A STUDY ON ROOF-SHAPE CREATION WITH FLOATING FEELING USING VIRTUAL REALITY

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ABSTRACT

This study aims to develop an optimum design method by using a genetic algorithm for roof shapes that provide both a floating feeling and dynamic rationality. The roof is asymmetrical. This asymmetry is expressed by Non-uniform Rational B-Spline (NURBS) curves. The roof shapes were evaluated from stress evaluation values and Kansei evaluation values. (Kansei means human emotion.) The stress evaluation values were obtained from the finite element method analysis. The Kansei evaluation values were calculated by using result evaluated by multiple regression analysis for the Kansei evaluation questionnaire data; these data were obtained using virtual reality. The synthetic evaluation values comprised stress evaluation values and Kansei evaluation values. The roof shapes with good synthetic evaluation values are created by the genetic operation. The shapes with floating feeling were created by adding the Kansei evaluation values; however, these shapes were not created in the case of stress evaluation values.

KEY WORDS

Kansei, shape creation, multiple regression analysis, genetic algorithm

INTRODUCTION

Recently, many researches on optimization of the structural shape have reported that dynamic excellent shapes can be generated by using evolutional techniques (e.g., Xie et al. 1997, Bendsoe et al. 1998). However, these optimization researches did not focus on Kansei that the shapes give man. The excellent shape which satisfies both a dynamic condition and Kansei, but does not provide a dynamic optimum solution, may exist (e.g., Asano et al. 1998, Tsutsumi et al. 2003). This study aims at acquiring structural shapes that fulfill dynamic conditions considering the ambiguous nature of Kansei. Therefore, the Kansei questionnaire is developed using virtual reality technology (e.g., Ohkura et al. 2005), and Kansei is

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evaluated based on the questionnaire result by using multiple regression analysis. The roof shapes are generated using a genetic algorithm. The roof shapes are asymmetrical and are expressed by NURBS curves.

OUTLINE OF THE SYSTEM

The objective of this research is the creation of an asymmetrical concrete roof that covers a design area with dimensions of 32 m × 48 m. The flow of the system is shown in figure 1. This system comprises two subsystems. One subsystem is a Kansei evaluation system and the other is shape evaluation system. Firstly, in the Kansei evaluation system, the Kansei questionnaire system is performed. The obtained Kansei evaluation values are analyzed using multiple regression analysis. In the shape evaluation system, the individuals are generated by random numbers and analyzed using the finite element method. The stress evaluation values are calculated using the analyzed result. The Kansei evaluation values are calculated by the multiple regression equation. Following this, genetic algorithm (GA) operations are performed and repeated until designated generations.

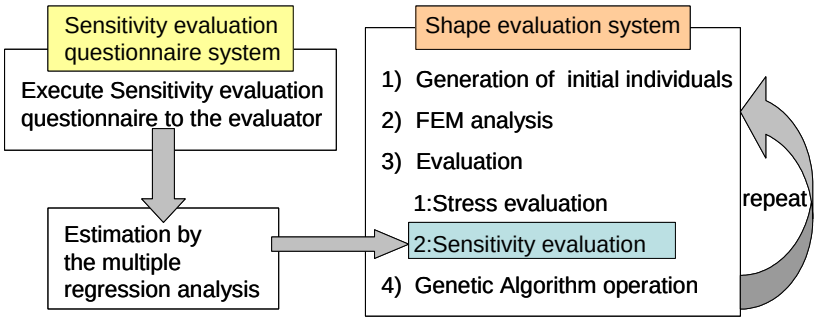

Figure 1: The flow of the system

THE NURBS CURVE

The NURBS curves are a type of spline curves. Using NURBS curves it is possible to draw soft curves with high degrees of freedom by specifying control points, rank number, and weights. An example of a NURBS curve using control points listed in table 1 is shown in figure 2.

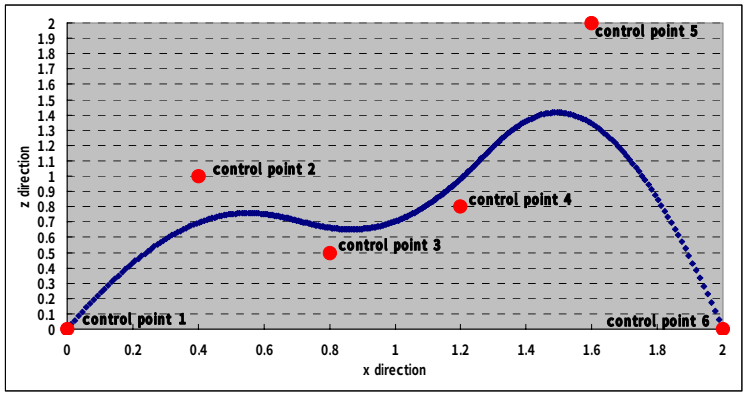

Figure 2: The example of a NURBS curve

Table 1: The control points

control point	coordinate	
	x	z
1	0	0
2	0.4	1
3	0.8	0.5
4	1.2	0.8
5	1.6	2
6	2	0

THE DEFINITION OF THE SHAPE

A shape is given by a gene locus shown in figure 3. The shapes of both the x-z and y-z directions can be defined by the chromosome of the same number by using the NURBS curve. In this curve, the coordinates of the starting and ending points are fixed. The number of control points is six, rank number is four, and all weights are one. While setting the position of the control points, the coordinates of the four control points with the exception of the starting and ending points are set along four divided sections. The horizontal coordinates of the control points are selected as either 1/3 or 2/3 of the section length. The maximum value along the z direction is 12 m, and the z coordinate value is selected as either 1/4, 2/4, 3/4, or 4/4 of the maximum height. During "selection," the opening or closing of roof end is considered. By considering the abovementioned conditions, the shape can be defined by a total of 26 chromosomes.

x-z direction

control points of x direction				control points of z direction								selection
control point 1	control point 2	control point 3	control point 4	control point 1		control point 2		control point 3		control point 4		
1	2	3	4	5	6	7	8	9	10	11	12	13

y-z direction

control points of y direction				control points of z direction								selection
control point 1	control point 2	control point 3	control point 4	control point 1		control point 2		control point 3		control point 4		
14	15	16	17	18	19	20	21	22	23	24	25	26

Figure 3: A gene locus

KANSEI EVALUATION QUESTIONNAIRE SYSTEM

In this study, the Kansei evaluation questionnaire system has been built in advance in order to study the Kansei of the evaluator. If Kansei can be evaluated generally by using the results of the questionnaire data, the Kansei of object roof shape can be evaluated even if the questionnaire data for the object roof shape does not exist. This questionnaire system uses virtual reality technology so that a more realistic Kansei evaluation may be performed. A 100-inch flat display was used for the questionnaire system. The subjects were positioned at a distance of 1.02 m in front of the screen. The horizontal viewing angle was 80 degrees and the vertical viewing angle, 64 degrees. The background consisted of the scenery of the city

on the surface of columnar object. A screenshot of the questionnaire system is shown in figure 4.
The questionnaire comprises of questions such as “Does the roof go well with the scenery?”, “Do you feel the floating feeling in the roof?” and “Do you feel the tension feeling in the roof?” These items were evaluated in five stages. Twenty three students answered the questionnaire. Fifty two individuals were generated for the questionnaire, that is, 36 individuals were generated for evaluation by the experimental planning method, and 16 individuals were generated for verification by random numbers.

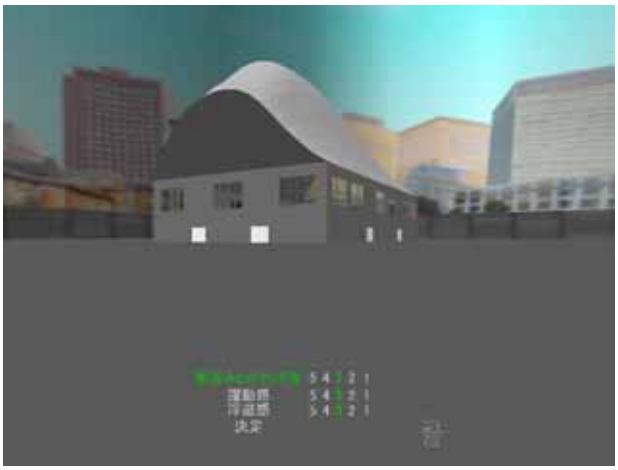

Figure 4: A screenshot of the questionnaire system

EVALUATION AND VERIFICATION BY MULTIPLE REGRESSION ANALYSIS

The evaluation data obtained in the Kansei evaluation questionnaire system are evaluated by multiple regression analysis. In this study, only the floating feeling was considered. It was assumed that the size of open parts, shape complexity, and height of the shape influenced the floating feeling. Therefore, “open rise ratio, x”; “open rise ratio, y”; “height rise ratio”; and “area ratio” were used as variables for multiple regression analysis. “Open rise ratio” is the ratio of the height of the open parts to building width. “Height rise ratio” is the ratio of shape height to the average span in the x-z and y-z directions.” “Area ratio” is ratio of the shape area to the projection area and it reflects complexity. The evaluated value for an individual used the average value of the questionnaire results for that individual.

Multiple regression analysis was used as an evaluation method for the questionnaire because there were high correlations between the evaluation values and factors. The evaluated values were estimated by using the regression equation, shown in Equation (1). The example of the correlation of the factor is shown in figure 5. The estimated values are shown in table 2. The percentage of the correct answer is implied by the ratio of the individual numbers that the estimated value is corresponded to actual value in the verification data. An estimation accuracy as high as 88% was obtained.

$$f(x) = 3.57x_1 - 1.88x_2 + 1.52x_3 + 6.77x_4 - 1.622 \quad (1)$$

x_1=area ratio x_2=height rise ratio x_3=open rise ratio, x x_4=open rise ratio, y

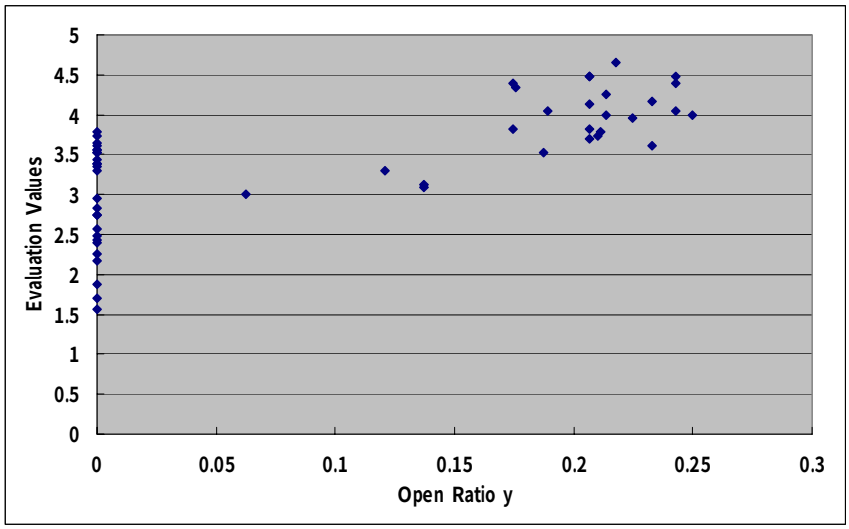

Figure 5: The example of the correlation of the factor

Table 2: The estimated values and the percentage of the correct answer

Number of Individuals	Estimated Value	Acutual Value	
1	5	4	
2	4	4	
3	5	4	
4	4	4	
5	3	3	
6	4	4	
7	3	3	
8	3	3	
9	4	4	
10	4	4	
11	3	3	
12	3	3	
13	3	3	
14	2	2	A percentage of correct answer
15	3	3	
16	2	2	88%

EVALUATION METHOD

Dynamic evaluation is evaluated by equivalent stress. The equivalent stress is calculated using the results of the finite element method. This equivalent stress is shown in Equation (2).

$$\sigma = \sqrt{\sigma_x^2 + \sigma_y^2 - \sigma_x \sigma_y + 3\tau_{xy}^2} \quad (2)$$

The Kansei evaluation uses values calculated by the regression equation. The synthesis evaluation targets only roof shapes where the Kansei evaluation value exceeds 4.0 because the aim of this study is to select roof shapes with high dynamic rationality from roof shapes that create a high floating feeling. If the Kansei evaluation value is four or more, the synthesis evaluation value is equal to the stress evaluation value. In the other cases, the synthesis evaluation value is set to 500. In GA, the minimum value retrieval is done, and the individuals whose synthetic evaluation value is smaller are selected.

STUDY RESULT

In order to verify whether or not Kansei is reflected in this system, this system was performed by the condition of Kansei evaluation only. Examples of initial and final generations are shown in figure 6 and 7, respectively; further, the Kansei evaluation values of initial generation and final generation are shown in table 3. The Kansei evaluation value increases with the size of the open part. Therefore, the individuals of the final generation are the shapes that open the in x-z and y-z directions. These results are same as the results obtained from multiple regression analysis. Therefore, the Kansei evaluation is considered to be reflected well in this system.

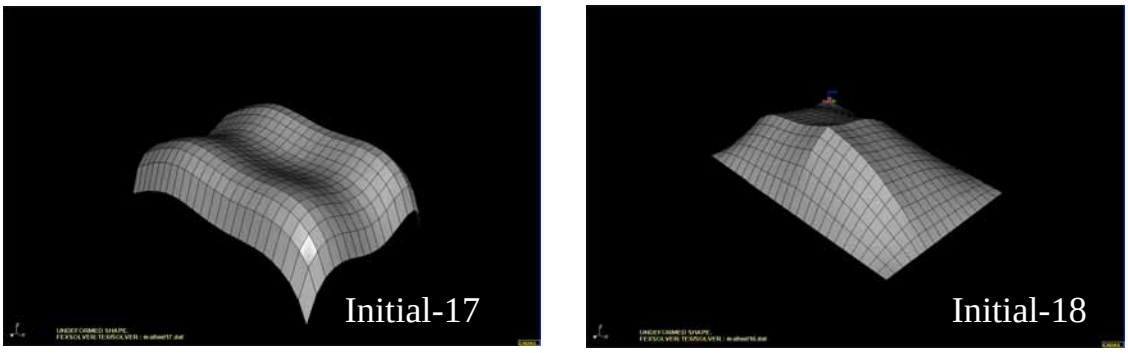

Figure 6: Examples of initial generation

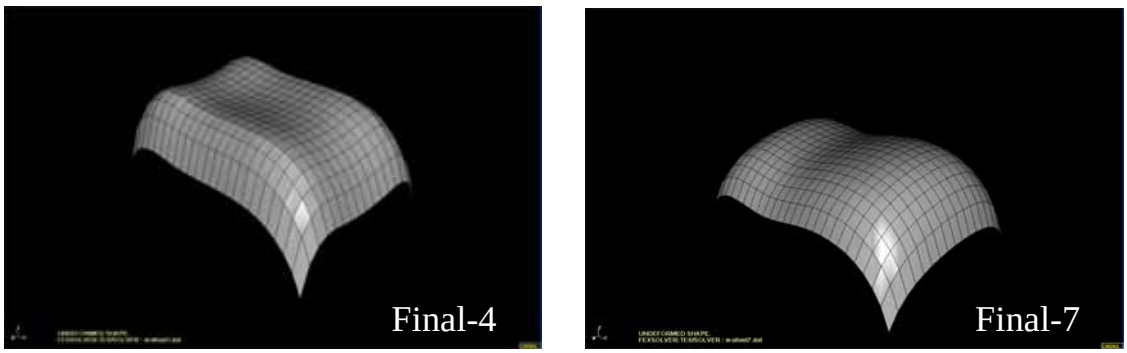

Figure 7: Examples of final generation

Table 3: Kansei evaluation values

Initial generation

Individual Number	Kansei Evaluation Value
1	3.39
2	3.87
3	2.31
4	2.34
5	3.22
6	2.31
7	3.49
8	4.27
9	3.45
10	3.33
11	2.87
12	3.50
13	3.07
14	3.19
15	4.18
16	4.01
17	4.53
18	2.29
19	3.27
20	3.73

Final generation

Individual Number	Kansei Evaluation Value
1	4.46
2	4.35
3	4.93
4	5.17
5	4.96
6	5.01
7	4.31
8	5.11
9	5.03
10	4.68
11	5.10
12	4.38
13	4.53
14	4.78
15	4.97
16	5.03
17	4.48
18	4.99
19	4.81
20	4.49

Next, the GA operations were performed by using the values of the synthesis evaluations of individuals. The Kansei evaluation value was four or greater for 90% of the individuals in the final generation. Therefore, it is proved that the shapes with floating feeling were generated. The examples of the final generation are shown in figure 8, and the evaluation values of final generation are shown in table 4. The individual number of elite individual of final generation is 10. The shape has both a good stress evaluation and high Kansei evaluation. The shape with good stress evaluation is the one in which the roof end is closed, while the shape with high Kansei evaluation is the one in which the roof end is open in the y direction. The shape with a bad synthesis evaluation in final generation is similar to that created by considering Kansei evaluation only. The shape in which both roof ends are open is undesirable in synthesis evaluation because it possesses a large stress evaluation value. The shape in which the roof end opens in the y-z direction is common in the case of all individuals. This proves that Kansei is reflected in the synthesis evaluation.

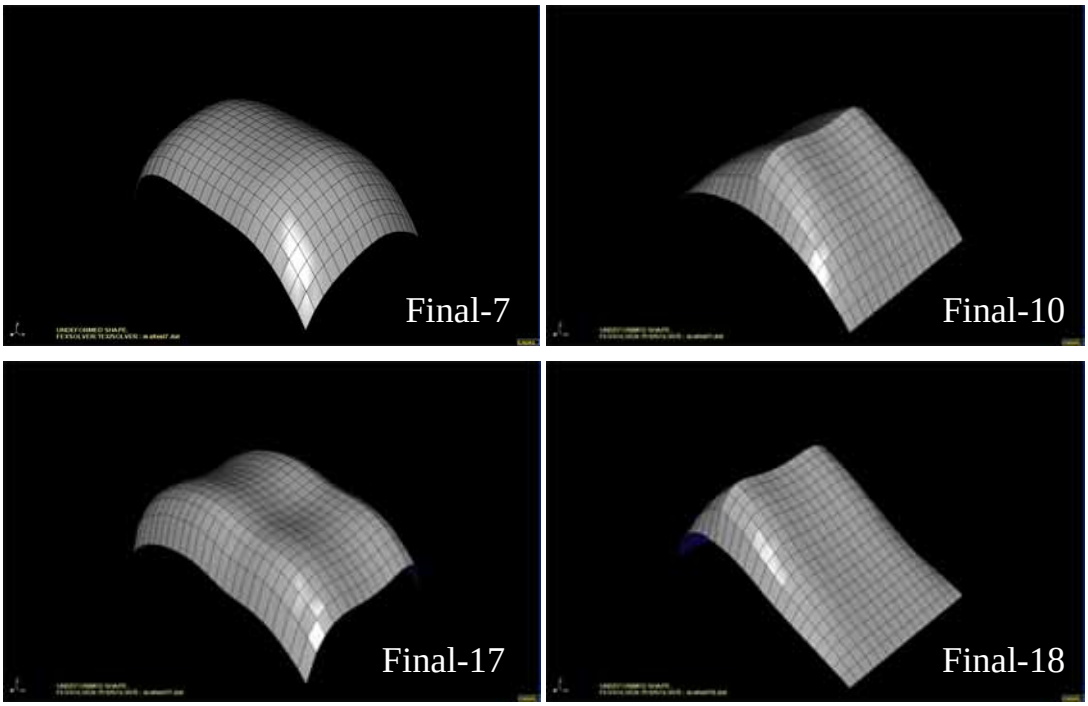

Figure 8: Examples of final generation

Table 4: Synthesis evaluation values

Initial generation

Individual Number	Stress Evaluatio	Kansei Evaluation	Synthesis Evaluation
1	6.78	3.15	500.00
2	26.62	4.56	26.62
3	4.06	2.37	500.00
4	38.87	3.66	500.00
5	93.88	3.57	500.00
6	35.68	3.53	500.00
7	7.67	2.24	500.00
8	20.77	3.52	500.00
9	5.04	2.25	500.00
10	25.01	2.48	500.00
11	10.57	2.86	500.00
12	90.58	3.79	500.00
13	4.52	2.53	500.00
14	33.56	3.68	500.00
15	33.87	4.20	33.87
16	44.15	4.06	44.15
17	67.08	3.85	500.00
18	46.39	3.16	500.00
19	51.80	3.55	500.00
20	40.57	3.49	500.00

Final generation

Individual Number	Stress Evaluation	Kansei Evaluation	Synthesis Evaluation
1	27.25	4.73	27.25
2	29.59	4.57	29.59
3	35.30	4.03	35.30
4	28.22	4.17	28.22
5	37.93	4.59	37.93
6	28.64	4.54	28.64
7	31.17	4.04	31.17
8	27.08	4.24	27.08
9	36.00	4.27	36.00
10	12.07	4.09	12.07
11	36.14	4.41	36.14
12	36.40	4.43	36.40
13	12.42	3.63	500.00
14	25.44	4.07	25.44
15	24.54	4.09	24.54
16	47.32	4.27	47.32
17	26.86	3.74	500.00
18	65.89	4.42	65.89
19	30.13	4.76	30.13
20	30.56	4.11	30.56

CONCLUSION

The conclusions obtained through this study are described as follows:

- More accurate Kansei evaluations can be obtained using virtual reality.
- The floating feeling can be expressed by four parameters, namely, “open rise ratio, x”, “open rise ratio, y”, “high rise ratio” and “area ratio.”
- The floating feeling for the verification individuals could be estimated with an accuracy as high as 88% by multiple regression analysis.
- When the shape creations are performed by Kansei evaluation only, the individuals of final generation possess shapes in which the roof ends open in both the x-z and y-z directions. Therefore, it was confirmed that this system reflects the result of multiple regression analysis.
- When the shape creations are performed by synthesis evaluation, Kansei evaluation value of 90% of the individuals in the final generation was four or greater than four. Therefore, it was confirmed that the shapes that created floating feeling were generated. The elite individual of the final generation was the shape with both good stress evaluation and high Kansei evaluation value. Therefore, many shapes that were not created by stress evaluation were created. Thus, the effectiveness of this system was demonstrated.

The creation of roof shapes with fitted landscape or with tension feeling is planned in the future.

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