Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 13 (21): 4355-4362, 2013
ISSN 1812-5654 / DOI: 10.3923/jas.2013.4355.4362

Study of the Digital Design Method on Tubular Steel Chair

Lei Wei, Sha Liu and Yun-Qi Wang
College of Engineering, China Agricultural University, 100083, Beijing, China

Abstract: In order to reduce the repeat design work of designers of furniture manufacturing industry and improve the application frequency of the 3D models, the article analyzes the character of tubular steel chair and presents a digital design method of it based on RhinoScript. With the parameterization of ergonomics sizes and exterior categories based on key curves, surfaces and points, the design work of tubular steel chair especially for the exterior of repeat texture partly can be finished by program, which can raises the efficiency of design and makes the evaluation among the products of different parameter values more convenient. In the last, the design process of a kind of tubular steel chair testified the method.

Key words: Rhinoceros, tubular steel chair, digital design

INTRODUCTION

From 1925 when Marcel Lajos Brever designed Wassily chair which is the first tubular steel chair in the world, tubular steel chairs have become a necessity to our life. Because of their material's character, they are durable with simple and beautiful appearance.

Common design process of industrial product is shown in Fig. 1. The chair of large production should have many proposals with different exterior to match human's body size and meet persons' preference. Therefore, standardized and digital design program is needed to make the design process of such chairs more simple and more fast (Liu and Sun, 2009).

The powerful and innovative 3D modeling software called Rhinoceros, or Rhino for short, is good at NURBS modeling. It can create, edit, analyze and translate NURBS curves, surfaces and solids in Windows (Acheson and Hardin, 2003). As one of the mainstream industrial design software, it has powerful modeling functions and simple interface. There are many plug-ins for it, such as Grasshopper, EasySite, Alibre Design, TechGems and so on. They are parametric modeling tools for different industries to meet their design requirements.

The study on this 3D modeling software is still at a preliminary stage in domestic research. Dai *et al*. (2004) realized design and implementation of two-dimension, three-dimension transformation with Rhino3D developer platform based on V^{C++}. Pan and Jiang (2007) developed modeling system of Tiffany lamp-chimney based on Rhino with VC. Su and Liu (2010) use Rhino.Net SDK (Software Development Ki) to develop ship design system based on Rhino. Su and Liu (2010) realized the rapid design techniques of crystal light based on Rhino using VB.

According to previous studies, there are four ways for secondary development of Rhino commonly: (1) Command Scripts. This is the easiest way for custom of Rhino with just inputting the script in the command line. (2) RhinoScript. RhinoScript is a scripting language based on VB, simple and easy to understand. (3) Rhino C^{++} SDK. It is based on the Microsoft Visual C^{++} platform and can directly generate the plug-in program or dynamic link library for users by the software development package provided by Rhino C^{++} SDK and (4) Rhino.Net SDK. This approach is similar to the former one. But it can use any kind of.net 2.0 languages (Sun, 2010).

METHOD OF DIGITAL DESIGN ON TUBULAR STEEL CHAIR

RhinoScript is the parametric editing script provided by Rhino. Similar to VB, it can develop functional module for special design demand with the parametric

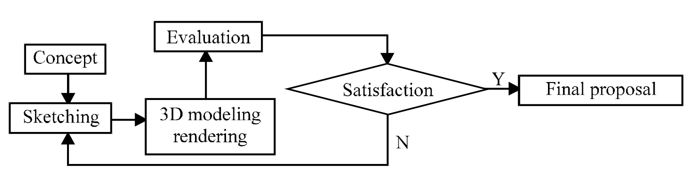


Fig. 1: Present design method of products

Corresponding Author: Sha Liu, College of Engineering, China Agricultural University, 100083, Beijing, China

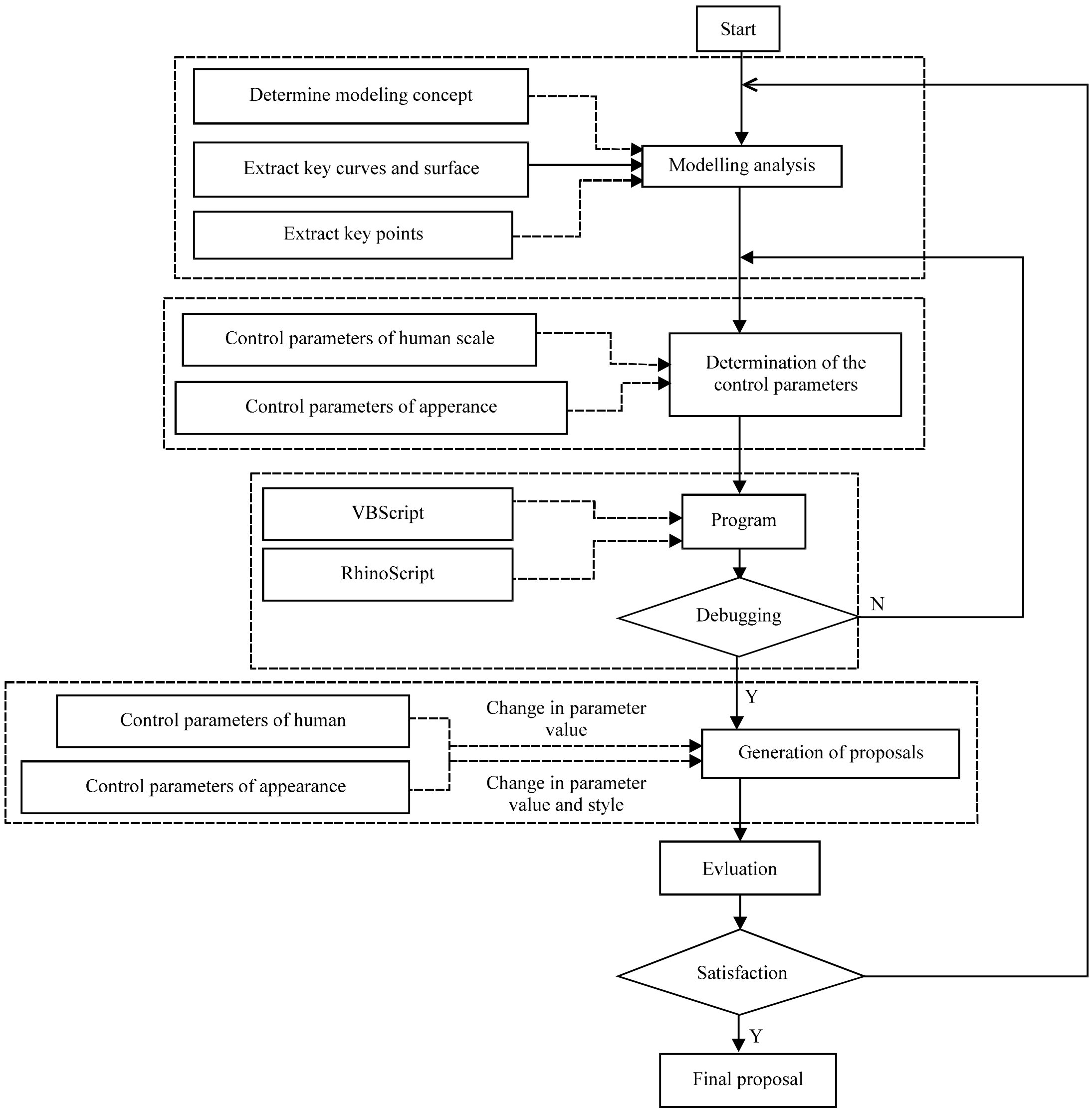


Fig. 2: Flow chart of design process of tubular steel chair

modeling functions provided by Rhino quickly and simply. As RhinoScript is good at avoiding the repeat modeling work, it is chosen to realize the tubular steel chairs' digital design. In this way, the design program could easily generate series of proposals with control parameters changed in less time. The basic aspects of the digital method could be seen in Fig. 2.

The working steps in the process are as follows: (1) Determine the shape of the tubular steel chair and analyze the styling feature. Extract the key curves and surfaces and determine the key points to create t hem. (2) Do parametric analysis in ergonomic and appearance style and determine the control parameters. Find the location of the key points based on the control parameters. (3) Program to create model. (4) Change the control parameters to obtain a series of products. (5) Evaluate the products in the views of ergonomics, aesthetics, engineering mechanics and so on to get the optimal one.

Appearance analysis of the tubular steel chair: There are varieties of tubular steel chair (Fig. 3) and in general it can be classified into four parts which are foot tube, seat tube, backrest tube and link tube.

Curve is the key element in its modeling according to the feature of its exterior. Therefore, the key curves are chosen to summarize the chair's styling feature in this article.

As there are many types of geometric curve (Fig. 4) (Rutten, 2004) and the difficulty of creating them is different, simple curve should be chosen to be key curve.

Fig. 3: Tubular steel chairs

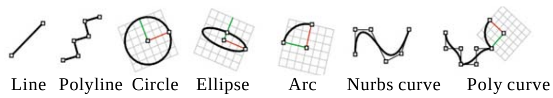


Fig. 4: Categories of curve

The extraction of the key curves must be in accordance with the following principles:

- **The principal of saving:** The key curve should be simple, such as line, arc and NURBS curve with fewer control points
- **The principle of full performance:** The key curve should be fully express the chair's styling features
- **The principle of segmenting according to geometric characteristics:** At the place having obvious geometric feature (such as vertex, inflection point, cuspidal point, tangent point, etc.), segment the curve and avoid choosing the polyline to be key curve. Ensure that each curve has continuous curvature (except for the key curve of straight line) (Liu *et al*., 2012)

Besides the key curves, it also needs to determine some key surfaces to help modeling, such as the seat surface and backrest surface. RhinoScript provides a lot of functions to create surface which are Surface from 2, 3 or 4 Edge Curves, Loft, Extrude Straight, Patch, Sweep and so on. Different function need different auxiliary curve. We should choose the easiest way to create and select auxiliary curve based on the way. Then choose the auxiliary point to create the curves and determine their coordinates (Wang *et al*., 2008).

Determination of the control parameters: Control parameters of human scale:

- The main control parameters according to ergonomics
- Human's body scale is the main sources to determine the basic data of the chair. The main data are shown in Fig. 5, including that the depth of the seat a, the width of the seat b, the height of the seat c, the width of the backrest d, the height of the backrest e, the backrest's angle f and the curvature of the seat g (Ding, 1997; Li and Shi, 2013; Wang *et al*., 2013)

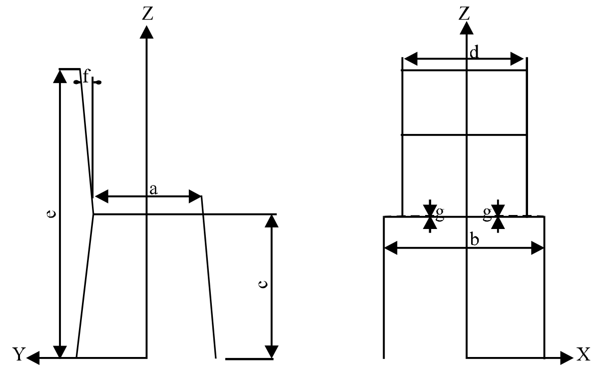


Fig. 5: Size model of the tubular steel chair

In order to guarantee the comfort of the seat, the data all refer to the adults' body scale in ergonomics to determine each of the control parameter's range.

Establishment of the coordinate system: The origin (0, 0, 0) is the center of the circle based on the endpoints of the foot tubes' bottom with the vertical direction as the Z-axis, the horizontal direction as the X-axis, the front-rear direction as the Y-axis (Fig. 5).

To determine the coordinates of the key points: Determine the coordinates of the key points based on the control parameters of the ergonomics such as the depth of the seat a, the width of the seat b, the height of the seat c, the width of the backrest d, the height of the backrest e, the backrest's angle f and the curvature of the seat g. Among them, there are absolute coordinates and relative coordinates. Absolute coordinate is directly related to the data of ergonomics and can be determined based on the control parameters of the ergonomics. Relative coordinate is related to modeling and should be determined based on absolute coordinate (Tang *et al*., 2004).

Control parameters of appearance style: When the scale of the chair is ensured, the surface's texture of backrest and seat is the main content of the appearance style. The backrest and seat surface, as key surfaces, can be seen as a NURBS surfaces with control points d_{ij} ($0 \le_i \le_n$, $0 \le_j \le_m$) and its rational fraction is expressed as:

$$p(u, v) = \frac{\sum_i^n = 0 \sum_j^m = 0\ \omega_{i,j}\, d_{i,j}\, N_{i,k}(u) N_{i,j}(v)}{\sum_i^n = 0 \sum_j^m = 0\ \omega_{i,j} N_{i,k}(u) N_{i,j}(v)} \quad (1)$$

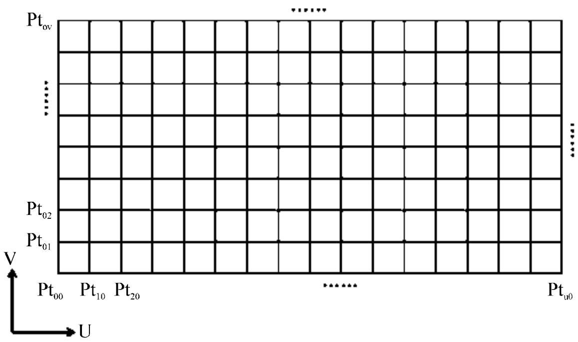


Fig. 6: Meshing schematic diagram

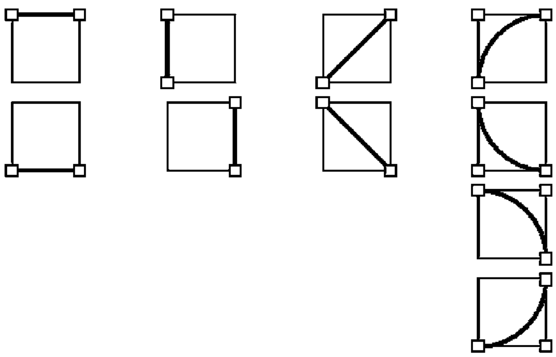


Fig. 7: Categories of cell's style

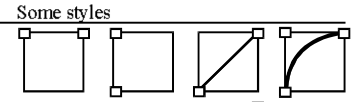
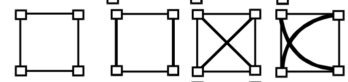
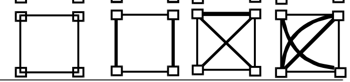
The surface could be divided into a grid in the direction of U and V and get the location of each node according to the positive operation and inverse of NURBS curves and surfaces (Wang *et al.*, 2000). Then the control parameters of U and V could be changed. And use the nodes Pt_{kl} (k = 0, 1, ..., u; l = 0, 1, ..., v) to create the key curves of texture (Zhou *et al.*, 2006; Li and Wang, 2005) (Fig. 6).

The style of the curves in cell is used to describe the pattern style of the chair. The styles could be classified into four categories: Horizontal straight line, vertical straight line, diagonal slash, arc. And horizontal straight line is classified into two categories: The upper one and the lower one. Vertical straight line is classified into two categories: The left one and the right one. Diagonal slash is classified into two categories: The one with left lower and the one with right lower. And arc is classified into four categories: The one with center of lower right, the one with center of upper right, the one with center of lower left and the one with center of upper left (Fig. 7).

With the control parameter U and V constant, the combinations of the ten categories of patterns above are as follow.

When select one from the ten categories, the number of combinations A1 is (Table 1):

Table 1: Some styles of each selection

No. of selection	Some styles
One from ten	
Two from ten	
Three from ten	

$$C(10, 1) = \frac{A_{10}^{1}}{1!} = \frac{10}{1} = 10 \tag{2}$$

When select two from the ten categories, the number of combinations A2 is (Table 1):

$$C(10, 2) = \frac{A_{10}^{2}}{2!} = \frac{10-9}{2} = 45 \tag{3}$$

When select three from the ten categories, the number of combinations A3 is (Table 1):

$$C(10, 3) = \frac{A_{10}^{3}}{3!} = \frac{10-9-8}{3} = 120 \tag{4}$$

When select m (m≤10) from the ten categories, the number of combinations Am is:

$$C(10, m) = \frac{A_{10}^{m}}{m!} \tag{5}$$

Above all, the number of combinations of cell is:

$$A = \sum_{m=1}^{10} C(10, m) = 20^{10} - 1 \tag{6}$$

The number of cell is U×V. As each cell could has different pattern style, the total number of combinations of the surface is:

$$B = A^{i \times j} = (2^{10} - 1)^{i \times j} \tag{7}$$

Some combinations of the entire grid's style are shown in the Fig. 8.

When U and V change, there could be more categories. In the situation above, make V double, the categories of the pattern style could be as the ones in Fig. 9. Above, after parameterization, the appearance of the backrest and seat could vary according to a certain rule.

Digital design expression: With the control parameters all determined, the design proposals I can be expressed as:

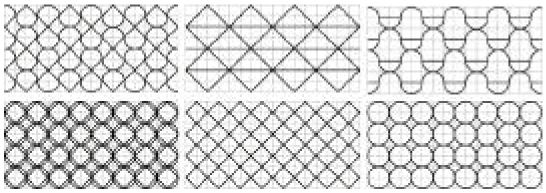


Fig. 8: Some combinations of the entire grid's style

$$I = [S_{ER}, S_{EX}]$$

$$S_{ER} = (E_a, E_b, E_c, E_d, E_e, E_f, E_g)$$

$$S_{EX} = (E_U, E_V, E_{PA})$$

$$E_x = \{E_{x1}, E_{x2}, \ldots, E_{xn}\}\ x = a, b, c, d, e, f, g, U, V, PA$$

(when X takes different values, Xn differ).

S_{ER} is ergonomic parameters set. S_{EX} is appearance style parameters set. E_x is the categories set of control parameters, x including the depth of the seat a, the width of the seat b, the height of the seat c, the width of the backrest d, the height of the backrest e, the backrest's angle f, the curvature of the seat g, U, V and pattern types PA. I would be changed by S_{ER} and S_{EX}. S_{ER} and S_{EX} are controlled by E_a, E_b, E_c, E_d, E_e, E_f, E_g and E_U, E_V, E_{PA}, respectively. Therefore, with the parametric relationship, there could be a lot of different designs.

Programming: According to the control parameters, the logic of the modeling is as follows:

- Define the control parameters
- Determine the parametric relationship among key curves, surfaces and points based on the control parameters
- Create the structure curves of the chair's steel tube
- Re-divide the seat and backrest surfaces' UV grid
- Set points on the nodes of each cell in the grid
- Create the pattern in the cell based on the nodes
- Set the radius of the pipe and create pipe for each structure curve

The program, following the VBScript's rules, should combine with the functions of RhinoScript to model. Key curves are created by the function of AddLine, AddCurve, AddArc in Curve Methods. The point, curve and surface are selected by the function in Selection Methods. The functions in View and Construction Plane Methods could be used to define working plane. The objects could be edited with the functions in Object Methods. At the same time, some new function should be defined to realize some specific work. For example, the function pipe1 (crv) which is used to create pipe with rounded end (Wang, 2011):

```
    Function pipe1 (crv)
    Dim strcmd, piperad, strline
    strline = crv
    piperad = 1
    strcmd = "! _Pipe _SelID "&strline&" _Cap = Round " &piperad&"
_Enter _Enter"
    Call Rhino.command (strcmd)
    End Function
```

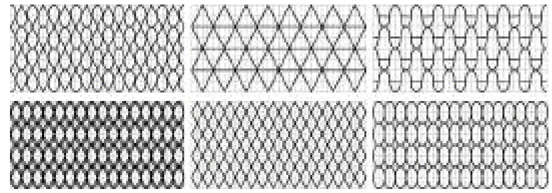


Fig. 9: Other combinations of the entire grid's style

Table 2: Values of each control parameter

Parameter	MIN	MAX
a (mm)	400	490
b (mm)	300	390
c (mm)	340	450
d (mm)	300	390
e (mm)	510	640
f (°)	10	
g (°)	3	
h (mm)	5	(e-c+0.26)

DESIGN CASE OF DIGITAL DESIGN ON TUBULAR STEEL CHAIR

Take this kind of chair as an example. Figure 10 it is made of front foot tube, back foot tube, seat tube, backrest tube, back link tube and fixed tube. Extract the key curves and surfaces based on its characteristic and then choose the key points of the lines (Fig. 10).

According to ergonomics, determine the corresponding position of the control parameters in this model and establish the corresponding size model. The control parameter values are as shown in the Table 2.

After that, establish modeling coordinate system and make sure of the position of key points. Take the back link tube of left side as an example (Fig. 11).

The line from P1 to P2 is the key line named as Lline22 (line). The line controlled by P2, P3 and P4 is the key line named as Larc21 (arc). And the line from P4 to P5 is the key line named as Lline21 (line). The coordinates of P1 and P5 are absolute coordinates which are related to the control parameters of ergonomics directly. The coordinates of P2, P3 and P4 are relative coordinates related to P1 and P5. They make sure that Lline21 and

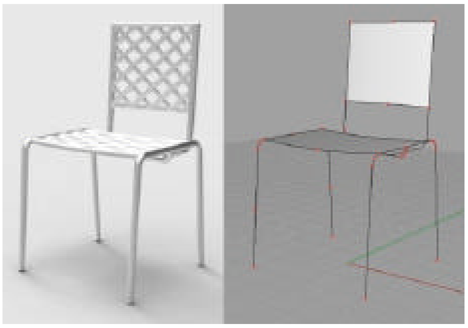


Fig. 10: A kind of tubular steel chair and the key curves, surfaces and points in the chair

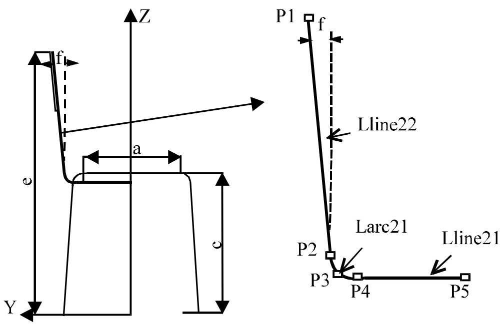


Fig. 11: Key curves and points in the back link tube of left side

Lline22 are connected by arc. The coordinates of key points are as follows.

```
    P1 = (-d/2, a/2+6.025+ (e-c+
0.26)/tan ( (85/180)*pi), e)
    P2 = (-d/2, a/2+6.025, c-0.26)
    P3 = (-d/2, a/2+5.065, c-2.21)
    P4 = (-d/2, a/2+3.035, c-3)
    P5 = (-d/2, 0.00, c-3)
```

Then, ensure the appearance style. Take the backrest as example. Its style is the combination of cross slashes. The backrest surface is divided into a grid of four lines and four columns. And each node in the grid are key points. Figure 12 shows the grid of backrest.

After the parameter determined, programming begins. The number of each size parameters inputted should between the max and min which determined before. Part of the program is as follows:

```
a = Rhino.GetReal ("input a number of the depth of seat  (40< = a< = 49,
unit:cm) ")
If  (40< = a)And (a< = 49) Then
        .......
ElseIf a<40 Then
Rhino.Print"The number is too small"
Else
        Rhino.Print"The number is too big"
End If
```

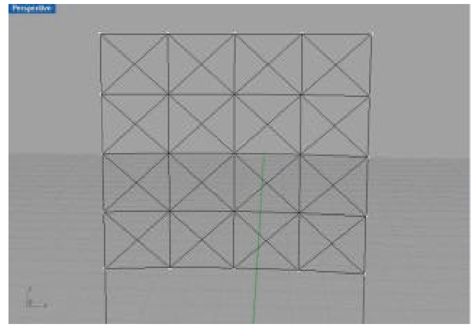


Fig. 12: Grid of backrest

Then use RhinoScript to create key curves with the coordinates of key points. When create key surface, we need to use the surface functions, for example, use the function named AddLoftSrf to create the seat surface. At first, create the upper and lower edges named strMScurve1 and strMScurve2.

Then create the seat surface by Loft. Part of the program is as follows:

```
Rhino.AddCurveArray (Array (b/2,  (a/2), c), Array (0.00, - (a/2),  (c-1)),
Array (-b/2, - (a/2), c))
strMScurve1 = Rhino.LastObject
Rhino.AddCurve Array (Array (b/2, - (a/2)+a, c), Array  (0.00, - (a/2)+a,
(c-1)),  Array (-b/2, - (a/2)+a, c))
strMScurve2 = Rhino.LastObject
'create the auxiliary curve for seat surface
Rhino.AddLayer ("surface")
Rhino.CurrentLayer ("surface")
'select working layer
Rhino.AddLoftSrfArray (strMScurve1, strMScurve2)
strSurfaceS = Rhino.LastObject
'create seat surface
```

In the stage of creating pattern, the UV surfaces of seat and backrest should be redefined. And create pattern in each cell of the UV surface. Part of the program is as follows.

```
ConstObjecttype = 8 'define the type of selection
secu = 4
secv = 4
'define the value of the surface's UV direction
ReDimcollec (secu, secv)
'define an array of U and V
Dim strsurfaceAs, strsurfaceA, arrpoints,  secu, secv
Dim Udomain, Vdomain,  Uparam, Vparam,  i,  j
 'define the names of the variables
strsurfaceAs = Array (strSurfaceS, strSurfaceB)
 'select a surface
For Each strsurfaceAInstrsurfaceAs
If IsNull  (strsurfaceA) Then Exit Sub
Udomain = Rhino.SurfaceDomain (strsurfaceA, 0)
Vdomain = Rhino.SurfaceDomain (strsurfaceA, 1)
        For i =  0 To secu
         For j  = 0 To secv
Uparam = Udomain (0)+ i* ( (Udomain (1)-Udomain (0)) / secu)
Vparam = Vdomain (0) +j* ( (Vdomain (1)-Vdomain (0)) /secv)
redefine the surface in the direction of U and V
arrpoints = Rhino.evaluatesurface (strsurfaceA, Array (Uparam, Vparam))
collec (i, j) =  arrpoints
```

```
        Next
       Next
Dim npoint1, npoint2, npoint3, npoint4
'define the nodes
       For i =  0 Tosecu -1 Step 1
        For j =  0 Tosecv -1 Step 1
npoint1 = collec (i, j)
npoint2 = collec (i+1, j)
npoint3 = collec (i+1, j+1)
npoint4 = collec (i, j+1)
Rhino.AddLayer ("point")
Rhino.CurrentLayer ("point")
Call addpts (npoint1,  npoint2,  npoint3,  npoint4)
'create the nodes
Rhino.AddLayer ("pipe")
Rhino.CurrentLayer ("pipe")
Call pipe (npoint1, npoint3)
        Call                                    pipe (npoint2, npoint4)
'create the pattern on the surface
        Next
       Next
Next
```

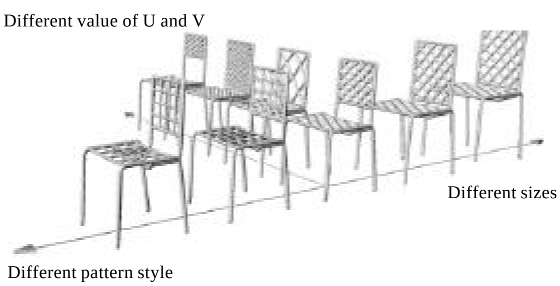


Fig. 13: Some of the design models

Debug after programming. Then generate a series of proposals with different input numbers of the parameters which are the ergonomics sizes (a, b, c, d, e, h), the values of U and V, the pattern in the cell and also the radius of the pipe (Fig. 13). It is easy to generate a series of proposals based on different persons' body sizes and change the appearance style. The whole design process meets the requirements of digital design.

CONCLUSION

By describing the basic theory of digital design of tubular steel chair, the study puts forward the basic method and testified it with a kind of tubular steel chair. This method realizes the digital design of tubular steel chair and can improve the efficiency of proposal design. In furniture manufacturing industry, it can realize customized system of tubular steel chair according to the users' body size and preference. Also, in the engineering and manufacturing industry, it can help analyze and evaluate the mechanical properties of different tubular steel chairs.

ACKNOWLEDGMENT

This study was financially supported by Basic Scientific Research Fund of Colleges and Universities, Research on design evaluation method base on the synchronization mechanism of psychology and behavior (2011JS024) and Special Fund for Agro-Scientific Research in the Public Interest (20123024).

REFERENCES

Acheson, D.C. and J.D. Hardin, 2003. Utilizing the NURBS modeler Rhino? for economical and intuitive 3D product development. Proceedings of the Electrical Insulation Conference and Electrical Manufacturing and Coil Winding Conference and Exhibition, September 23-25, 2003, USA., pp: 559-563.

Dai, Q., H. Yang and Y. Xu, 2004. Design and implementation of two-dimension, three-dimension transformation for last with rhino3d developer platform. Control Automation, 20: 134-135.

Ding, Y.L., 1997. Man-Machine Ergonomics. Beijing Institute of Technology Press, Beijing.

Li, Y. and G. Wang, 2005. On knot modifications of B-spline or NURBS surface. J. Comput. Aided Des. Comput. Graphics, 17: 986-989.

Li, Z. and K. Shi, 2013. Ergonomics design on bottom curve shape of shoe-last based on experimental contacting pressure data. Int. J. Digital Content Technol. Appl., 7: 86-93.

Liu, S., Y.Q. Wang, X.G. Ma and D.C. Wang, 2012. A design method based on extraction of key points of the contours of agricultural machinery's internal structure: A case study on the design of a small self-propelled square baler. Proceedings of the 2nd International Conference on Advanced Design and Manufacturing Engineering, August 24-26, 2012, Trans Tech Publications Ltd., Switzerland, pp: 372-377.

Liu, Z. and S.Q. Sun, 2009. A knowledge management system for product form design. J. Comput. Aided Des. Comput. Graphics, 21: 376-381.

Pan, L. and W. Jiang, 2007. Modeling system of Tiffany lamp-chimney based on Rhino. Comput. Eng. Des., 28: 4426-4428.

Rutten, D., 2004. vbScript|RhinoScript. Revised Workshop Handout.

Su, H. and X.J. Liu, 2010. Study on the rapid design techniques of crystal lighting. Proceedings of the IEEE 11th International Conference on Computer-Aided Industrial Design and Conceptual Design, Volume1, November 17-19, 2010, Yiwu, pp: 797-799.

Sun, H., 2010. Ship Design System Development Based on Rhino Software. Harbin Engineering University, Harbin.

Tang, L.Q., Z.F. Qian and T.J. Wu, 2004. Digital human model for industrial design. J. Comput. Aided Des. Comput. Graphics, 16: 865-868.

Wang, K.J., D.B. Zhou and Y. Zheng, 2008. Fluid flow topology extraction on 3D vector fields. J. Comput. Aided Des. Comput. Graphics, 20: 1514-1520.

Wang, S.C., R.G. Liu, Z. Li, G.D. Jiang, Z. Li and W.G. Zhang, 2000. Geometric description and mesh generation for three dimensional space surface based on NURBS. J. Harbin Inst. Technol., 32: 22-25.

Wang, W., 2011. Rhino Script Parametric Modeling. China Youth Press, Beijing, pp: 245-246.

Wang, X.T., J.X. Zhang, H.L. Su, X.F. Yang and S.S. Cao, 2013. Ergonomic design of the elderly walking aid appliance based on gait analysis. J. Convergence Inform. Technol., 8: 417-424.

Zhou, T.F., J.Q. Feng, C.X. Xiao and Q.S. Peng, 2006. Mesh deformation with hierarchical b-splines. J. Comput. Aided Des. Comput. Graphics, 18: 443-449.