Parametric Design Method Based on Grasshopper and Shoe Last Bottom Pattern Moulding Characteristics

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Abstract. To adapt to the user's need for flexible and custom design of shoes, a more efficient customization method is explored. Combined with the formation characteristics of the shoe last bottom map, each characteristic parameter and related algorithm are analysed. Based on the importance of the shape control, the feature parameters are graded. The parametric design plug-in Grasshopper of Rhino software is used to construct the automatic moulding program of the shoe last bottom to form a professional and feasible design method. Through the time consumption comparison between the traditional method and the parametric design method, the efficiency advantage is analysed, so as to truly improve the design and production efficiency of the customized shoe last bottom.

1. Introduction
In the new age, people have had new and customized requirements for the shoes. How to design and process shoes quickly and flexibly has become a problem urgently to be explored by every shoe company[1]. Various custom design methods have also been developed that are used in all aspects of shoe design. The design of the shoe last bottom is an integral part of the design and production of any type of shoe, and its morphological features play an extremely important role in the aesthetics and comfort of the final shoe. In the shoe last bottom design process, quickly producing various types of shoe last bottom based on different needs has become the key to customization.

Parametric design is a non-linear design method allows you to quickly generate different design patterns by changing parameters in a visual programming language[2-3]. In the shoe last bottom design process, looking for characteristic parameters and morphogenesis logic, combined with parametric nonlinear thinking features, can effectively meet flexible design and production requirements[4]. Based on the Rhino parametric design plug-in Grasshopper, this paper analyses the forming characteristics of the last bottom, constructs the parameter logic, and forms a rapid prototyping method for the customized base.

2. Parameter analysis of traditional last bottom moulding characteristics
The shoe last bottom is based on the foot shape, and the shape of the shoe last bottom must follow the foot shape, so the design of the shoe last bottom is closely related to the parameters of the foot[5]. This article takes the length of female standard shoes as 230 mm as an example to briefly introduce the drawing steps of traditional shoe last bottom, as follows:
2.1. Calculation of shoe last bottom moulding characteristic point data

Based on the length of the foot, the reference value of the formed feature point of the last bottom was calculated from the percentage relationship between foot length and parameters in national standards. It can be adjusted based on the measurement data of the foot type and design style in customization, including the length direction and the width direction, and a total of 16 related molded feature points were obtained (Table 1).

Table 1. Determination of last bottom moulding characteristic parameters of standard female shoe with a foot length of 230 mm.

| Direction                  | Parameter                                | Calculation method                              | Length (unit: mm) |
|----------------------------|------------------------------------------|-------------------------------------------------|-------------------|
| **Length direction**       | Foot length                              | Measurement data (Known data)                   | 230               |
|                            | Posterior tolerance point                | ≈ Foot length *2%                                | 4.5               |
|                            | Heel point                               | ≈ Foot length *18%                               | 36.9              |
|                            | Waist point                              | ≈ Foot length *41%                               | 89.8              |
|                            | The fifth metatarsal-phalange point      | ≈ Foot length *63.5%                             | 141.6             |
|                            | The first metatarsal-phalange point      | ≈ Foot length *72.5%                             | 162.3             |
|                            | Outer convex of little toe               | ≈ Foot length *78%                               | 174.9             |
|                            | Outer convex of big toe                  | ≈ Foot length *90%                               | 202.5             |
|                            | Toe endpoint                             | ≈ Foot length – posterior tolerance              | 225.5             |
|                            | Last toe allowance                       | Based on the design style, an intermediate value is given here | 16.5               |
| **Width direction**        | Heel overall width                       | Based on the national standard reference data, it can be adjusted based on the measurement data of the foot type in customization. | 50               |
|                            | Waist outer width                        |                                                | 32.5              |
|                            | Fifth metatarsal-phalange outer width    |                                                | 43.9              |
|                            | First metatarsal-phalange inner width    |                                                | 31.2              |
|                            | Outer width of the little toe            |                                                | 43               |
|                            | Inner width of the big toe               |                                                | 27.7              |
|                            | Toe cap width                            | Based on the design style, an intermediate value is given here | 30               |

2.2. Measurement of length characteristic markers

![Figure 1](image)

**Figure 1.** Measurement of length characteristic markers (unit: mm).

Draw a straight line as the bottom axis and measure the following dimensions on the shaft: OA, the length of posterior tolerance is 4.5 mm; AB, the length of heel point is 36.9 mm; AC, the length of waist is 89.8 mm; AD, the length of the fifth metatarsal-phalange point is 141.6 mm; AE, the length of the first metatarsal-phalange point is 162.3 mm; AF, the length of the outer convex of small toe is 174.9 mm; AG, the length of the outer convex of big toe is 202.5 mm; AH, the length of toe end is 225.5 mm; HI, last toe allowance is 16.5 mm, as shown in Figure 1.

2.3. Measurement of width characteristic markers

With the above point as the standard, the vertical line of the axis is as follows: the upper and lower parts of heel point are 25 mm, two points BB1, BB2, the full width of heel is 50 mm; CC', outer width
of waist is 32.5 mm; DD', fifth metatarsal-phalange outer width is 43.9 mm; EE', first metatarsal-phalange outer width is 31.2 mm; FF', outer width of the little toe is 43 mm; GG', Inner width of the big toe is 27.7 mm, I1I2, toe cap width is 30 mm, as shown in Figure 2.

![Figure 2. Measurement of width characteristic markers (unit: mm).](image)

2.4. Determination of center line and heel width
The connection point of the branch line is determined by the equidistant relationship between the width of the first and the fifth metatarsal-phalange outer width, and D'J = EE' is measured on DD' to obtain the connection between points J and A. With A as the centre, the length of AB is the radius of the arc, AJ is taken as B', and B' is taken as the vertical line of AJ, and the two sides are divided into 25 mm, and B'B'1 and B'B' 2 are obtained. B'1 B' 2 is the width of heel, move B'1 B' 2 to point A to get A1 A2, as shown in Figure 3.

![Figure 3. Determination of centre line and heel width (unit: mm).](image)

2.5. Curve connection after straight line connection
As shown in Figure 4, these lines connect E, B'2, A2, A, A1, B'1, C', D', F', I, I1, I2, G', E' and C and the curve is connected to A, B'1, C', D', F', I, G', E' and B'2 based on the arrow, which is a female standard shoe map with a foot length of 230 mm.

![Figure 4. Curve connection after straight line connection.](image)

3. Parametric logic construction based on Grasshopper

3.1. Hierarchical logic summary of characteristic parameters
Based on the importance level of the shape control of the parameter, the first level parameter, the second level parameter and the third level parameter are shown in Table 2. The first level parameter
refers to the length of the foot, which is the basic parameter that should be determined first. The secondary parameter is a key feature parameter that is extracted through the standard drawing process, but it can actually be used to customize the shoe last bottom process. The measurements are modified; the third level parameters are based on the secondary parameters, and morphological control points are added for the morphological details to be used for the shape curve shape and the accuracy of the customization process. The corresponding step is to connect the key feature points to the last bottom curve in the shoe map. The shape of the connection curve is usually determined by the plotter's personal data experience and line aesthetics, so there is some uncertainty. The third-level parameters have no determined parameter values, and it is still necessary to adjust the curve by adjusting the points of each position with a certain experience. The logic organization is as shown in Figure 5.

**Table 2.** Parameter variables required for last bottom pattern moulding with Grasshopper.

| Level   | Parameter                                                                 | Effect                                                      |
|---------|---------------------------------------------------------------------------|--------------------------------------------------------------|
| Level 1 | Foot length                                                               | Overall foot length controlled for different users           |
|         | Percentage of posterior tolerance point                                   |                                                              |
|         | Percentage of heel point                                                  |                                                              |
|         | Heel point width                                                          |                                                              |
|         | Percentage of waist point                                                 |                                                              |
|         | Waist outer width                                                         |                                                              |
|         | Percentage of the fifth metatarsal-phalange point                         |                                                              |
|         | Fifth metatarsal-phalange outer width                                     |                                                              |
| Level 2 | Percentage of the first metatarsal-phalange point                         | Characteristic point of last bottom pattern moulding         |
|         | First metatarsal-phalange outer width                                     |                                                              |
|         | Percentage of outer convex of little toe                                  |                                                              |
|         | Outer width of the little toe                                             |                                                              |
|         | Percentage of outer convex of big toe                                      |                                                              |
|         | Inner width of the big toe                                                |                                                              |
|         | Allowance                                                                 |                                                              |
|         | Toe cap width                                                             |                                                              |
| Level 3 | Heel control point                                                        | Control the shape of heel curve between posterior tolerance point and heel point |
|         |                                                                          | Control the shape of heel curve between outer heel point and outer waist |
|         |                                                                          | Control the shape of heel curve between inner heel point and first metatarsal-phalange point |
|         | Outer heel anterior shape control point                                    | Control the shape of heel curve between outer heel point and fifth metatarsal-phalange point |
|         | Inner heel anterior shape control point                                    | Control the shape of heel curve between inner heel point and first metatarsal-phalange point |
|         | Fifth metatarsal-phalange posterior shape control point                    | Control the shape of heel curve between outer heel point and first metatarsal-phalange point |
|         | First metatarsal-phalange posterior shape control point                    | Control the shape of heel curve between inner heel point and first metatarsal-phalange point |
|         | Outer shoe shape control point                                             | Control the shape of shoe curve between outer convex of little toe and toe cap |
|         | Inner shoe shape control point                                             | Control the shape of shoe curve between outer convex of big toe and toe cap |
3.2. Grasshopper edit input logic relationship

The above characteristic parameter parameters are logically coupled in combination with the moulding process of the conventional shoe last bottom pattern. It includes the length calculation method and shape connection method of each feature part. The bottom map is obtained based on the personal data of the custom measurement. The basic operation method is used for the logic construction in the three-parameter plug-in Grasshopper of the three-dimensional modelling software Rhino. During the construction process, you’ll see the results immediately on the Rhino interface. The final logical relationship between the program interface and the bottom graph is shown in Figure 6.
3.3. Operation and inspection drawing effect
After modifying the shape of the curve by three levels of parameters to make the bottom map accurate, the final bottom curve will be baked separately to the Rhino interface, and you can open the edit point verification again, as shown in Figure 7. In order to facilitate the next 3D design and production of the last bottom, the corresponding format can be derived based on different moulding software.

4. Comparative analysis of traditional and parametric last bottom drawing in shoe last bottom customization

4.1. Brief description of traditional last bottom drawing of shoe last bottom customization
Based on the traditional personal shoe last bottom process, the traditional drawing process steps are as follows:
   (a) Measure the characteristic parameters of the target user's foot, including the foot length, percentage of heel point, heel point width, percentage of waist point, waist outer width, percentage of the fifth metatarsal-phalange point, fifth metatarsal-phalange outer width, percentage of the first
metatarsal-phalange point, first metatarsal-phalange inner width, percentage of outer convex of little toe, outer width of the little toe, percentage of outer convex of big toe, inner width of the big toe.

(b) Determine the tolerance and width of the toe based on individual needs and styles.

(c) Based on the length of the foot, draw the bottom axis, and mark the position of the length direction of each point from the axis based on the measurement data.

(d) Mark the position in the width direction of each point based on the measurement data.

(e) Determine the allowance and shoe cap width.

(f) Connect each feature point with a polyline and calculate the remaining feature points based on the calculation.

(g) Connect each feature point with a smooth curve.

(h) Adjust the shape of the curve, curvature, etc. based on personal experience to make the shape more smooth and accurate.

(i) Scan the image and import it into a computer, then draw a curve for further 3D production.

Use the program you have written to complete the Grasshopper parameter shoe persistent drawing program. The steps to customize the personal basic map are as follows:

(a) Measurement parameters are the same as the conventional method.

(b) Determine the allowance and shoe cap width in the traditional method.

(c) The measurement data is directly input into the main and secondary parameters in the program, and the initial bottom curve is automatically generated.

(d) Adjust the position of the third-level parameters to make the curve shape more accurate.

(e) Direct output curve for further 3D production.

Compared to the parametric design process, the traditional drawing process requires a nine-step process, but the method of drawing the shoe bottom map is different. Due to the different experiences of the painter, in order to avoid the influence of the artist's experience, this article invites an experienced footwear primary student to use the above two methods for time-consuming comparative experiments. Finally, it was found that in the process of customizing the last bottom, the measurement of the characteristics of a single foot type is made to the production of an electronic version that can be further used. The basic map, the cumulative time of the traditional method is about 45 minutes; the parameterized bottom map method takes only 5 steps, about 11 minutes and 30 seconds, which greatly shortens the time of customizing the new bottom as shown in Table 3.

Table 3. Comparison of time consumption between traditional and parametric drawing methods.

| Step Description                                                                 | Time Consumption | Traditional bottom drawing | Parametric bottom drawing |
|---------------------------------------------------------------------------------|-----------------|-----------------------------|---------------------------|
| Measure the characteristic parameters of the target user's foot                  | 5 min           | √                           | √                         |
| Determine the allowance and shoe cap width                                       | 2 min           | √                           | √                         |
| Based on the foot length, determine the bottom drawing axis, and mark the length direction of each point in the axis based on measured data | 5 min           | √                           | ×                         |
| Mark the width direction of each point in the axis based on measured data        | 5 min           | √                           | ×                         |
| Determine the allowance and toe cap width                                        | 3 min           | √                           | ×                         |
| Connect each characteristic point with broken lines and obtain the remaining characteristic points based on the calculation | 5 min           | √                           | ×                         |
| Directly input measurement data into the level 1 and 2 parameters in the program, automatically produce the preliminary bottom curve | 2 min           | ×                           | √                         |
| Connect individual characteristic points with smooth curves                      | 5 min           | √                           | ×                         |
| Adjust the curve shape, curvature based on                                       | 5 min           | √                           | ×                         |
personal experience to make the shape smoother and more accurate

| Action                                                                 | Time  | ✓ | √ |
|------------------------------------------------------------------------|-------|---|---|
| Adjust the position of the level 3 parameters to make the curve shape more accurate | 2 min |   |   |
| Scan and import image into the computer, and draw the curve for 3D production | 10 min |   |   |
| Directly output curves for further 3D production                        | 30 s  |   |   |
| Cumulative time                                                         | 45 min|   | 11 min 30 s |

5. Summary
Based on the moulding characteristics of the shoe last bottom and the parametric plug-in Grasshopper, the drawing method greatly improves the efficiency and ensures the accuracy of the form. In the future, individual foot parameters can be imported into actual production. The shoe last bottom is truly customized to ensure personal comfort. Such a combination is a technological innovation with commercial value, which will bring more possibilities for future shoe design.

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