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Creation of 3D printed fashion prototype with multi-coloured texture: A practice-based approach

The use of three-dimensional printing is prevalent in many industries, including that of fashion. Three-dimensional printing has come into wide use in different industries as well as fashion industry. Fashion and textile designers adopt 3D printing technology as their creative design tools, for example, when creating 3D printed garments, fabrics, or fashion accessories. It can be predicted that 3D printing technology will be rapidly applied and play an important role in the fashion industries in the future. This research study aimed to develop a theoretical design process model specifically for the creation of a 3D printed fashion prototype with multi-coloured surface texture. By adopting the practice-based research methodology and the developed design process model with reference to the theories of 3D printing technologies, practical concept, physical prototyping techniques and corresponding evaluation of various design elements, an innovative 3D printed fashion prototype was finally produced.

Keywords: 3D printed fashion; multi-coloured texture; theoretical design process model

1. Introduction

Three-dimensional printing technologies help improving the design and manufacturing process of industries by streamlining different operations, such as the replacement of assembly lines of production with a single-step process for minimising complicated manufacturing steps, digitalising designs for eliminating the process of transforming information into materials, customising products of different types and in a range of sizes for minimising additional costs, and reducing labour requirements (Campbell, Williams, Ivanova, & Garrett, 2011). In particular, 3D printing has revolutionised the process of design; while traditionally, design and manufacturing processes have been clearly defined and demarcated, the use of 3D printing in designing has resulted in designers being involved in the determination of ways to transform 2D concepts (computer-aided design (CAD)/computer-aided manufacturing (CAM) processes) into

3D objects (real products), and participating in manufacturing processes (Petrick & Simpson, 2013). Recently, in the fashion and textile industries, 3D printing has been a creative tool to produce fabrics, it has also been used to produce products such as fashion lifestyle products and accessories. This practice-based research study adopted the theories of 3D printing technologies to develop an innovative fashion prototype based on a theoretical design process model. The technologies and their applications were comprehensively investigated for the possible use of identified technologies which were appropriate for designing fashion garments with innovative surface textures.

2. Literature review

2.1. Three-dimensional printing technology

Three-dimensional printing is an additive manufacturing technique to create a solid object. During the manufacturing process, materials are successively assembled on one cross-sectional layer at a time, with the final product comprising many layers (Campbell et al., 2011). The process starts with a 3D digital model that is generated on a computer by using different types of 3D drawing software programs and is referred to as CAD. A software program slices the model into layers and converts the layers into readable files for a 3D printer; subsequently, materials are added layer-wise by the printer to form a 3D object. Three-dimensional virtual objects are created by combination of 3D modelling, texturing and rendering in CAD design. In 3D modelling process, polygon mesh and polygons can be assembled together to form shapes. Texture mapping is a method to add illusive textures on 3D virtual objects, whereas texture can be images of pictures, or hand paintings. During the rendering process, the texture meshes are unwrapped to one flat image, then texture is projected onto the meshes (Ahearn, 2014; Mullen, 2011). Rendering is a mathematical process to calculate every pixel of the virtual object to produce a final image (Murdock, 2012).

Different types of printing methods require different types of 3D printers and materials. The PolyJet 3D printer was selected in this study. It is capable of high-resolution and smooth surface colour 3D printing, and it is also capable of using translucent materials (Stratasys, 2018; Vidimče, Wang, Ragan-Kelley, & Matusik, 2013). The PolyJet 3D printer is the only printer that can mix rigid and flexible materials simultaneously for producing a 3D printed product. During printing, droplets of a liquid photopolymer are deposited by nozzles and ultraviolet light is used to cure the photopolymer to harden the droplets. The printing process requires a supporting material to support the model material during its solidification. The supporting material can be removed after the completion of printing. The PolyJet 3D printer is capable of pixel-wise printing with different materials, and therefore, materials can be combined or blended to obtain a product with a specific colour or flex gradient, however, the texture mapping colouring method is not available in printing with soft and flexible materials (Stratasys, 2018; Xiao, Sohiab, Sun, Yates, Li, & Wuerger, 2016).

2.2. Need for theoretical design process model of 3D printed fashion

It was observed that there is no specific theoretical design process model that has been developed on the basis of 3D printed fashion garments with multi-coloured texture. Although 3D printing is an innovative concept in the fields of fashion and textile, monochromatic products do not fully meet customers' expectations. In addition, the coloured texture mapping used in 3D printing methods on fashion prototypes has not been fully investigated in past studies due to the limitations of 3D printers, 3D modelling methods and available materials. Limited types of 3D printers (such as PolyJet printers) could print texture mapping 3D models and it is not possible to print on soft and flexible materials. The ergonomic aspect of current 3D printed fashion products has not been fully explored. In this study, the consideration of ergonomics helped increase the comfort of wearable 3D printed garment since a new set of ease allowances and a specific joint and interlock design for holding various garment panels together were developed and added to the final prototype. This study addressed the aforementioned shortcomings of 3D printed fashion products, and a 3D printed fashion prototype with innovative multi-coloured texture which took the ergonomic factors into account was produced.

3. Methodology

A practice-based methodology was adopted in this study, the main focus was the design practice. A specific theoretical design process model for a 3D printed fashion prototype with multi-coloured texture was developed. The developed design process model was implemented and initial prototypes were developed and assessed. A final 3D printed prototype was then created. The practice-based research was an original investigation that could generate new knowledge in terms of practice and together with the new concepts and methods (Candy, 2006).

3.1. Development of theoretical design process model for 3D printed fashion

A design process involves creative activity and the process of finding specific problems and their best solutions (Chapman, Bahill, & Wymore, 1992; Medland, 1992). The aim of designing is to simplify a complicated concept or object, and hence, a systematic design approach is required (Jones, 1992). According to the literature (Labat & Sokolowski, 1999; Lamb & Kallal, 1992) on the design process models in the fields of fashion and textile design, the theoretical design process model for 3D digital printed fashion was proposed to be based on the concept of ‘analysis–synthesis–evaluation’, with three main stages. The analysis stage involved defining and considering the problem process and setting the objectives; synthesis involved a feasible solution generation process; and evaluation involved the critical assessment of the solutions. The model is summarised in Figure 1.

3.1.1. Analysis stage

3.1.1.1. Problem definition. The first step was to identify the specific design problem. In the definition process, objectives were established and feasible resources and design boundaries were reviewed (Regan, Kincade & Shelden, 1998). In the current study, the research aim was to create a 3D printed fashion prototype with multi-coloured texture, and the objective was to combine artistic innovation, ergonomics, and 3D printing technologies to create a 3D printed fashion prototype that was appropriate for wearing in terms of fitting and ergonomics.

3.1.1.2. Identification of sub-problems. A review of recent colour 3D printed products in various markets, including the product design, fashion design, textile design, and medical aspects, showed that the sub-problems involved 3D printing technologies, materials that could be used in fashion garments, and multi-coloured 3D printing methods appropriate for producing the texturised 3D printed garment.

3.1.2. Synthesis stage

3.1.2.1. Investigation of problem. The problems were investigated before conceptual solutions were generated through literature review, which can retrieve required information and help identifying the design needs (French, 1999). Evaluation of the information in the objectives, design constraints, and design criteria was required, and a feedback loop connection was established between the generation and evaluation processes (Cross, 2008).

3.1.2.2. Conceptual design. On the basis of the investigation of the problem, preliminary ideas were generated; these ideas should be developed further. The main factors on which ideas were generated include: (i) types of 3D printers, (ii) 3D printing materials, (iii) texture patterns, (iv) colour printed texture, and (v) ergonomics. In this stage, designers were required to use their imagination for idea generation for improvements (Fiore & Kimle, 2010).

3.1.2.3. Determination of solutions. The solutions were abstract, and they did not describe details and small activities involved in obtaining solutions (Wynn & Clarkson, 2005). In the present research, solutions were proposed on the basis of previous problems and ideas and they were: (i) PolyJet 3D printers were used, (ii) the 3D printing materials were rigid resins, (iii) different types of texture patterns were designed by using computer software 3ds max, and texture patterns of various sizes and forms were obtained by Photoshop CS6, (iv) colour printed texture was obtained through direct colour printing with the 3D printers, and (v) the aspect of ergonomics involved creating style cutting lines and adding ease allowances for the fashion garment. Furthermore, the silhouette, proportion, colour, and embellishment of the fashion prototype were also be considered.

3.1.2.4. Searching for alternatives. The fashion prototype should be visually appealing, and hence, alternative design sub-solutions could be generated by considering aesthetic requirements regarding the printing materials, texture patterns, colouring methods, and seam placement of the garments.

3.1.2.5. Development of prototypes. In this stage, feedback on the conceptual design stage was reviewed to create various initial prototypes, and after experimental sampling, the final solution can be decided. The types of 3D printers, printing materials, printing texture designs, and colour methods were fully considered.

3.1.3. Evaluation stage

3.1.3.1. Evaluation of initial prototypes and decisions. The initial prototypes were evaluated according to the aesthetic and technological characteristics of the 3D printing materials, colour, texture performance, and comfort that could be applied in fashion garments. A feedback loop was established between the synthesis stage and evaluation stage for designers to redesign and improve an unsatisfactory design.

3.1.3.2. Detailed design with specifications. The final stage provided the detailed design with specifications for the final prototype. The materials, printing method, colour, and texture of the pattern were identified with integration of ergonomics. All illustrations and specification documents were produced. [insert Figure 1 near here]

4. Results: Creation of 3D fashion prototype

4.1. Creation of colour patterns

In order to ensure colour harmony, colour patterns were developed from the six colour schemes including monochromatic, analogous, complementary, split complementary, triadic and tetrad. Blue or blue green were the colour groups preferred most across different cultures (Saito, 1994). Hence, firstly, the primary colour was chosen from the blue-green tone of the Natural Colour System (NCS) colour wheel and soft cyan (S0540-B30G) with hex code #74d1d7, was selected because it was available to print out by CMYK colorants (Figure 2(a)). Next, a series of colour groups based on the six colour schemes and hex codes were created. The selected colours were printed out by

CMYK colorants. The patterns were drawn on a segmented square and filled in with colours according to the colour variation groups using Photoshop CS6 (Figure 2(b)). Colour sequence was the only variable, whereas the pattern segmentation, gradient colour direction, and texture of the 3D virtual object were kept constant. [insert Figure 2 near here]

4.2. Design creation in 3D modelling

The 3D virtual modelling process was performed in 3ds Max with a Para 3D plugin. A basic 3D object was created through polygonal modelling, with three modifiers (blending, tapper, and twist) involved in the process (Figure 3(a)). The basic 3D object was then calculated automatically by the Para 3D plugin and laid out on a curved plane (Figure 3(b)).

4.3. Texture mapping on meshes

After creating the 3D virtual design, colour patterns were texture-mapped (projecting colour patterns onto the 3D object) (Figure 3(c)). Based on the six colour schemes, colour pattern variations with different sequences developed in Photoshop CS6 and various textures were wrapped onto the 3D virtual object. [insert Figure 3 near here]

4.4. Development of initial 3D printed prototypes

After creating the initial 3D virtual design with texture pattern mapping, the required files were exported using 3ds Max. The 3D printer software received the files and processed slicing the 3D object. The software then sent instructions to the 3D printer for controlling and processing the 3D printing. Stratasys J750 PolyJet printers were available for multicolour printing, which the files were using texture mapping colouring method during the 3D modelling process. In total, 16 physical prototypes with size of 7.5 × 7 × 2 cm were grouped into six colour schemes (Figure 4). [insert Figure 4 near here]

4.5. Colour assessment

Although the 3D printer Stratasys J750 could achieve nearly full-colour printing in both CMYK and RBG, with more than 360,000 colours, it still had technical limitations in terms of colour accuracy (Stratasys, 2018). Colour fidelity problems occur not only in 3D printing but also in image processing during CAD (Xiao et al., 2016). In assessing colours, physical prototypes with serious colour fidelity problems were eliminated from the study. These problems included (i) fading on the Ana-1, Ana-2, Ana-3, Comple-1, Comple-2, Split Comple-2, Split Comple-3, Te-1, Te-2, and Te-3 prototypes; (ii) colour switching on the Ana-2, Te-1, Te-2, and Te-3 prototypes; (iii) colour pattern image blurring on the Mono-1, Mono-2, Comple-1, Comple-2, Split Comple-2, Tri-3 and Te-3 prototypes; and (iv) serious colour fidelity defeats on light and soft colour on the prototypes of analogous, complementary, split complementary, and tetrad schemes.

Researchers (Pentak & Lauer, 2015; Stewart, 2002) indicated that the triadic colour scheme was perceived as lively and can be used for a strong effect. Therefore, the Tri-1 and Tri-2 prototypes were the focus of further evaluation. Blue was the dominant hue in Tri-1, and red of Tri-2. Several studies indicated that longer-wavelength colours such as red and orange were perceived as arousing, whereas shorter-wavelength ones were viewed as calming (Kwallek, Woodson, Lewis, & Sales, 1997; Stone & English, 1998). Blue was the colour preferred most with constant positive preference results (Saito, 1994). Perceptions and associations of blue were mostly positive and related to pleasant feelings such as, limitless, calm, and serene, relating blue to the ocean and sky (Hemphill, 1996).

Some researchers found red to be associated with happiness (Soldat, Sinclair, & Mark, 1997), but other researcher suggested to associate red with negative meanings (Setchell & Wickings, 2005; Valdez & Mehrabian, 1994). Red was usually the representative colour in warning symbols and alarms, or with a meaning of failure (Elliot, Maier, Moller, Friedman, & Meinhardt, 2007; Moller, Elliot, & Maier, 2009). In summary, following the assessment of 16 physical prototypes and comparison with virtual rendering models, the Tri-1 and Tri-2 prototypes showed satisfactory performance. Moreover, blue was the preferred hue in most studies of colour perceptions and associated meanings. Therefore, the Tri-1 prototype was selected for further examination in this study.

4.6. Preparation for 3D modelling of final prototype

Similar to the draping method used in real garment pattern making, a 3D virtual dummy was required as a template for 3D modelling of the virtual garment and mapping of the virtual fabric mesh. A 3D body scanner, 'TC^2' was used to adapt the 3D virtual model and obtain accurate measurement data for a standard size 10 dummy (Figure 5). The 3D model of the dummy was imported into 3ds Max as a basic template for 3D modelling development of the final garment. [insert Figure 5 near here]

4.6.1. Adding ease allowances through 3D body scanning

The amount of ease allowances added was examined because it determined the wearing comfort of the final 3D printed garment. The final prototype was regarded as the first-degree garment (clothing worn on top of underwear). According to the ease allowance data in the literature (Haggar, 2004), an ease allowance percentage was calculated and applied to the 3D virtual dummy. A final 3D model of the size 10 dummy with added ease allowances was created and prepared for the 3D modelling process of the final garment. The measurement of the size 10 dummy before and after adding ease allowances is shown in Table 1.

[insert Table 1 near here]

4.6.2. Design considerations for final 3D printed prototype

The garment panel’s weight distribution on the body and the amount of additional load bearing that its weight added could cause discomfort to different body parts. The load tolerance of body parts has been studied (Gemperle, Kasabach, Stivoric, Bauer, & Martin, 1998) and researchers have suggested that, from a physiological point of view, the lower torso can bear higher loads than the upper torso. Sensitive areas, such as area around the neck, or areas where veins, arteries, or nerves were concentrated beneath the skin, were highly sensitive to both weight and pressure. Moreover, pain could result if weight was applied to bony areas. To avoid affecting balance, weight should be evenly distributed over the body, mainly on the stomach, waist, and hips, which formed the centre of gravity. A body map of affordable load values for different body parts was developed by Zeagler (2017) and modified according to the factors considered in this study. The newly developed body map is shown in Figure 6(a).

The final garment prototype was divided into several panels according to the specifications of the 3D printer, where the maximum size of the printing platform was 49 × 39 × 20 cm (Stratasys, 2018). Thus, each panel had to be designed within this size limitation. Cutting lines should be placed on areas with joint stretch or flex to enable the body to bend and move effectively. Silhouette was the overall outline of the garment that gave its first impression (Technology and Living Resource Depository, 2011; Wolfe, 2012). One of the design considerations in this study was to apply shape factors for visual weight. Arnheim (2004) noted that regular, simple, geometrically or vertically oriented forms were perceived as heavier than irregular or oblique shapes. Considering this, the final 3D printed garment was designed with an hourglass silhouette, and the bottom part was given an irregular, tulip-like shape for fullness. Base on the location of seams, panels cutting, fashion illustration and production drawings were created (Figure 6(b)). [insert Figure 6 near here]

4.7. Modelling of final 3D printed prototype

At this stage, a dummy's 3D model and a drawing draft of the final garment with specified panel cuttings should be ready for importing into 3ds Max, as a reference template for the 3D modelling process. The PolyDraw function in 3ds Max could quickly outline the desired silhouette to create mesh that project on or said as "Draw On" the surface of the dummy's 3D virtual model (Figure 7(a)). Topology was a geometry tool in PolyDraw, during the drawing process, lines were drawn to form a grid of quads. The tools could transform the quads into polygon faces and create new faces. The new mesh was plastered beyond the dummy's 3D model, it was necessary to drag and move the meshes to create the desired silhouette according to the draft template (Figure 7(b)). The panel meshes were then smoothed to form the basic silhouette of the final garment, and formed the base template for the Para 3D plugin to further work on. Para 3D also helped to tile and place the basic object on the panel meshes and create pattern density (Figure 7(c)). [insert Figure 7 near here]

4.7.1. Adding shell thickness

After the 3D modelling process was finished, the shell thickness was added onto the meshes. Shell thickness greatly affected the weight of the prototype and final garment. According to the 3D printer's specifications, the minimum thickness of each layer was 0.8mm, any thickness below 0.8mm could cause tearing and the 3D printing process could not proceed. Thus, in this study, a minimum thickness of 1.5–2 mm was selected for better reinforcement.

According to the design considerations and the weight distribution body map developed in this study, garment panel weights were kept within the defined values. The panel weight with different shell thicknesses was calculated using GrabCAD Print, which was recommended for the Stratasys J750 3D printer. By using this software, the final weight and materials consumption of 3D objects and supporting materials could be estimated automatically. As illustrated in Table 2, the total weight of the final 3D printed garment was 5,684 g (12.53 lb), which was within the maximum amount, 13 lb that the human shoulders could bear. [insert Table 2 near here]

4.7.2. Designing joint and interlock

A pair of joint and interlock design were developed in this study. Because number of large separate panels were designed, the interlocks had to provide a sufficiently large opening for assembly. Joint was designed with a 6mm slit distance between panels as a precondition. The joint thickness was unified to 3mm. The prototypes were printed on resin materials using the Stratasys J750 printer. Resin had low flexibility and elasticity, a resin interlock could easily cause breakage in a large prototype because of the force concentrated on the joints. The interlock design thus returned to the conceptual development stage to seek alternative methods of solving the problems of flexibility and elasticity. Rather than 3D printing materials, neoprene fabric was selected for the modified design and was digitally printed with colour patterns The Velcro strips were used to hold the joints together. A pair of joint and interlock is shown in Figure 8 (a). The opening in the final prototype was on either side. All the joints were evenly distributed in pairs (Figure 8(b)). [insert Figure 8 near here]

4.7.3 Colouring and texture mapping

After choosing suitable parameters and previewing colour performance, a texture rendering process was performed to unwrap the meshes and create a UV map. From a design aspect, colour and pattern created a rhythm in the final 3D garment. The warm, dark and bright colours tended to look dense or heavy, and cool, light and dull colours were visually lighter in weight (Stecker, 2010). Thus, the main colour of the final 3D garment was blue, which belonged to the cool colour temperature category; it was light and without any reflective effect because of the texture.

Due to the effect of texture density and colour pattern, the bright pink on the groove between the triangular patterns created diagonal lines and formed a V-shaped pattern. Diagonal lines visually suggested a strong dramatic effect of the garment, whereas opposing diagonal lines (V-shaped pattern) provided a sense of balance within the design (Wolfe, 2012). Owing to the illusion of an uplifting movement, humans perceived a lightweight object when there were inverted v-shaped graphic patterns printed on a garment (Technology and Living Resource Depository, 2011). Looking at the front of the final 3D garment, the red line had an uplifting effect, whereas viewed from the back, the red line pattern presented an inverted V-shape, because the back side was designed as a halter and the whole back was nearly devoid of visual weight, and therefore, visual weight had to be created at the bottom for balancing the whole garment design.

4.8. Materials used in 3D printing process

Resin was the 3D printing material used in the final stage of developing the 3D printed garment. All the required files were then imported into the 3D printer software PolyJet Studio. The software sliced the 3D model and automatically calculated the amount of

3D materials required. In this study, matte resin materials and soluble supporting materials, were involved in the 3D printing process. The total printing time was approximately 309 hours. After the post-processing washing, all the panels were joined by using the interlocks, and the final 3D printed fashion prototype with an innovative surface texture was complete. It is presented on a size 10 dummy, with different side views and details in Figure 9. [insert Figure 9 near here]

5. Conclusion and discussion

The purpose of this study was to combine innovative fashion design, ergonomics, 3D printing technology, and related 3D computer modelling techniques to develop a 3D printed fashion prototype with an innovative multi-colour surface texture. This practice-based study involved the development of a theoretical design process, a practical design concept, and physical prototypes through the application of 3D colour printing technology, 3D modelling using CAD, and consideration of ergonomic and aesthetic factors. The resulting 3D printed fashion prototype contributes both theoretically and practically to the fields of high fashion, education, and research related to fashion and textiles. The design process model developed in this study can benefit fashion designers, researchers, and engineers in the related fields.

The 3D printing technique is an evolving breakthrough technology in the fashion and textile fields, it still represents a new phenomenon for designers and researchers integrating 3D printing technology into fashion to create innovative products. The design process model developed in this study can provide a structured framework to assist practitioners in design problem-solving process. For fashion designers, creating 3D printing prototypes requires computer knowledge during the development process, such as 3D modelling with CAD, creating compatible file formats suitable for 3D printer to produce the fashion prototypes. However, fashion designers may not possess such computer skills, and design may not be an area of expertise of engineers. This leads to a knowledge gap between design and practical computer skills. The practice-based methodology and design process model established in this study can help to integrate technology with practice and ensure the development of successful projects according to specific criteria, thus creating stronger links between design skills and the practical context.

This study presented the application of 3D body scanning technology to 3D printing and provided a model for generating 3D garment meshes with suitable ease allowances. Designers could use a 3D body scanner to develop their own methods to assist the 3D modelling process, such as 3D scanning of the desired paper pattern or directly build the garment structure in CAD. Such contributions will offer attractive elements and high-quality innovative designs to the field of fashion and textile design.

By adopting the 3D printing technology into the field of fashion and textile design, the colour fidelity and platform size of the 3D printer are the major technical limitations, for which researchers are still seeking solutions. Recently, only PolyJet can 3D print objects with a mixture of materials. But, when a design requires colour printing with texture mapping, the rigid resins are the only choices for the printing materials. Employing hard materials exclusively in 3D printed fashion or textile design may not be appropriate because the final product could cause discomfort or hinder body movement when worn. In addition, the colour 3D printing is time-consuming because it is a pixel-wise type of colour printing and the cost of 3D printing technology is still relatively high because of the high material costs in the current market. Therefore, it may not be practical for the mass production of 3D colour printed garments.

In conclusion, although 3D printing technology still has many limitations, it is developing at a considerable speed and “the fashion industry can ill afford to ignore the inevitability of 3D printing” (Sedhom, 2015, p.880). Colour printing represents a potential development area in 3D printed fashion, given that colour is one of the most attractive design elements for design innovation. Therefore, more research studies into the 3D colour printing are required to resolve the current limitations and create more successful 3D printed garments that can be integrated into the fashion and textile fields.

Declaration of interest statement

No potential conflict of interest was reported by the author(s).

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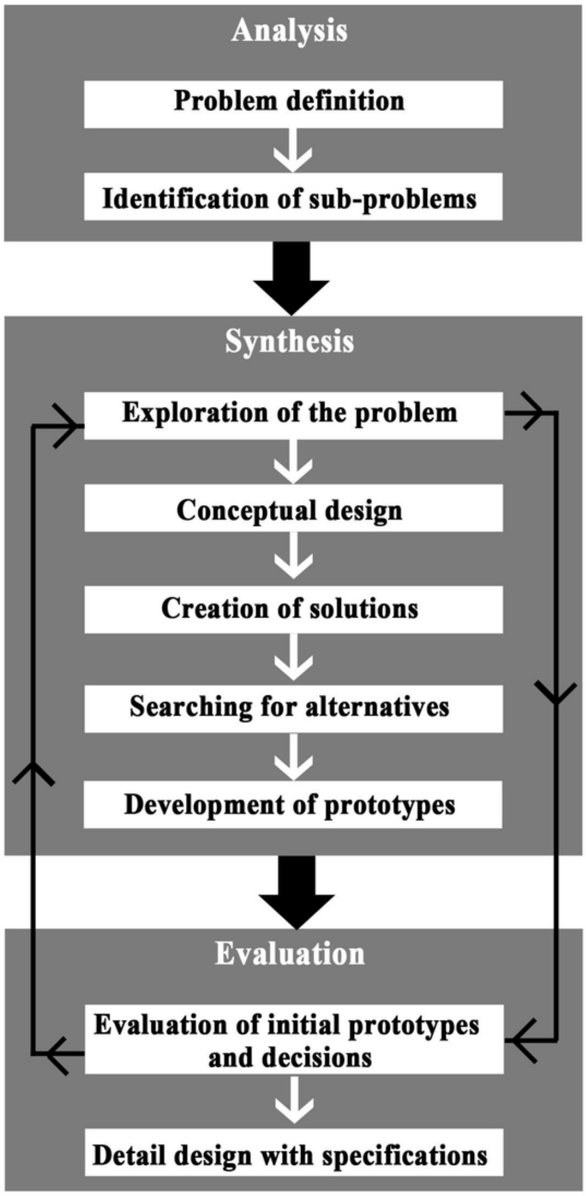

Fig.1: A theoretical design process model for 3D digital printed fashion with an innovative surface texture.

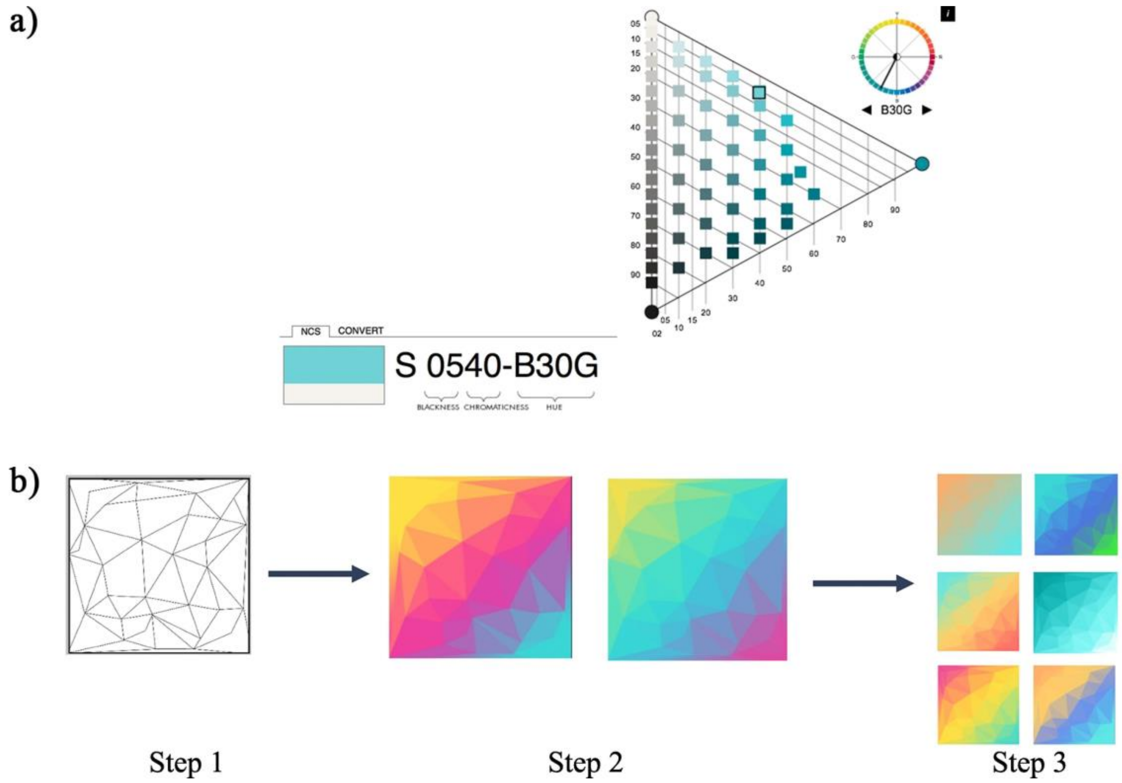

Fig 2: (a) The primary colour selected in NCS colour wheel; (b) Colour patterns creation process, Step 1: Segmenting the square; Step 2: Filling in with colours; Step 3: Creating colour variations.

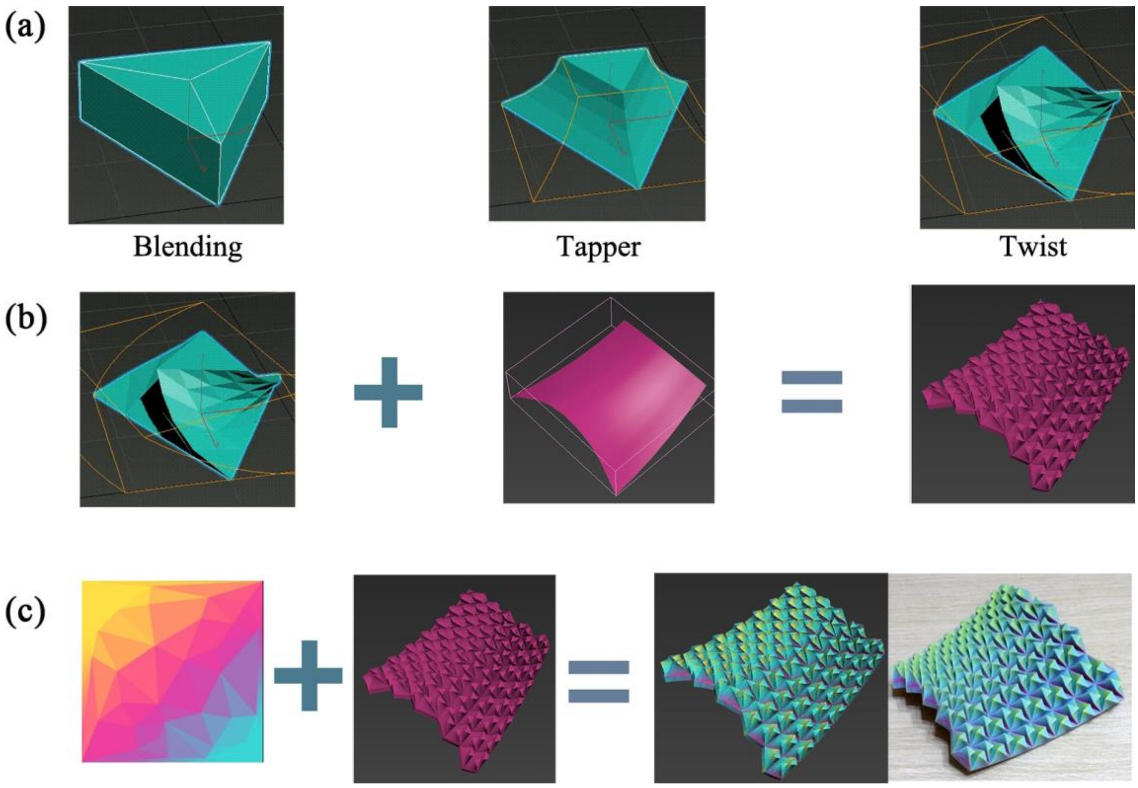

Fig 3: (a) Basic 3D object creation process, Step 1: Modelling the basic object by blending modifier; Step 2: Using tapper modifier to create the desired shape; Step 3: A final basic object was created by twist modifier; (b) The basic object laid out on a curved plane; (c) Texture mapping (projecting colour patterns) onto the meshes and the 3D printed physical prototypes.

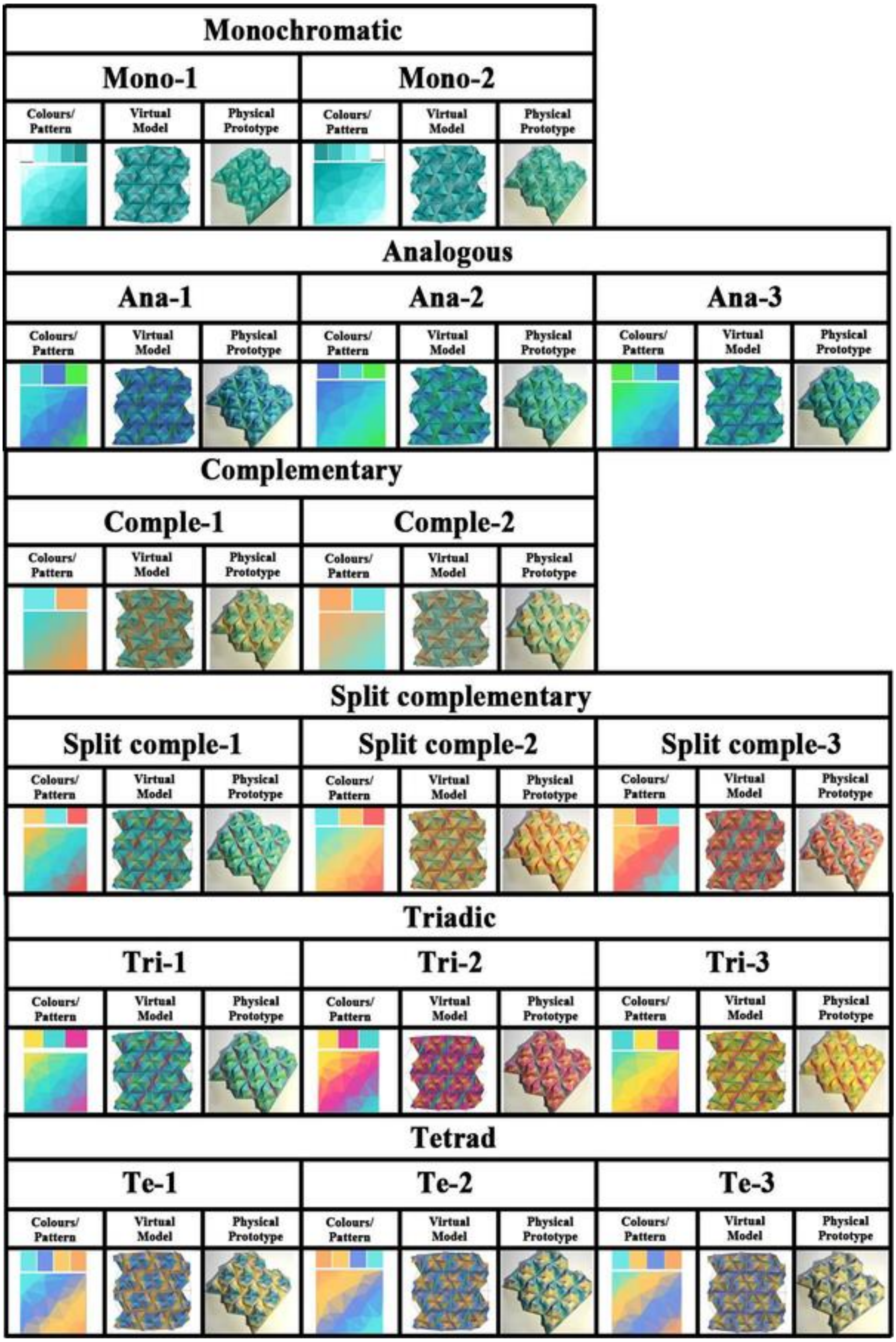

Fig 4: Summary of the initial 3D printed prototypes.

Fig 5: A size 10 dummy in a body scanner TC2 and a virtual model of size 10 dummy.

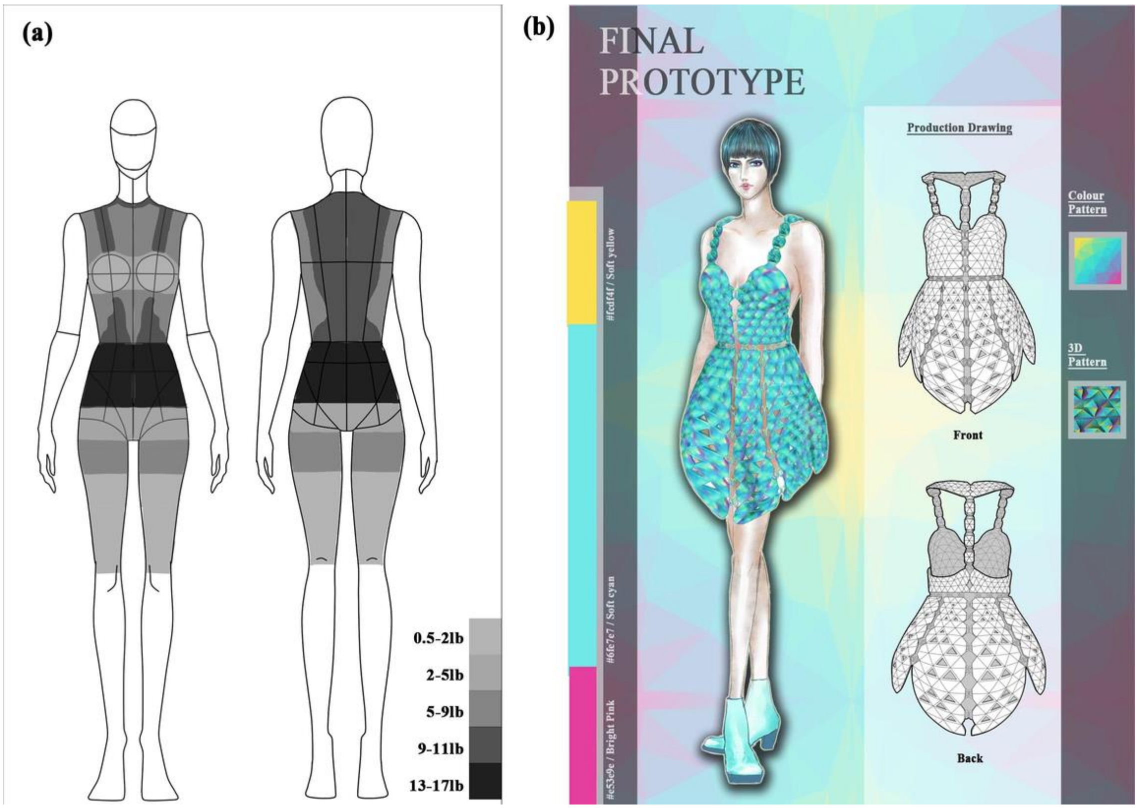

Fig 6: Body map of affordable load values for different body parts; (b) Fashion illustration and production drawings of the final prototype.

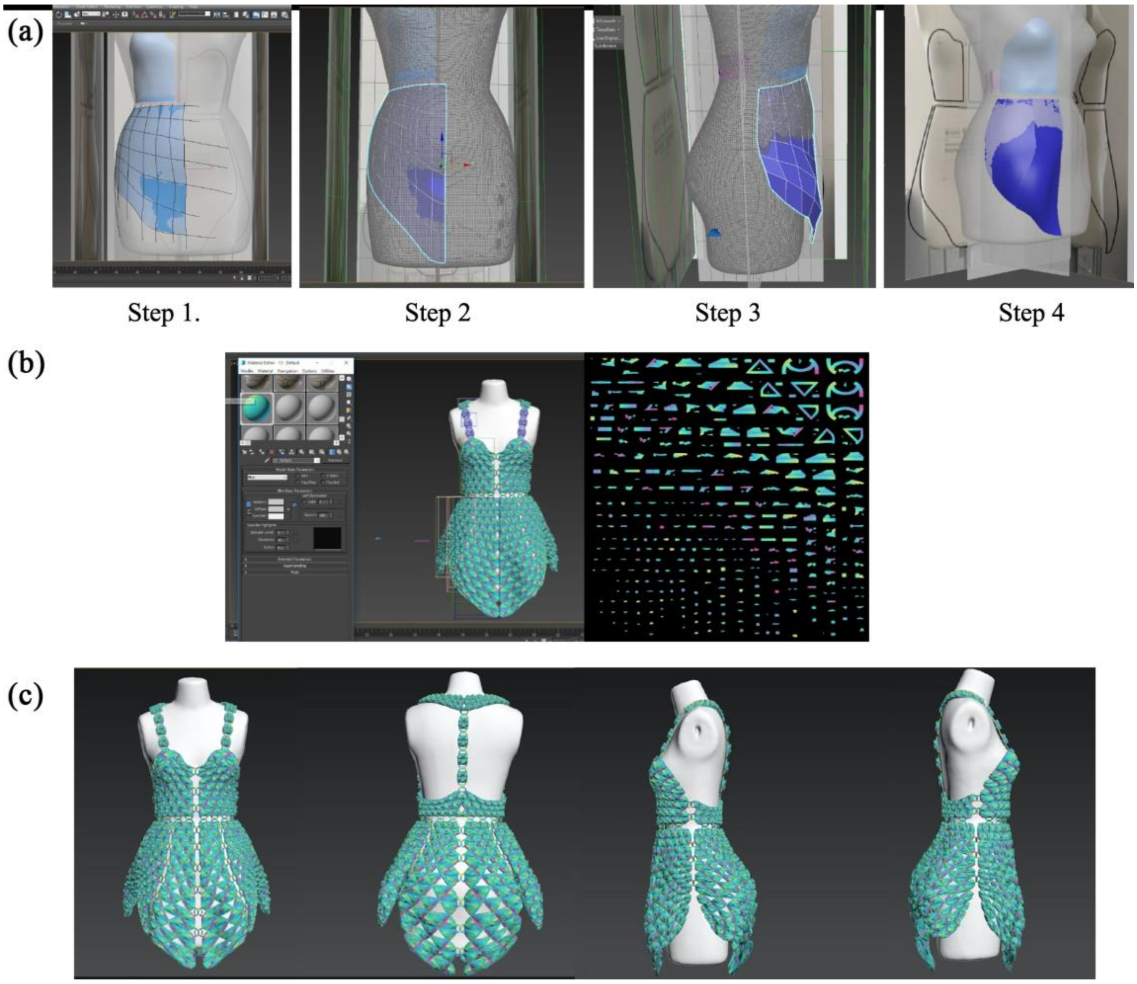

Fig 7: (a) The PolyDraw process, Step 1: Drawing grid of quads; Step 2: Creating a new mesh; Step 3: Dragging vertexes; Step 4: Smoothing the mesh; (b) Texture mapping process and a UV map after unwrapping process; (c) Rendering pictures of the final prototype in different views.

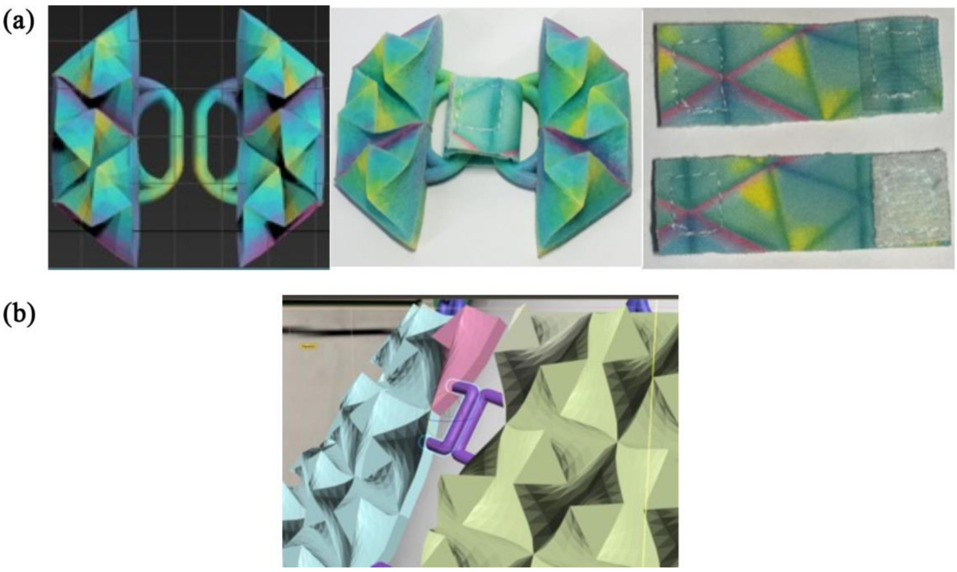

Fig 8: (a) Left: A 3D model of joint; Middle: A physical 3D printed joint; Right: Neoprene fabric interlocks; (b) Position of joints on the final prototype.

Fig 9: Different views of the final fashion prototype.

Measurement point	Original measurement (cm)	Ease allowances (cm) suggested by journals	Measurement after adding ease (cm)	(+) %
Neck	34.00	0.75	34.75	2.2
Shoulder	38.00	3.00	41.00	7.9
Bust	82.00	6.00	88.00	7.3
Waist	64.00	4.00	68.00	6.3
High hip (10.16cm below waist)	79.00	6.00	85.00	7.6
Top hip (22.86cm below waist)	89.50	6.00	95.50	6.7

Table 1: The measurement of the size 10 dummy before and after adding ease allowances

Name of the panel	Weight (g/lb)	Shell Thickness (mm)	
		Minimum	Maximum
Right bust (RB)	252/0.56	1.5	2.0
Left bust (LA)	252/0.56	1.5	2.0
Back top (BT)	201/0.44	2.0	3.0
Neck collar (NC)	109/0.24	2.0	3.0
Centre front right (CFR)	522/1.15	1.5	2.0
Centre front left (CFL)	522/1.15	1.5	2.0
Side front right (SFR)	224/0.49	1.5	2.0
Side front left (SFL)	224/0.49	1.5	2.0
Centre back right (CBR)	883/1.95	1.5	2.0
Centre back left (CBL)	883/1.95	1.5	2.0
Side back right (SBR)	286/0.63	1.5	2.0
Side back left (SBL)	286/0.63	1.5	2.0
Small segment (each, total 10 pieces)	104/0.23	2.0	3.0
Total weight	5684/12.53		
Weight of front garment	2620/5.78		
Weight of back garment	3064/6.76		
Weight of top garment	1854/4.09		
Weight of bottom garment	3830/8.45		

Table 2: Total weight of the final 3D printed garment