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Application and Parametric Design of Line Visual Illusion Graphics in Clothing

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Abstract
This research adopted literature analysis methods to explain the principles and types of line illusion and, secondly, using Grasshopper software generated some fashion design samples with visual illusion element application. Then semantic analysis was applied to investigate audiences' cognition, with the aim to improve the design. Lastly, Grasshopper software was used to generate new design patterns by changing the set of generated points through algorithm operation and dotted line interference to change the presented linear illusion forms and patterns. The results of this research show that with the support of parametric technology, the opportunities and space for creating line elements in clothing will be further expanded, enabling that real-time pattern or apparel design changes, and adjustments can be realized by parameter variable controlling. The research comprised a new attempt at combining linear visual illusion, fashion design and parametric design, showing the content and design case studies for relevant research in this area.

Keywords
clothing line elements, computer-aided fashion design, fashion design, line visual illusion, parametric clothing design, parametric design.

1. Introduction

The line element visual illusion pattern derived from Op Art extracts the visual characteristics of the line element in Op Art. The periodic changes of lines are matched with colors to form a longitudinal and precise arrangement pattern, which is favored by fashion designers and consumers for its simple artistic style. Since the 1860s, the art of visual illusion of line elements has been used by fashion designers as an artistic element in the artistic creation of clothing, accessories and so on. The visual effects produced by the combination and composition of such patterns have also been studied by academics, such as Thompson, who applied Helmholtz visual illusion to garments and argued that horizontal striped lines create the illusion of thinness more than vertical striped lines [1]. Jung Hyun et al. also conducted a related study, and they proposed that the change of line shape and line direction, the superimposition of line elements, and the combination of line element pattern design can cause a visual illusion effect, which can affect the viewer's perception of clothing form [2]. Meanwhile, researchers conducted an extensive design case study analysis and found that most of the current works of virtual fashion mostly use line visual illusion elements and apply them in the creation of clothing patterns and silhouettes, resulting in clothing that presents a strong three-dimensional sense, a sense of space, a sense of technology and emotional expression. The most famous brands and designers are famous for the application and creation of line visual illusion design elements on costumes, such as Iris van Herpen, Christopher Kane, Issey Miyake etc.

Nowadays, the concept of digital fashion is widely circulated, and it has enriched the art form of fashion art work creation and expanded the boundaries of clothing-related research with new concepts, technologies and scenes. Its creation technology is largely inseparable from the development of computer technology, which has made it easier to solve multi-parameter driven problems [3]. Parametric thinking is a term first defined by David Karle and Brian Kelly as "*Parametric thinking is a way of relating tangible and intangible systems into a design proposal removed from digital tool specificity and establishes relationships between properties within a system. It asks architects to start with the design parameters and not preconceived or predetermined design solutions*" [4]. Parametric design started in the architecture area. Nowadays, parametric thinking has pervaded other areas of design, such as industrial design, product design and apparel design. In the field of apparel, there are two main steps in 3D parametric design based on computer technology: garment model construction, garment model editing and modification. The methods of garment model construction mainly include point, line and surface modeling according to human body features, adding constraints to make it a garment feature framework and completing the reconstruction of the garment surface, sketch interactive modification, deformation and other methods; while the methods of garment model editing and modification mainly include sketch interactive modification, deformation technology and parametric deformation technology, etc. These techniques are important ways to realize a personalization garment [5]. Distinguished from traditional garment design, parametric modeling is a digital modeling technique based on data and algorithms to design complex geometries through computer programming tools [6]. In addition, under the concept of

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sustainability, parametric design has the unique advantage of rapid modeling and real-time reshaping. By defining, changing or coding the pattern or garment shape through parameters and variables, multiple modifications and diversity creation can be realized during the design generation process [7].

There are some interdisciplinary studies which combine parametric design and fashion design. Wang et al. (2021), using Voronoi graphics as the experimental object, generated Voronoi graphics by parametric design and changed the set of generated points through point and line interference, thus changing the presentation form of the apparel [8]. Jiwoon et al, investigated the application of parametric design in 3D fashion printing in 2021 [9]. Related studies have proved that the application of parametric design in fashion design has become an industry trend. Through combing and searching the relevant literature, it has been found that there are few cross studies about combining line visual illusion with parametric design in the fashion design research field.

This research first illustrates the principle of linear visual illusion, and parametric design was used to generate design samples of visual illusion in apparel. After that the semantic analysis method was used to test the feedback of the audience and further optimize the design scheme. Grasshopper, as a parametric design tool, was applied in the design process, producing some samples of a linear visual illusion pattern and clothing, as well as showing the design process and results.

2. Principles and types of line visual illusion

Visual illusion refers to the fact that human eyes cannot correctly understand the essence of external objective things, and misunderstand the size, shape, and color of objective things [10]. The incorrect perception caused by objective objects or visual stimulus must be rectified timely because it may cause serious distortion of facts. However, in long-term practice, people have realized that visual illusion cannot be eliminated, so that people change from simply trying to rectify it to utilising it skillfully, serving human production and life.

Early forms of visual illusion appeared in the 19th century, where it was used in the creation and research of graphic painting to explore how graphics and color act on human vision. At that time, visual illusion artists used vertical lines, parallel lines, and curves as style shaping elements, and then stimulated the viewer's retina through a special arrangement to make the viewers feel motion effects like flickering, flowing, rotating, radiating, etc [11]. The basic types of visual illusion can be roughly divided into three categories: segmentation visual illusion, angle visual illusion, and contrast visual illusion.

(1) Segmentation visual illusion: It includes horizontal line segmentation and vertical line segmentation. It specifically refers to horizontal or vertical segmentation on a plane, range or object. Horizontal line segmentation can guide the sight lines of human beings to make lateral motion, enlarging the width of the original object; and the vertical line segmentation can guide the sight lines of human beings to make vertical motion, enlarging the height and depth of the original object. The visual illusion phenomenon caused by the segmentation of the square of the meridional segmentation and the square of the latitudinal segmentation is shown in Figure 1a. Figure 1a shows 2 squares of the same size; the left side square is divided in the longitudinal direction and the right side square is divided in the latitudinal direction. It can be seen that the warp-sectioned square looks narrower, and the weft-sectioned square looks wider.

b) Picture from:https://www.shutterstock.com, c) Picture from:https://www.alamy.com/stock-photo-visual-illusion-49644970

(2) Angle visual illusion: It refers to visual illusion caused by crosswise arranged oblique lines composed of certain angles. A different crosswise arrangement of oblique lines would lead to a different feeling of convex or concave due to the influence of the tilt angle, which makes the originally parallel lines or line with equal length seem not parallel or seem stretchable. The most famous, the Hering illusion, is shown in figure 1b. The Hering illusion is one of the geometrical-visual illusions and was discovered by the German physiologist Ewald Hering. When two straight and parallel lines are presented in front of radial background (like the spokes of a bicycle), the lines appear as if they were bowed outwards. The Orbison illusion is one of its variants, while the Wundt illusion produces a similar, but inverted effect [12].

(3) Contrast visual illusion: Contrast visual illusion usually refers to two objects of the same size and shape under the influence of two different opposing environments, such as length, size, depth, etc., which can cause the human brain perceptual system to produce incorrect visual perceptions of unequal graphic areas [13]. A circle surrounded by a large circle environment and one surrounded by a small circle environment are shown in figure 1(c), where the two circles in the middle are equal in size, but the middle circle on right side of the figure is much smaller due to being in different opposing environments.

In traditional clothing making techniques, the use of the above line elements requires a lot of fabric testing to achieve the design effect, and the tailoring and stitching piece by piece is also cumbersome, so that the more effective methods which can solve this problem should be explored. As a matter of fact, the parametric design technique can help to solve this problem.

On the basis of the parametric clothing surface structure, computer code variables, or algorithm tools attached to the algorithm language are used. By controlling the parameter variables in it, more variable and complex clothing structures, two-dimensional skin patterns and three-dimensional space forms are generated.

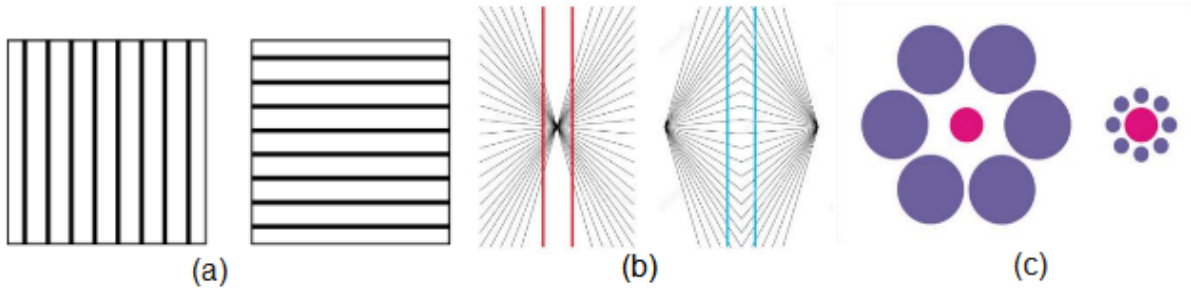


Fig. 1. Segmentation (a), angle (b), contrast, (c) visual illusion

3. Research Process

The research process included three steps:

(1) Establishing the design prototype with linear visual illusion characterization features of clothing by using parametric design.

Design prototype is the most basic product form to meet the needs of users, and it is the common cognitive basis of designers and users, with a certain characteristic or attribute [14]. According to Aldo Rossi, archetypes are the basic forms of things, and types are the principles of formal change and logical rules behind archetypes [15]. By refining the consensus characteristics of line elements to obtain design prototypes, referring to different line visual illusion form composition rules, and consciously deforming the design prototypes, new design solutions and inspirations can be generated. The initial design scheme of linear optical illusion is established according to the above method.

(2) Semantic analysis for users' cognition and design form extraction and transformation;

User semantic extraction generally consists of three steps: user semantic acquisition, text organization and semantic vocabulary refinement [16]. Firstly, the interview method and qualitative analysis method are used to obtain user semantics; then the original semantic description text is normalized to transform natural language information into a lexical form suitable for research and analysis. Finally, the semantic vocabulary is generalized, refined and embellished to obtain core semantic vocabulary with high user attention and good semantic expression. The core semantic vocabulary mainly includes adjectives, adjective phrases and degree adverbs, among which adjectives and adjective phrases can reflect the emotional image at the subjective level; it can help to form a suitable design strategy for follow-up design improvements.

(3) Design optimization and parametric design process analysis. The design process with the parametric design uses tools, shown later, based on the design improvement strategy.

4. Approach and design process

4.1. Basic design samples for linear visual illusion fashion design creation

Rhinoceros 3D is the most widely used 3D modeling software for modelling surfaces ("Rhino"). Grasshopper is a Rhino-based visual graphical algorithm editor that focuses on geometric editing and can be programmed to generate 3D shapes. The interface of Grasshopper is intuitive, with less code and high practicality. It is possible to complete most of the modeling functions in scripting through algorithmic editing, to quickly present ideas in 3D virtual space, and to realize the adjustment of the design object form by adjusting the parameters, while observing the changes of the generated pattern in real-time from the visualization interface. In Grasshopper, the rational control of lines by computer logic is precise, fast, and correlated. Through variable control, the program can quickly make changes to the lines in response to the designer's expectations and come up with a variety of styles. Several options are preset for filtering and variation techniques in the database: filtering includes proportional filtering, random filtering, and directional filtering; variation includes overall shift, random shift, sinusoidal shift, and center point offset, etc. [17]. In this research, Rhino and Grasshopper were chosen as the software platforms to demonstrate the application of parametric techniques in the design of garments with linear visual illusions. The experiment was divided into the following two parts: the demonstration of the linear visual illusion pattern and the demonstration of the overall shape of the garment.

According to the above analysis of the principle of line illusion, the lines as design elements were redesigned and combined with the clothing structure, producing a design prototype as follows:

(1) Vertical-type visual segmentation: a design abundant with vertical stripes at the front and back of the clothing using the principle of visual illusion segmentation, and carrying out tests by equidistant, gradual, and shifting techniques. The three same appearance models in Figure 2 are segmented by vertical lines, while Fig.2-① looks flat and ordinary with no change, only seeming to stretch the length of the clothing. The internal elements of Fig.2-② and Fig. 2-③ change with the outer contour changes of the clothing, thereby stretching the clothing shape length and defining waist. The visual

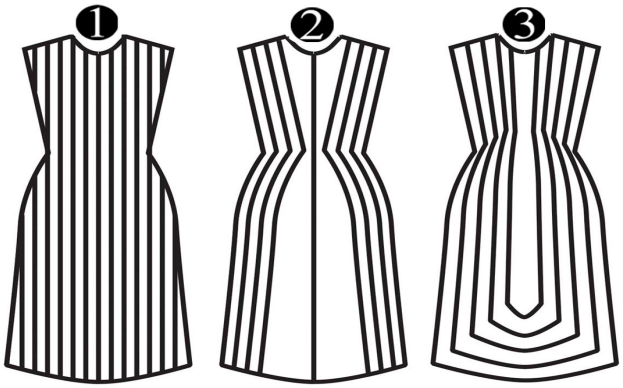


Fig. 2. Vertical-type visual segmentation



Fig. 3. Horizontal-type visual segmentation



Fig. 4. Oblique-type visual segmentation

effect of Fig.2-③ seems to raise the waist line upwards, which makes the clothing look slim and tall, full of rhythm, and with a draping effect. People with a relatively short stature can take either of the three designs for reference.

(2) Horizontal-type visual segmentation: design abundant with horizontal stripes at the front and back of the clothing using horizontal line segmentation. The three graphs in Figure 3 show three different design effects: Fig.3-① applies the equidistant horizontal line design, which is a basic design method to stretch the width of the clothing; Fig.3-② also applies the equidistant design. The only difference is the that the segmentation interval is enlarged, but we can still feel that Fig.3-① seems longer than Fig.3-②. Therefore, the stripe interval is quite important for horizontal segmentation because it can directly affect the overall visual effect of the clothing. Fig.3-③ applies gradual design to arrange horizontal lines from dense to sparse. In this way, it can also achieve the visual effect of being longer than Fig.3-② for it contains principles like the golden ratio, which should be taken into consideration in practical design.

(3) Oblique-type visual segmentation: Since an oblique line is a kind of line between a vertical line and horizontal line, the sense of height of oblique lines approaching the upright is stronger than that of the vertical segmentation (Fig. 4-①), and the sense of width of oblique lines approaching horizontal is stronger than that of the horizontal segmentation (Fig.4-②). 45°oblique line segmentation shows the neutralization effect of the two line types, so that it can be applied to cover the defects of various body shapes and is suitable for both obese and slim people[18] (Fig. 4-③). In most cases, designers won't select oblique line segmentation for the whole design, but for part of it, because such a design makes people feel flexible and fashionable (Fig.4-④).

(4) Curve-type visual segmentation: The curve is called the line of the female. Adding curves into a design could make the clothing full of a sense of rhythm. Figure 5-①② applies horizontal and vertical curves to a segment, and Fig.5-③ integrates the two to achieve an elegant and conservative sense of beauty. As for the connecting of chest dart and waist dart, curves can be applied to replace short and intermittent dart lines to achieve perfect visual illusion through its functional and decorative performance (Fig.5-④).

(5) Comprehensive-type visual segmentation. In the design of a series of garments, a segmentation pattern or design technique may be able to achieve a simple aesthetic, but in order to make the shape of the garment more diverse, designers usually use a variety of segmentation line forms, making full use of the aesthetics generated by different line segmentation arrangements to achieve a more fashionable and beautiful garment design (Figure 6).

Semantic analysis for users' cognition and design form transformation

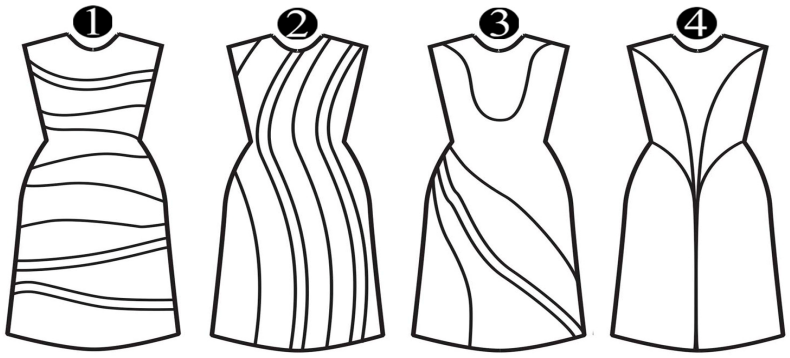


Fig. 5. Curve-type visual segmentation



Fig. 6. Comprehensive-type visual segmentation

Class 1	Class 2	Class 3
Complicated-Simplified Pristine-Elegant Classic-Technological Traditional-Fashionable Compact-Grand	Mature-Lovely Soft-Tough Steady-Dynamic	Horizontal-Vertical Dynamic-Static

Table 1. Clustering result of perceptual image adjectives

Fashion design major students, teachers and 20 female fashion enthusiasts with good fashion taste were selected as the subjects to conduct individual interviews aiming to obtain female users' opinions, purchase behavior focus and design expectations of the above clothing design prototype, as well as to evaluate and optimize the design.

(1) Build adjective pairs. By sorting out and normalizing the text information acquired from the interview, 24 independent words were obtained after preliminary screening. Considering factors such as frequency, the implication expression and description object, the adjective pair of the vocabularies group are summarized as follows: "Complicated-Simplified", "Mature-Lovely", "Classic-Technological", "Steady-Dynamic", "Pristine-Elegant", "Traditional-Fashionable", "Compact-Grand", "Soft-Tough", "Horizontal-Vertical", "Dynamic-Static".

(2) Determine the image vocabulary. In order to obtain the users' perceptual evaluation of the linear visual illusion fashion design prototypes, a five-level Likert scale was established between the ten groups of opposite adjectives, and a questionnaire was made with the five kinds of line visual illusion fashion design samples above as the evaluation objects. Twenty subjects were required to score the perceptual evaluation of the sample. SPSS software is applied to do cluster analysis of the survey results. Cluster results of the perceptual imagistic pairs are shown in Table 1.

According to the cluster analysis and the correlation analysis of female users' preferences, the final design is modified and improved with "technological", "elegant", "dynamic" and "vertical" target images.

4.2. Design optimization and parametric design process

The first pattern design is shown in Figure 7, which is the linear visual illusion pattern generated by the parametric design. Six figures show the process of the pattern generated by the parametric design, in which Fig. 7-⑥ is the final linear visual illusion pattern.

For the parametric design of this pattern, first we connect a "Polygon" plane battery to make polygons, and the "Number Slider" value is set to 4, to get a quadrilateral. If we set the number slider to 3, we obtain a triangle, and with 5 a pentagon. The number slider can be adjusted according to the needs of the design. In this research, a quadrilateral was selected as the basic pattern shape. After that, the "Radius" of the "Polygon" is linked with the "Mapped" end of the "Remap Numbers" battery to get multiple squares. The "Range" option in the "Range" battery is an equal series, "Domain" is the of arrangement among patterns, and "Steps" is the number of planes. By connecting the "Range" with "Remap number value", one can evenly arrange the squares among sizes. In this design, the researchers wanted to get unevenly arranged squares, therefore they had to add one more battery, which is the "Graph mapper". By entering the corresponding values in the X-axis coordinates of the "Graph mapper", one can get the corresponding values on the left side of the Y-axis. By adjusting the nodes of the XY axis, a polygon pattern arrangement with different combinations of columns can be obtained. Designers can make multiple adjustments to match the aesthetic needs of the pattern. The pattern generation effect of this

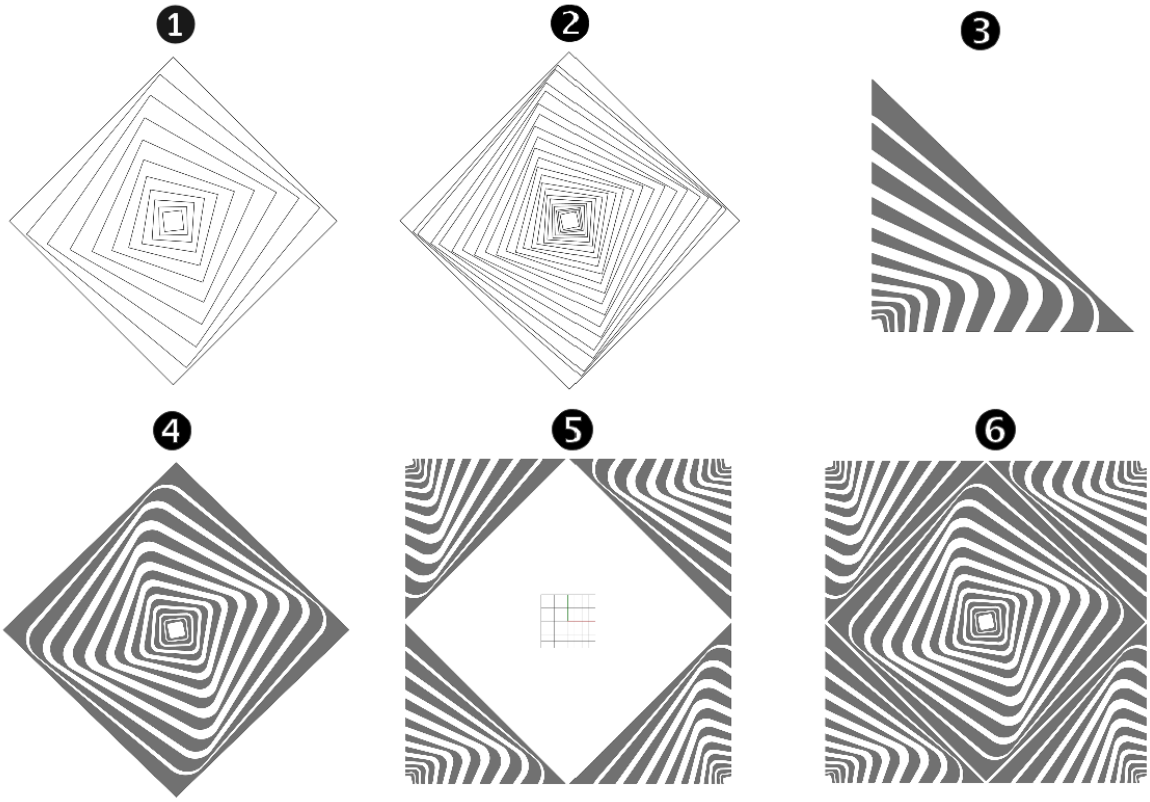


Fig. 7. Parametric design of the line visual illusion pattern generation process

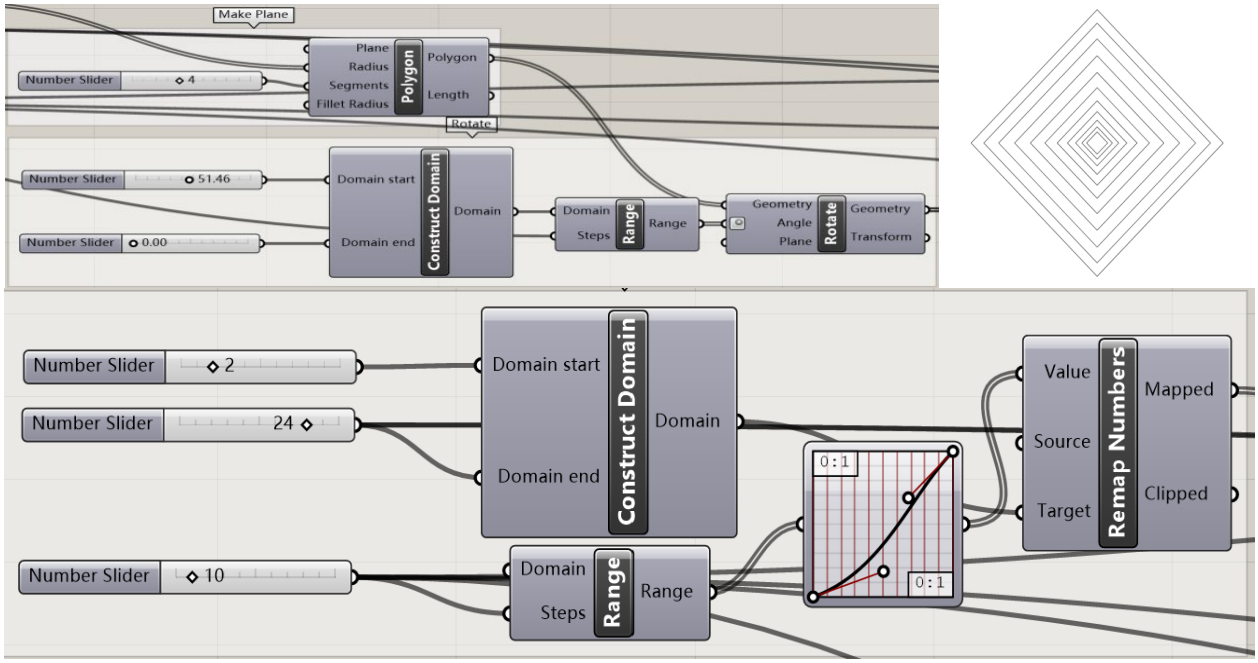


Fig. 8. Parametric design process and batteries map

research design and the battery roadmap are shown in Figure 8. By accessing the "Construct domain", "Range", and "Rotate battery" in turn, and adjusting the value of "Number slider" in the "Domain Start" to adjust the rotation angle of the square, such as 60°, 70°, etc., get different rotation effects. By connecting the "offset Curve" battery and offsetting the polygon, we get the thickness between the polygon patterns, the pattern effect of which is shown in Fig.7-④. By adding one more "Range Curve" battery to make the polygon rotate several times, this figure has more thickness compared

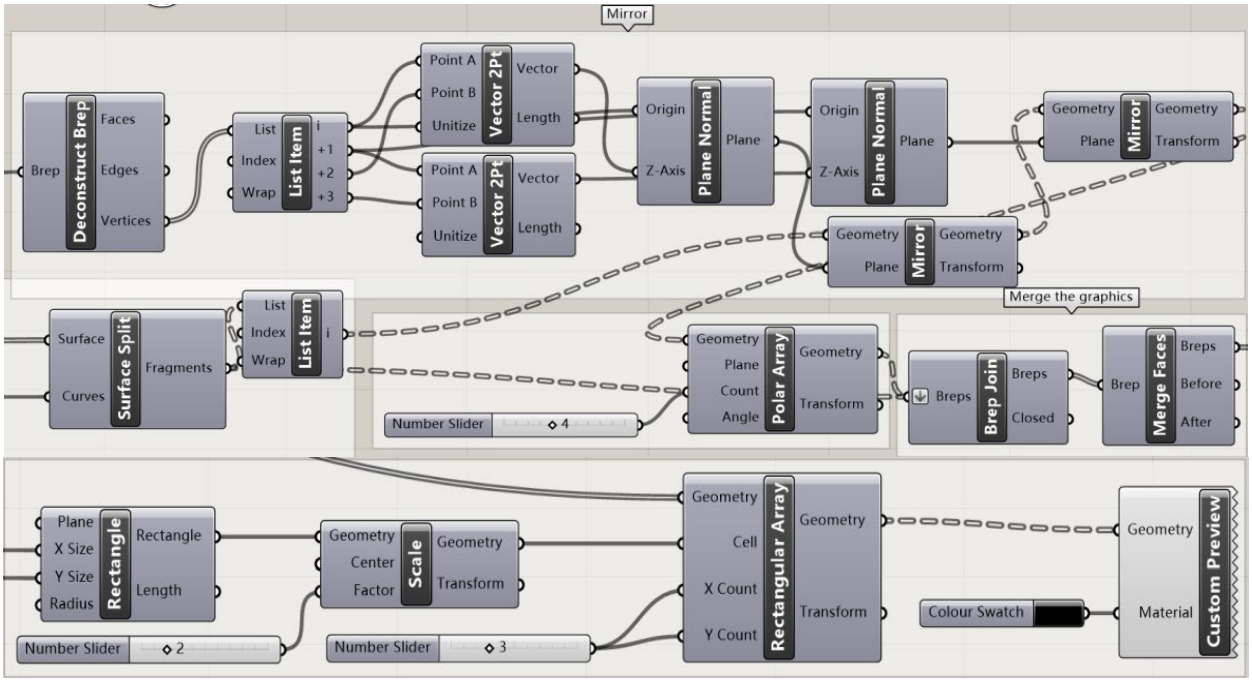


Fig. 9. Pattern mirroring, array and merge layer battery route map

to the polygon before the battery is connected.

Referring to Fig.7-③, in order to convert the polygonal range to an arc, the "Fillet" battery is accessed, so that the corners of the pattern present a rounded state. Using the "Surface Split" battery and "List" battery, we intercept the quarter corners of the rotated polygon, connected by two "Mirror" batteries. The cut corners can be rotated and put into the edge position, and then the "Polar Array" battery can be accessed, the pattern of which generated is shown in Fig.7-③ and Fig.7-⑤. After the pattern generation, the "Brep join" and "Merge Face" batteries are connected. The batteries diagram is shown in Figure 9. The final generated pattern is shown in Fig.7-⑥. By controlling the batteries, different rotation angles and rotation frequencies of the square can be obtained, in which the parameter values can all be adjusted at any time, and the pattern form will change according to the different parameters.

By accessing the "Rectangle" battery and "Scale" battery again, adjusting the Number slider, and then connecting with the "Rectangular Array" battery, this step can copy the previous polygon pattern to form an area pattern.

The "Surface" battery is used to draw the basic curve of the silhouette of garment. To increase the three-dimensionality and beauty of the garment shape, the researchers created two contour lines in the process, as shown in Fig.10-①. In this step, one should be careful to make predictions about the line direction of the silhouette. The "Construct Point" and "Iso Curve" batteries are connected, which step can derive regularly arranged structure lines for the approximate shape of the contour, as in Fig.10-② and Fig.10-④. As with the pattern design process above, the degree of curvature of the lines and the density of the structural lines can be adjusted at any time using the "Number Slider" value. However, the lines of the apparel are different from the flat pattern; the line arrangement rules and structure need to be combined with the overall silhouette of the apparel. Thus, in the process of parametric design, the line curve cannot be adjusted only by parameter variables, but also needs to cooperate with the adjustment nodes of the lines, and the arrangement and bending degree of the lines be manually adjusted., as shown in Fig.10-③. The final effect created by the line arrangement is determined by the needs of the designer or client.

After this step, accessing the "Surface Split", "Brep Edges" and "Join Curve" batteries in turn, merges the two pattern layers, cuts the pattern according to the basic outline of the garment, and removes the excess pattern and screen of the pattern area. The pattern effect of the cutting process is shown in Fig.10-⑤, and the final pattern after area screening is presented in Fig.10-⑥.

In this design process, the pattern can be generated by adjusting the "Number Slider" value in the battery, and patterns with different arrangement densities can be obtained. The "Number Slider" in Fig.10-② is 25, and that in Fig.10-④ is 20. The visual illusion effect caused by the different arrangement densities of the lines is different. The different density of the line arrangement will cause different visual illusion effects. The basic curve obtained by dividing the surface is basically a homogenized center-symmetric shape, and it is necessary to screen and change the basic curve in the subsequent design in response to the design concept so as to achieve the design objectives. The batteries adjustment in the parametric design should connect the "Area", "Circle" and "Flip Curve" batteries to align the line arrangement. After combining the

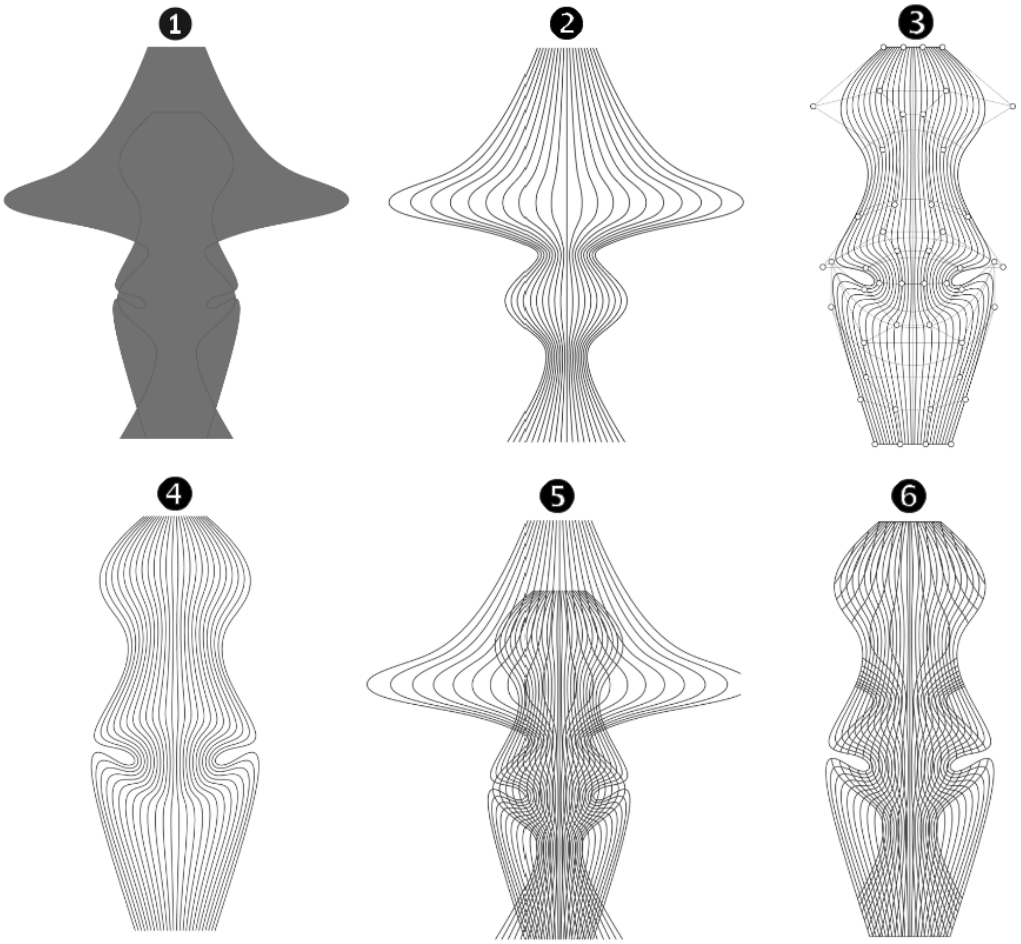


Fig. 10. Line visual illusion clothing parametric design process

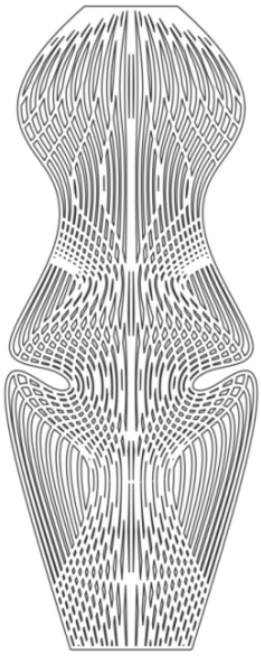


Fig. 11. Parametric Design of Line visual Illusion Clothing

two pattern layers and adjusting the number slider, the overall effect of the final design is achieved, as shown in Figure 11. Different parametric values can obtain different patterns and line arrangements by adjusting the "Number Slider" threshold.

5. Discussions

Through the experimental design testing, the workflow and generation logic of the linear pattern or clothing for parametric design can be summarized in Table 2.

The linear visual illusion apparel pattern generation logic can be decomposed into four steps: surface segmentation, line screening, line construction and base surface construction. The research follows these four steps and edits the layer-by-layer correlation generation procedure.

This paper, taking the line visual illusion pattern as an example and using parametric design as a tool, verifies that parametric design can adjust the line structure and arrangement pattern to generate parametric patterns or clothing structures in parameters in fast real-time, which can be achieved by adjusting various built-in parameters. In each step, new patterns and parameters can be added according to the designer's vision, resulting in a new surface form. The design approach demonstrated in this paper is reproducible and extended. However, this research did not combine the final pattern and garment design results with 3D printing or curved structures. Future research can be expanded on this basis and combine with other art visual elements, such as other geometric shapes or applied it in digital fashion.

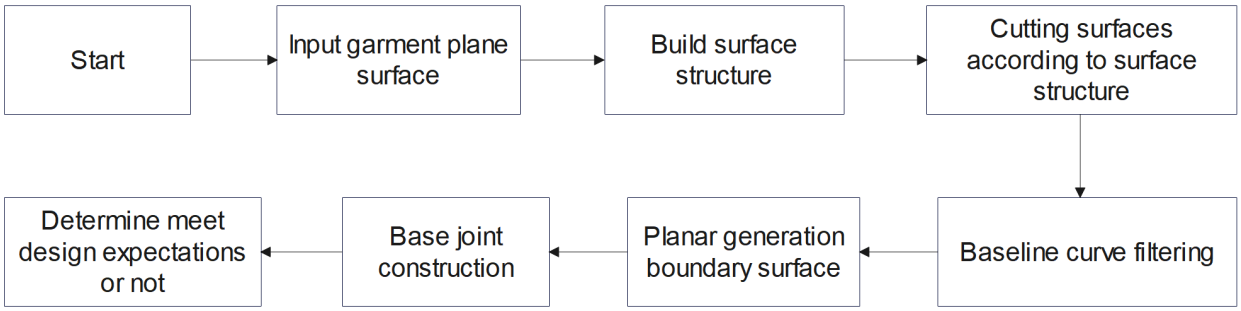


Table 2. Parametric Linear visual Illusion Clothing Generation Logic

The artistic pattern represented by the linear visual illusion and its underlying mathematical logic are realized in parametric apparel design. The traditionally opposing concepts of qualitative and quantitative, technical and artistic, and natural and artificial are also reconciled in this process. The unique advantage of parametric design in controlling complex patterns can help designers create more imaginative and creative works, which has important application value in the creation of modern garment styling.

6. Conclusion

The research analyzed visual illusion elements and their application in costume design, and composed an example, where the parametric design method was used to expand the possibility of personalized clothing design. Through Rhino's Grasshopper parametric design platform, the complete process from data acquisition to data logical relationship construction was completed. The process can be summarized as formulating a design style, drawing sketches, establishing a logical model, and adjusting built-in parameters to adjust the line bending radian, angle, arrangement, arrangement density, arrangement direction, etc., and realize various combinations of line design. The series of operations can quickly and dynamically adjust in real-time the final design results, optimize and compare according to the intention of the designer or the customer, thereby verifying the feasibility of applying parametric technology to the customized design process. In the current fashion industry, due to the rapid development of digital technology, related digital products such as virtual clothing have been derived, which have been popular in the market and the public's attention. Virtual clothing or digital design have surpassed the limitations of physical carriers and traditional design techniques, becoming more imaginative and creative. The use of parametric design technology can help expand the boundaries and imagination of clothing design.

Although the study provided some useful literature information and did undertake testing, it has some limitations that can be addressed through future research. Except line visual illusion, there is also the Voronoi diagram and other visual illusion elements. The extended design can be produced by the parametric design method as well. This issue deserves to be explored in depth and could be a topic for the next phase of research.

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Author contributions

Yixin Zou conceived the ideas, experimental design, data analization, interpretation of the results, and drafted the manuscript of the analysis. Yan Wang gave technical guidance and provided continuous support to perform the experiment successfully, and gave the suggestions about the writing. Ding-Bang Luh contributed to the interpretation of the results and revised the manuscript. All authors read and approved the final manuscript.

Availability of data and materials

The datasets supporting the research process and conclusions of this article are included within the additional files. For databases and research results, which is available and has no restrictions to its use by academics or non-academics.

Competing interests

No conflicts or potential conflicts of interest regarding this research, authorship, and publication of this article.

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