 3D Systems also mentioned 3D printers empower sustainable developments while producing products efficiently because 3D printers only use the required amount of materials for specifically designed parts with near zero waste. Using recycled plastic can be a good way for sustainable design. The Ekocycle 3D printer uses recycled PET plastic to print bracelets, shoes and many other objects (see the right of Figure 7, [5]).

Figure 7 3D printed shoes and Ekocycle 3D printer, [7] and[5]

## V. CONCLUSION

The most surprising thing about 3D printing is that this area is developing incredibly fast. It is radically innovative and is a point where human designers and computers can co-work creatively but sustainably. 3D printing design still has problems to be solved [7]. For sustainable 3D printing, how we use the tool is the most important factor for the environmental influence. 3D printers have much potential to improve sustainable manufacturing [9]. First, 3D printers can print any product with optimised conditions for appropriate purposes and usage. Second, saving design files (digital stocks) which can print anytime is more environmental and economic than storing real stocks. Third, it can be expected that 3D printing manufacturing companies can be placed closer to the local community. Lastly, 3D printing technology has possibilities to minimise pollution using recycled and environmentally-friendly raw materials [7]. However, Faludi also mentioned that 3D printers are not less wasteful because they consume significant electricity. Reducing printing time is the best way to reduce energy usage. Nevertheless, 3D printers are more eco-friendly than machine work. Considering the environment is the most important strategy for adopting 3D printing technology which helps designers' creativity to embody real products.

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