Design in 3D: A computational fashion design protocol

Introduction

Computational fashion design research is an important area of inquiry for both design researchers in the apparel industry as well as academic community. Throughout the last 50 years, clothing design and construction methods have already undergone significant changes to become a fully automated, computer-aided process (Lee, 2014; Loker, Ashdown, & Carnrite, 2008). The use of computer-aided-design (CAD) software offers many new possibilities and it is critical to reconcile the use of technology and traditional garment construction methods for wide-scale implementation in the design process (Lee, 2014). In this paper, the definition of parametric and algorithmic design refers to processes based in parametric mathematics and manipulated through the particularity of an algorithm. In what follows, the use of algorithms and computational design methods were explored to add to the growing body of literature on the use of digital technology in computer-aided fashion design. While parametric design is not new, computational programs have enabled a wider retinue of options to build and design with greater dexterity and reproducibility.

The purpose of this study was to create a corset—understructure as well as fabric covering—using only computational, 3D approaches to fashion design. The process incorporated 3D body scan data, parametric methods for the 3D printed design, and algorithmic methods for the automated, custom-fit fabric pattern. In what follows, researchers situate the relevance of this project and provide an adapted framework to guide future methods-based design scholarship.

Design Framework

Elizabeth Bye's paper, "A Direction for Clothing and Textile Research" (2010) provided much-needed context and infrastructure for design-based research in the field of apparel design.

Inspired by Bye's 'research-through-practice' framework (2010, p. 208), a method or procedure-based design framework is proposed in this paper to provide context and precipitate conversations among designers about nascent techniques and construction methods, where innovation and reproducibility are the final contributions to the larger apparel design field. The orbital model presented in Figure 1 places the methods at the nucleus of the diagram where inquiry, contextual review, practice and reflection, analysis, and the final prototype or artifact, are all reflexively informed by modifications to the algorithms in the computational design protocol. While this project used a computational approach, the framework below acknowledges the significance of procedure and technique in many forms of design research.

Design research is often characterized by the blurring of the distinction between research and design which ultimately becomes a circular, iterative process (Edelson, 2002). In keeping with the circular nature of the design process and the three-dimensional ethos of this paper, Bye's framework was modified to illustrate the procedure in this design project wherein the protocol is located at the center of the sphere because the construction of a protocol/process is both the nucleus for the research as well as the final outcome (Figure 1).

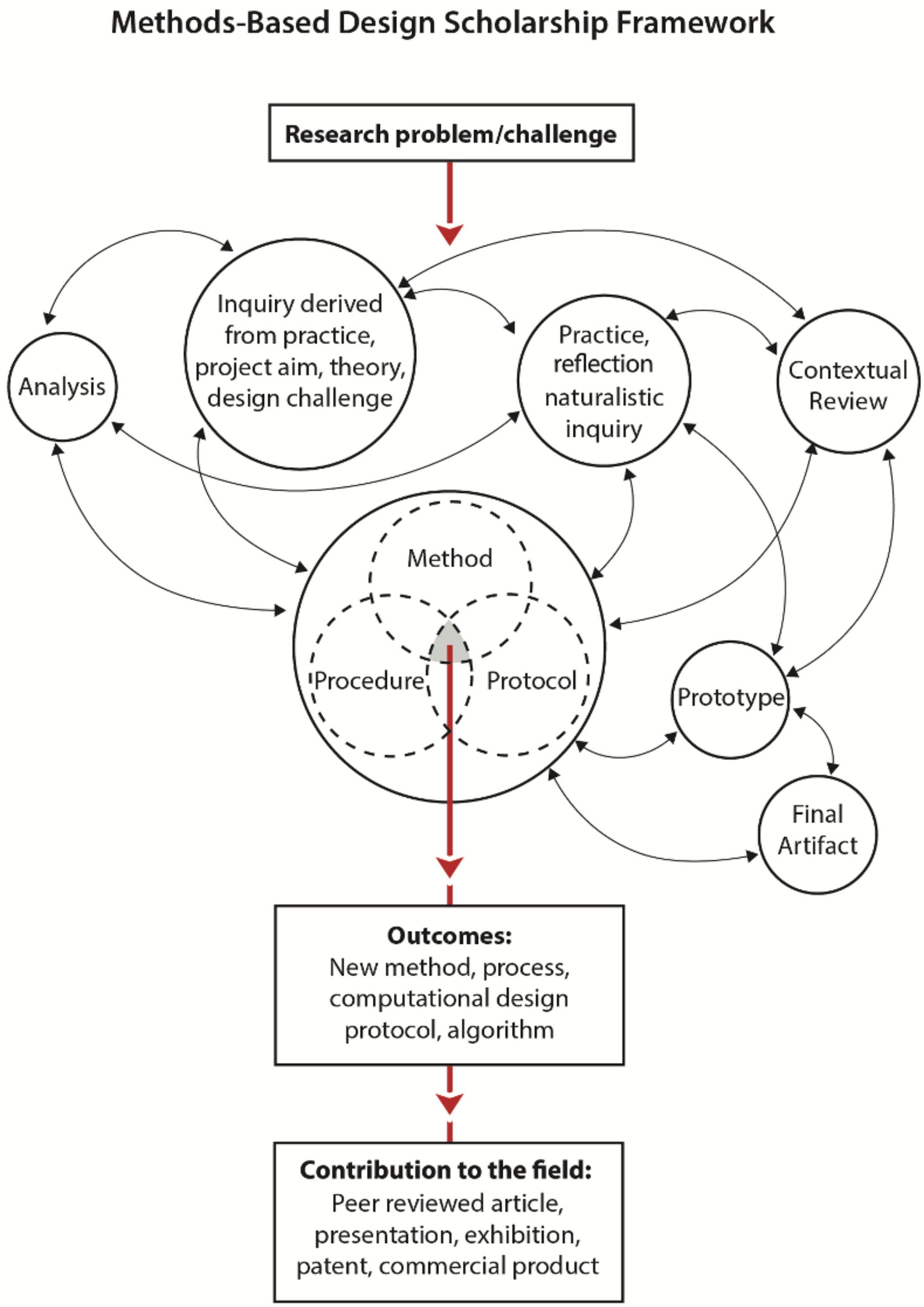

Figure 1. Methods-based design scholarship framework.

Situating 3D Computational Fashion Design

In the late 1980s and early 1990s, research in sizing and fit used somatograms to experiment with accuracy in moving from three-dimensional forms to two-dimensional computer-generated patterns (Winakor et al., 1990). Because the widescale adoption of CAD programming was relatively new, researchers explored the use of geometric pattern classification through body measurements, to assess whether or not computer-generated patterns were as easily altered as traditional pattern drafting techniques. Later, as CAD programming became more widely adopted, researchers in the mid-2000s explored the use of 3D body scan data to create a basic skirt patterns (Griffey and Ashdown, 2006), the relationship between body shape and ease value in trousers (Petrova and Ashdown, 2008), and automatically place a side seam using only scan data (Ashdown et al., 2008). The increased availability of CAD programing enabled researchers to examine 2D and 3D shape construction in conjunction with traditional draping techniques (Townsend, 2004; Bye, 2010). Song and Ashdown (2010) conducted an exploratory study into the use of body scan data in virtual fit assessment analysis and later, they similarly explored the use of virtual fit software with respect to pants (Song and Ashdown, 2015). Song and Ashdown (2010, 2015) showed the ways in which 3D simulation enables the designer to zoom, rotate, and analyze fit issues in a virtual format, techniques which if perfected, would minimize the need for muslin fittings and increase production efficiency. As such, apparel product design companies have largely adopted the use of virtual simulation software to save both time and money (Lee, 2014). Apparel industry adoption of virtual fit analysis software has also been a subject of ongoing research in consumer behavior, fit analysis, and marketing (Beck & Crié, 2018; Kim & Forsythe, 2008; Lee & Park, 2017; Lin & Wang, 2016; Merle, Senecal, & St-Onge, 2012).

Sungmin Kim's (2015) paper on the use of parametric design methods to analyze bodily concavity and convexity, offered insight on the interplay between parametric design in conjunction with 3D body scan data sets. In the fashion industry and museum world, 3D printed garments have been shown on the runways and have subsequently been accessioned into museum fashion collections. Fashion designer Iris van Herpen's iconic 3D printed designs are emblematic of the use of parametrics on the fashion runway. Referred to as "haute couture's chief scientist and perhaps also its leading futurist" Van Herpen's recent Fall 2018 show titled *Syntopia* was called a merging of biology and technology (Verner, 2018). Merging traditional tailoring techniques and the latest in computer aided design, Van Herpen is known to start from a sketch after which she works with an architect to realize the 3D structure. *Syntopia* was just one example of innovation driven design and construction methods which rely on parametrics to capture the marriage between analogue and machine techniques.

Methods and Computational Design Protocol

The 3D computational methods used in this study enabled a new way of rendering the body-to-pattern relationship through the use of multiple software platforms. Drawing on a 19th century historical garment—the corset—computational design methods were used to similarly manipulate 3D proportion and form using a structured undergarment and custom fit pattern for the fabric layer. Because the corset typifies an early synthesis of clothing and technology, it was chosen as the starting point for this research. The 3D printed structure was created using parametric design techniques while the design of the fabric layer used an integrated computer algorithm which automatically generated snug-fit pattern pieces for the 3D scanned body on which the 3D printed structure was based. The automated operation of pattern generation took one click, in a timeframe of less than two seconds. It has been shown that 3D body scanning offers exponentially more data points which provide a more accurate account of an individual body (Ashdown and Loker, 2010; Daanen and Ter Haar, 2013; McKinney et al., 2017; Poole and Shvartzberg, 2015).

The individual 3D body scan used in this study originally had 780,381 points and was randomly selected from the CAESAR® (Civilian American and European Surface Anthropometry Resource Project) database. Four computer software/programs were used to process the scan: Geomagic® and Rhinoceros® in creating the 3D corset structure; Matlab® and CLO3D to automatically generate and modify the customized pattern pieces. The fit of the raw patterns was verified in CLO3D, a virtual garment simulation software. CLO3D was chosen as the visualization software because it was thought to be more user-friendly as compared to the 3D simulation function in Optitex™. Figure 2 features the work flow of the design protocol and what follows is a more detailed description of the procedure.

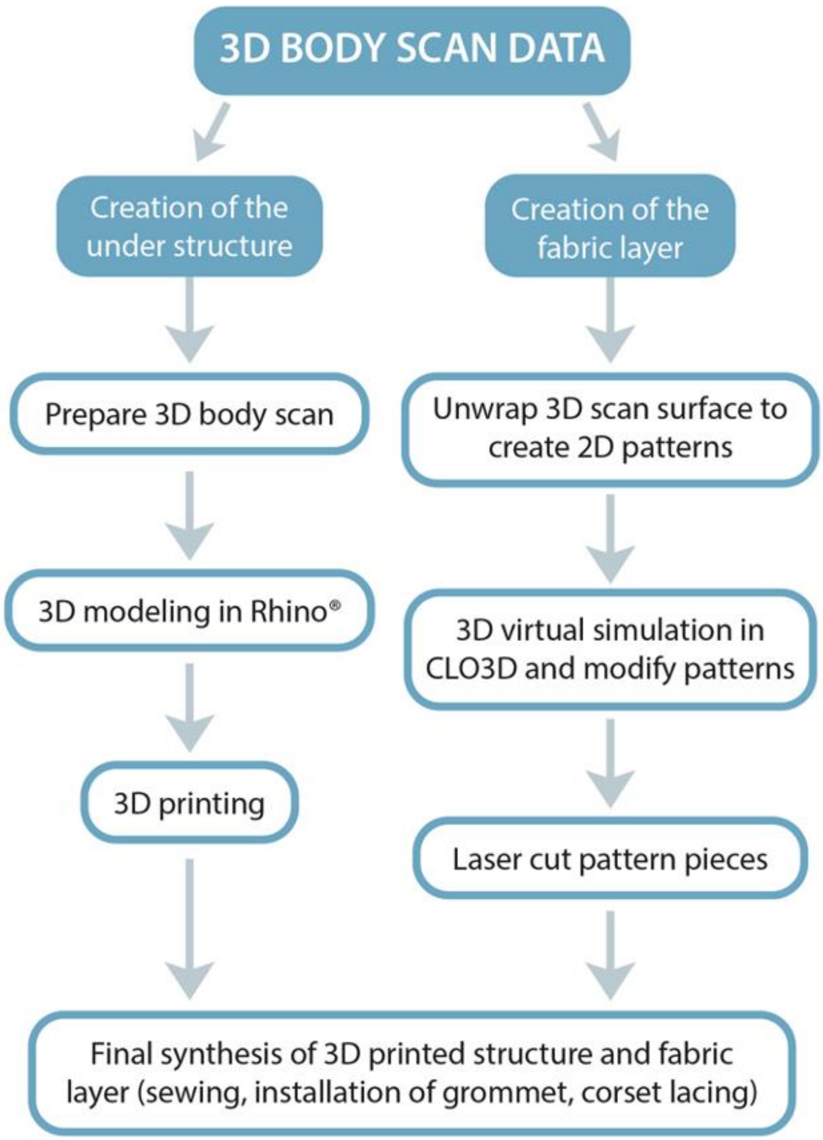

Figure 2: Work flow of the design protocol.

The 3D Printed Corset

The construction of the corset structure began by using Geomagic®, an engineering software which enables 3D scan data to be processed and analyzed in CAD software. This software was used because of its ease in rendering mesh shapes as they translate into solid forms.

The scan selected for this project was imported into Geomagic®, where the head, the neck and the limbs of the scan were removed, keeping only the torso as this research focused only on the creation of a wearable garment for this area of the body. Due to the fact that participants of the CAESAR Project were scanned facing a 45˚ angle to the true front, all CAESAR scans require rotation. In this case, rotation was also done in Geomagic®. Functions such as “Mesh Doctor” and “Fill Holes”, both built-in applications or plug-ins, were used to enhance the quality of mesh on the scan surface thereby improving the quality of the 3D printed object. It was necessary to wrap the mesh into a smooth surface to be able to work in most CAD software. To these ends, the following steps were taken: Contour detection and manual edition, patch and grid construction, fitting of surfaces and conversion to CAD file (Figure 3). The exported file was in .igs format and was ready to be imported into Rhino® for parametric design (Figure 4a).

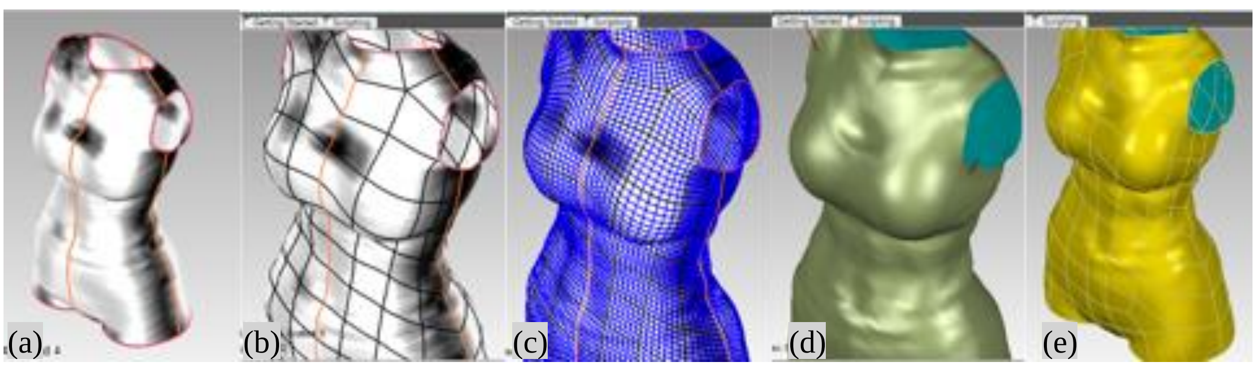

Figure 3. Processing of the 3D body scan in Geomagic®: (a). Contour detection. (b). Creation of patches. (c). Creation of grids. (d). Fitting of new surfaces. (e). Conversion to CAD file.

In Rhino®, horizontal contour lines were re-constructed from the scan surface (Figure 4b). A Grasshopper program—a visual programming language that runs within Rhino®—was written to create a multi-hexagon structure that fits to the new surface formed by the contour lines (Figure 4c). Transforming 1D hexagonal line segments into 3D pillars was attempted; however, due to software limitations it was not possible to join the pillars. In addition, there were small gaps at the edges of the pillar connections. These two factors increased the likelihood of significant problems during the 3D printing process. Therefore, the Grasshopper program was modified to create a 2D surface composed of the same hexagons, only this time the sides of the hexagons included widths (Figure 4d). Then the shape of the structure was modified aiming for asymmetrical design elements. Multiple trials were undertaken during this process before finalizing the object shown in Figure 4d.

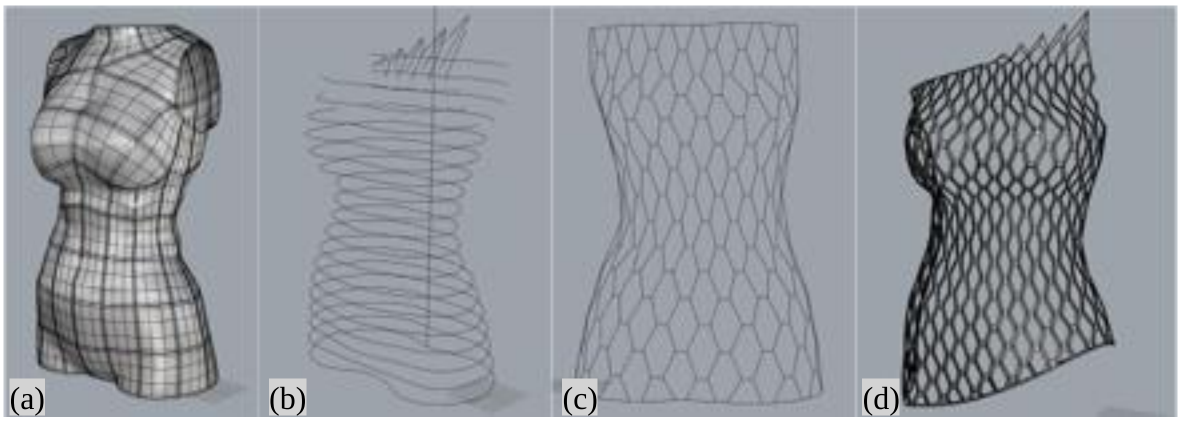

Figure 4. Creation of a surface with hexagon hollows in Rhino®: (a). Initial import. (b). Reconstructed horizontal contour lines. (c). 1D Multi-hexagon structure. (d). 2D Multi-hexagon structure.

Once the necessary contours that modify the shape of the structure for wearability were achieved, drill holes were added at center front, center back, and down both the proper left and right seams for lacing; the aim was to ultimately separate the structure into four separate quadrants for 3D printing (Figure 5). To add the drill holes for lacing, the hexagonal structure along the computer-generated seams were closed as directly cutting holes on the hexagon edges reduced the strength of the structure, making it very likely to break under pressure. Moreover, a few hexagon hollows at the bust area were also closed in consideration of modesty (Figure 5a). At this stage, there was a technical challenge in transforming the two-dimensional surface into three dimensions (i.e., the addition of thickness added to the hexagonal geometry), due to the excess number of faces on the surface area. This was resolved by first turning the parametric surface into a mesh surface (Figure 5b). Figure 5 also shows the initial design aesthetic designed via 3D modeling in Rhino®. The file was then exported into .stl format for 3D printing.

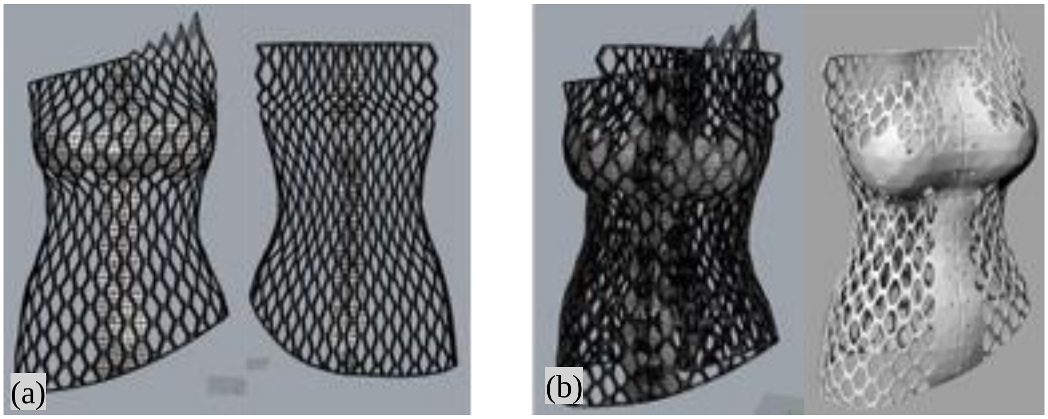

Figure 5. Creation of the 3D model in Rhino®: (a). Hexagon hollows closed at where the drill holes will be and at bust area. (b). The final 3D structure.

Several additional technical challenges arose in the 3D printing phase, namely, the 3D structure was too large for the 3D printer available for this research. This project was printed on a Stratys Fortus 400mc 3D printer with black ABS-M30™ material and SR-30™ soluble support material. Therefore, it was necessary to cut it one more time horizontally at the waist. Ultimately eight pieces were 3D printed (Figure 6). Geomagic® software was used again to re-render the meshes for improved behavior in printing, and the re-rendering created the change in edge formation along the top and bottom of the structure. These applications reduced the 3D printing time and changed the edge formation along the top and bottom of the structure which subsequently became an unanticipated aesthetic innovation (Figure 6).

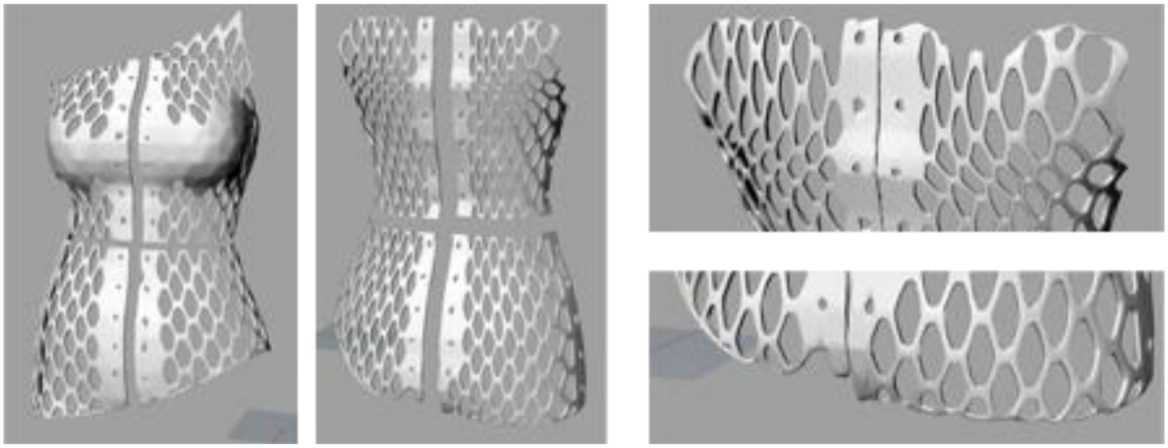

Figure 6. The final 3D pieces that were sent to the 3D printer.

The Customized Pattern Making for the Fabric Layer

Because corsets are typically covered in fabric to disguise the boning (neither binding tape, lining, nor coutil were used in this project), it was necessary to create a fabric layer for the 3D printed structure. To do this, we developed a program in Matlab® to automatically generate customized pattern pieces based on any body scan (Figure 7a). This methodology was used to create the raw patterns for the scan upon which the 3D corset structure was built. At this point in the process, the patterns were plotted out, digitized into Optitex™ and exported in the .dxf-aama format, the only format importable to the CLO3D virtual fitting platform.

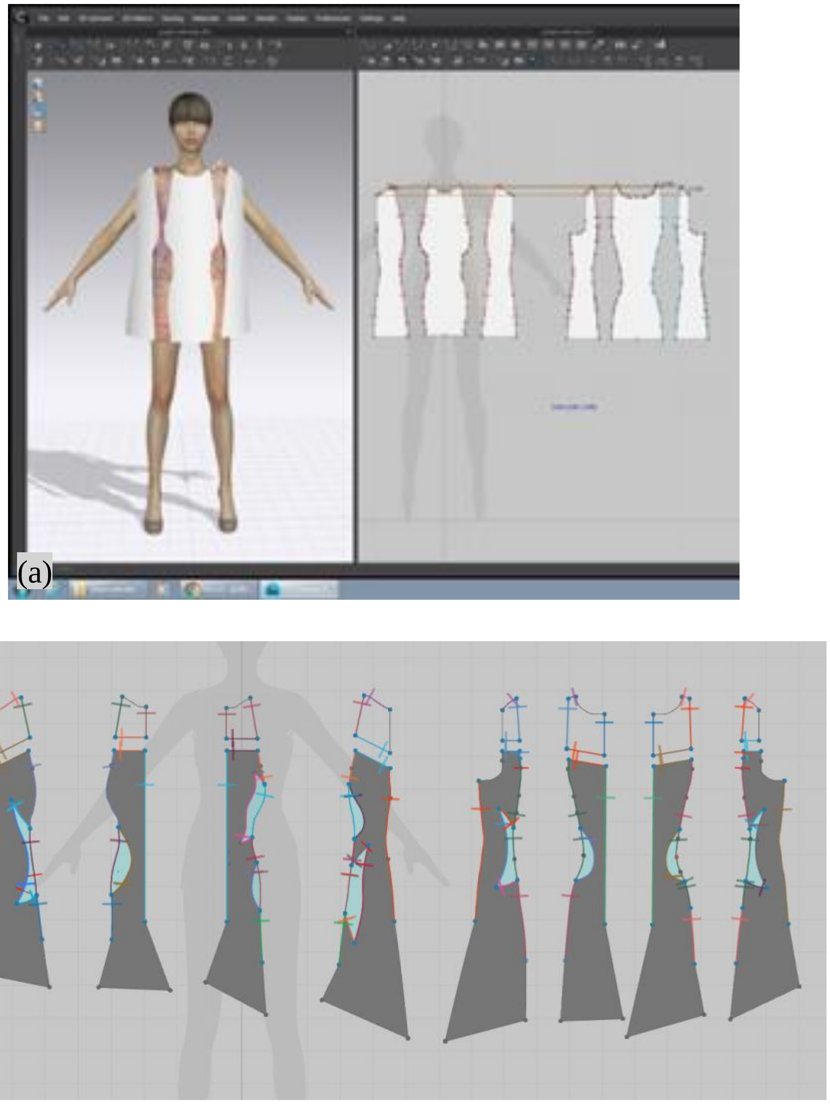

Figure 7. (a) The customized pattern pieces created through Matlab® imported into CLO3D. (b) The final pattern pieces with design elements incorporated.

It has been shown that 3D virtual try-on technology is an effective way of synthesizing parametric models and offering more realistic visualization (Baytar and Ashdown, 2015; Yu et al., 2012). Using the CLO3D software, it was possible to import the 3D corset structure and place it around the avatar’s torso (Figure 7a). It was then necessary to adjust the dimensions of the avatar to fit the shape of the 3D body scan and therefore, to properly test the fit of the pattern pieces. Because CLO3D software cannot guarantee perfect fit, the virtual software was used to make design decisions in a visual format. Given that corsets have historically not had ease, this contemporary construction similarly did not factor in ease. This was done in attempt to highlight the accuracy of the pattern drafting methods in capturing the shape of the 3D printed structure. One of the greatest design challenges in this project was deciding which design elements to include in in the final artifact. To showcase both designed elements of the final artifact—the 3D printed corset and fabric layer—it was decided to cut decorative shapes into the pattern pieces to draw attention to the 3D printed corset beneath. To create the cut-outs, draft lines were directly drawn on the 3D virtual garments to experiment and come up with the desired shapes. Those draft lines were instantly reflected on the 2D patterns and the pattern pieces were modified based on those draft lines.

The finalized patterns (Figure 7b) were exported and converted into an .ai format. Seam allowances were added in Illustrator®. Because it was necessary for the outer layer and the under layer to work in tandem as an overall garment, metal eyelet grommets were used to lace the fabric layer to the 3D corset structure. The holes for lacing were built in to the 3D file in Rhino as shown in Figure 5b. In all instances, the fabric was laser cut to maintain the degree of precision from the final pattern pieces (Figure 7b).

Figure 8. (a) The front view and (b) the back view of the final corset and garment.

Discussion and Conclusion

The methods or protocol-based framework which nucleated this design project enabled more concentrated research into the step-by-step procedure and computational techniques. The final artifact illustrated the efficacy of the design methods. As such, the framework in this project offered potential avenues to further computational design research and build a computational design practice. As a method, the scan-to-pattern process was fast, integrated (the process went from body scan to pattern in one-click), and there was no need for detecting and placing landmarks on the body. The algorithm factored in body shape, body thickness, minor concavity/convexity in contours; and the connectivity of parametric theorems made it possible to manipulate shape in 3D more easily on a computer as opposed to multiple rounds of muslin prototyping. By using body scan data and computer coding, the computational construction methods in this study demonstrate a pliant and sustainable method of clothing design wherein designers were able to use the X, Y, and Z planes in differentiating shapes and sizes throughout the construction process. While previous garment construction techniques have relied on the tailor's skill in translating the 3D shape of the body into 2D patterns and vice versa, the computational methods discussed in this paper enabled work to take place in three dimensions from ideation to creation.

In practice, the use of the virtual simulation software (CLO3D) streamlined the prototyping process. Mesh projection uses a series of data points from the 3D body scan which are patched using computer generated algorithms and then easily replicated on other parts of the body. Through the use of parametrics, the data points collected in 3D body scanning enabled the regulation of each aspect of shape manipulation through modifications of the algorithm. The use parametrics aided in balancing interference in the scan's data points. Because each 3D mesh is composed of multiple planes, every aspect of shape manipulation in the X, Y, and Z coordinates was manipulatable through the use of the computer.

The challenges presented in the transition to the final 3D printing process led to the re-rendering of the parametric design using Mesh Doctor in Geomagic® (Figure 6). The results of these efforts became an unexpected design element and subsequently a source of further research. The irregularities that arose in the transition from software to software were at first viewed as a dilemma, however, upon further research they became integral to the research driving this study. While the design irregularities in this research were not consciously constructed, they served as an important factor in shaping the context and aesthetic of the final designed objects (Figure 9).

Figure 9. The detail view of the final corset and garment.

While this study was less concerned with artificial intelligence and the possible uses of machine learning, the construction of patterns using algorithmic design techniques have the potential to be used in approaches which are unscientific and biased. As body scan data and the use of biometric information become increasingly common components of computational fashion design, the ethical use of larger data sets, particularly with the aim to use predictive modeling, should a significant consideration for research agendas. Future directions for this project entail conducting a formal fit test to measure the accuracy of the computational techniques.

Through the use of computational design methodology, this study sought to illustrate the use of algorithm driven computer programming to advance creative design practices. As a design tool, a custom-coded garment based on a unique body scan offered a highly malleable method of pattern construction. The corset, the final artifact of this study, was created to explore the vast web of data from a 3D body scan as an expressive way of creating form, shape, and proportion. The process of designing in 3D with the additional use of the z-plane, allowed for the dynamic capability to manipulate proportion and form using parametric design techniques. Further, the use of parametric design in one of the early stages of development allowed for increased flexibility in tackling challenges inherent in the design process. The need for adaptability and responsiveness in fashion design is reflective of systematic analysis of daily wear and tear. As such, advancements in design protocol and the creation of a forum for methods-based research is imperative as digital innovation transforms the apparel industry.

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