Relationship between Beauty and Shape/Force Factors in Japanese Art, Bonsai

Haruyuki Dei, Keio University
Yoshiyuki Matsuoka, Keio University
Takashi Maeno, Keio University

Keywords: Cognitive structure, Factor analysis, Correlation, Multiple regression analysis, Beauty, *Bonsai*

Abstract

Cognitive structure of beauty of *Bonsai* in brain of human is modeled in three layers. First layer is the beauty itself. Second layer consists of sensory factors of beauty that are obtained as a result of factor analysis using semantic differential method for fifteen objects of *Bonsai* conducted for nineteen subjects. Third layer consists of statistically calculated shape/force numerical factors including stress of trunk, area of trunk and leaves and thickness of trunk. Stress of the trunk is calculated by Finite Element analysis. Relationship between the second and third layer is obtained by analysis of correlation. As a result, test subjects are divided into two groups. One group is a "simple" group which cognize beauty of *Bonsai* by symmetry. Other group is a "complex" group which cognize beauty of *Bonsai* by symmetry, size and internal force. In conclusion, cognitive structure of beauty of *Bonsai* is modeled as a three-layer structure and test subjects are divided into two groups by their nature.

1.0. Introduction

Evaluation standards by customers for artificial products have changed according to the change in life styles in recent years. Namely, not only a function but also an easy handling and an excellence in design of product are taken into account. In other words, customers are trying to buy things having both the good performance and good-design. The easy handling and usage for the product is studied in the field of ergonomics. In the ergonomic approach, function and mechanics of artificial products are studied. Takashima, for instance, studied a design of keyboards using the ergonomics approach (Takashima, 1986). Five points, feeling, shape, arrangement, performance and environment of key, are found to be important for designing the keyboard. These are evaluated from tactile sense of human. The physical quantity of tactile sense is determined from mechanical point of view. So, we can say that the keyboard is designed from mechanical point of view. Verterasian studied on comfort of seats for automobile (Verterasian, 1982). A specific feature of human body is measured in order to design a new type of automobile seat. The comfortableness of seat is determined from characteristic of human body when the seat vibrates. The vibration of the seat can be controlled from mechanical point of view. So the design of seat is determined by mechanics, as well. It is found that the comfortableness of seat is related to well-used and well-handled condition. On the other hand, the excellence in design of form is difficult to analyze numerically. Design of form is brought only by the sense of designers. So, the design of product is just composed of the beauty, i.e., mechanical factors are separated from design of form. When we recognize artificial things, various emotions are raised due to sensations. These emotions due to sensations are thought to be divided into conscious and unconscious groups. The unconscious group is related to the mechanics of the product because, for example, architecture and industrial arts are produced by mechanical engineering. Most people, who live in these architecture and industrial arts, must feel unconsciously the internal stress and strain caused by gravity and external force. So, the good-design can be result not only from external appearance but also from mechanics. Kubo studied a relationship between force and likeness for beer mug handles and found that likeness is felt unconsciously (Kubo, 1998). Likeness seems to have similar structure as beauty. It is also found that there is a definitive relationship between the aesthetic desirability of shapes and stress coherence (Kubo, 1998), though this study is not for design.

In order to make good products, both the external beauty and performance must be considered as mentioned above. The beauty is related to the external appearance and mechanics. However, this relationship is rarely studied, because it is difficult to construct numerical methods for estimating beauty. We analyze the cognitive structure of beauty for the fundamental study, systematizing the beauty and mechanics, in order to obtain a guide to design both beauty and performance at the same time for artificial things. In this study, *Bonsai* is adopted as an object of the study, because *Bonsai* is a work of aesthetic value and has mechanical factors in it.

2.0. Models

2.1. Model of Structure

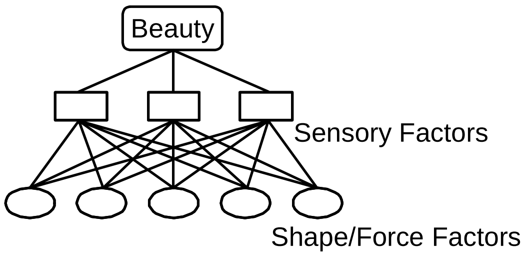

Figure 1: Model of cognitive structure of beauty

(a) Picture of *Bonsai* (b) Diagrammatic *Bonsai*

Figure 2: Picture of *Bonsai* and the diagrammatic *Bonsai*

Normally, cognition process for beauty is complex. The cognitive structure of beauty is thought to be composed of various sensory factors. When human recognize the beauty, sense pass through various processes until they feel beauty. The principal purpose of this study is to construct the cognitive structure that is simple enough for finding out definitive relationship between beauty and mechanics. When human feels beauty of objects, human detects stimulus due to object, first. Then, they consider the cognitive structure in human's brain. Finally, they judge the beauty or ugliness of the object. So, the cognitive structure must be constructed at least from three layers. Therefore, the cognitive structure of beauty is expressed as simple linear three layers as shown in Figure 1. The minimum number of layers that express the cognitive structure of beauty is three.

Next, the factors are defined to construct the cognitive structure as mentioned above. The factor for first layer is the beauty itself. The ones for second layers are sensory factors. These are adjective factors of beauty that are obtained as a result of factor analysis using semantic differential method which is usually used in psychology. The factors for third layer are shape/force ones. These factors are taken from the physical quantities that relate to beauty of *Bonsai*.

2.2. Mechanical Model of *Bonsai*

Bonsai is modeled for clarifying the fundamental cognitive structure, and for extracting the one that is the most related to the beauty from the various elements that influence beauty. The details are described as follows.

2.2.1. Dimension

Bonsai has its front-side and backside, and it is usually evaluated from the front-side. So, *Bonsai* is modeled as a two-dimensional object from a picture of front-side view. Two-dimensional model can also calculate the physical quantity representing *Bonsai* easily.

2.2.2. Diagrammatic Drawing

Beauty of *Bonsai* is composed of various elements including color element and texture element. The purpose of this study is to investigate the relationship between beauty and mechanical factors, especially, shape and force. So, *Bonsai* is diagrammatically drawn to delete the information of the color and texture. The method for drawing is plotting the outline of picture first, and then, connecting the each point. A diagrammatic *Bonsai* can be drawn accurately using the proposed method. Figure 2 shows the picture of *Bonsai* and the diagrammatic *Bonsai*.

When *Bonsai* is modeled as above, the beauty of *Bonsai* may change from the original one.

However, focus of this study is to find out that the relationship between the mechanical factors and beauty of *Bonsai* can be modeled even when the structure of the beauty is changed. So the change in the structure of beauty is not a large problem.

3.0. Methods

3.1. Shape/Force Factors

There are four factors that are related to the beauty of *Bonsai*. These are Shape, Force, Color, and Texture. Human judges the beauty from the shape and the internal force of the object. Also, *Bonsai* has color and texture; these two factors are related to the beauty of *Bonsai*, naturally. In this study, *Bonsai* are expressed by the diagrammatic drawing in order to delete the effects of color and texture. So, the physical quantities that represent the characteristics of *Bonsai* are limited to the quantities of shape and force.

Emotion is raised from spread of shape and symmetric shape. The Area and statistic of area distribution represent the spread and symmetry. So the area and statistics of area distribution are defined as shape quantities.

Emotion seems to be raised not only by shape but also by force. Force is due to knowledge of mechanics, in subconscious. When some parts of object have stress concentration, human feels the object can be easily broken or the object is unbalanced to be fallen down. These emotions are raised from the sense of toughness and stability. So the maximum value of equivalent von Mises stress and the statistical values of thickness distribution of *Bonsai*'s trunk are defined as the force quantities. The defined quantity can represent the sense of toughness and stability. Further details of the method are shown below.

(a) Area

Area of *Bonsai* is calculated from the two-dimensional model. The scales of models are the same as those of the models that are evaluated by test subject.

(b) Statistics of Area Distribution

First, all of the models are converted to bitmap format in order to calculate the areas of models by counting the pixel unit. Next, the values of areas are projected to horizontal to make an area distribution map. The statistical values such as coefficient of standard deviation and degree of skew of the distribution map are calculated. Coefficient of standard deviation indicates the spread of distribution map. Coefficient of standard deviation V_s is calculated by

$$V_s = S / \bar{x} \tag{1}$$

where, S is standard deviation calculated by,

$$S = \sqrt{\sum f_i \left(x_i - \bar{x}\right)^2 / \sum f_i} \tag{2}$$

where, $\bar{x}$ is average of x calculated by,

$$\overline{x} = \sum f_i x_i \Big/ \sum f_i \tag{3}$$

Degree of skew indicates the symmetry of distribution map. Degree of skew S_k is calculated by,

$$S_k = \frac{\sum f_i \left(x_i - \overline{x}\right)^3 \Big/ \sum f_i}{S^3} \tag{4}$$

If S_k is larger than 0, distribution map leans to left. If S_k is equal to 0, distribution map is symmetry. If S_k is smaller than 0, distribution map leans to right. The absolute value of degree of skew is selected as a factor because the degree of symmetry is needed to express one of the properties of *Bonsai*. In this formula, x shows the class of distribution map and f shows the frequence of distribution map.

(c) Maximum value of equivalent von Mises stress

The models evaluated by test subject have leaves and branches. So, not all the trunk can be seen. Therefore, outline of the trunk hidden by leaves and branches is supplemented. When the outline is supplemented, the outline is carefully drawn to show the natural shape. Furthermore, leaves and branches are deleted. The part of root is drawn as a horizontal line to simplify the geometry. The stress/strain of the trunk models under the effect of gravity are analyzed using a finite element method (FEM). Plane stress elements are used to regard the shape as thin board. In other words, the force/stress in out-of-plane direction is neglected. Boundary condition is to fix nodes at the root. Weight of leaves and branches are neglected because they are small enough. Young's modulus, Poisson's ratio, and density of the trunk are 1.23 GPa, 0.40, and 510 kg/m^3, respectively. These are the property of red pine when moisture content is 13.5%. Isotropic material is assumed.

Equivalent von Mises stress in each area is calculated using the FEM. Equivalent von Mises stress is calculated from,

$$\sigma = \left\{ \frac{1}{2} \left[\left(\sigma_x - \sigma_y\right)^2 + \left(\sigma_y - \sigma_z\right)^2 + \left(\sigma_z - \sigma_x\right)^2 + 6\left(\tau_{xy}{}^2 + \tau_{yz}{}^2 + \tau_{zx}{}^2\right) \right] \right\}^{1/2} \tag{5}$$

Maximum value of equivalent von Mises stress is calculated in each model.

(d) Thickness of Trunk

The centerline is drawn in the middle of trunk and divided into 50 points at even intervals. Perpendicular bisector is drawn at each two consecutive points. Thickness of the trunk is the length of line that is linked by two intersecting points of perpendicular bisector and outer line of trunk.

The thickness of trunk is divided by length of centerline in order to normalize the condition. Thickness distribution map is represented from this standard thickness. Furthermore, in order to investigate the average of thickness, average of distribution map is calculated from,

$$\overline{x} = \sum f_i x_i \Big/ \sum f_i \tag{6}$$

3.2. Sensory Factors

First, experiments for sensory evaluations are conducted to test subjects. Next, from the data of experiments, test subjects are classified for judging beauty by cluster analysis. Naturally, there are various processes for judging beauty, which changes due to living environment of the subjects. Factors constructing the beauty must differ in each subject as the perception of beauty differs. Therefore, each test subjects are classified into groups due to the structure between the sensory factors and beauty. Finally, the sensory factors are extracted by factor analysis in each group.

(a) Method of Sensory Evaluation

Experiments for sensory evaluation are conducted to fifty students. Experimental results are analyzed using a Semantic Differential Method (SDM). The condition of this experiment is evaluated in pent-level from nineteen adjective pairs with fifteen models of *Bonsai*. The adjective pairs, which represent the shape and internal force of *Bonsai*, are selected. For example, symmetry-asymmetry pair represents the shape of *Bonsai*.

(b) Method for Classifying Test Subjects

The distribution of score of beauty obtained by subjects is analyzed. If the distribution map of score of beauty has two peaks, each test subject seems to have different processes for recognizing beauty of the models. So, kurtosis of distribution map representing sharpness of the peak is calculated. Kurtosis K is calculated from,

$$K = \frac{\sum f_i \left(x_i - \bar{x}\right)^4 \Big/ \sum f_i}{S^4} - 3 \tag{7}$$

If K is 0, the sharpness of the peak is the same as the sharpness of normal distribution. If K is larger than 0, the peak is sharper than that of the normal distribution. If K is smaller than 0, the peak is blunter than that of the normal distribution. Kurtosis of each distribution map is calculated. The distribution map, whose kurtosis is smaller than -1, has definite two peaks. On the basis of these distribution maps, test subjects are classified into two groups using cluster analysis.

(c) Method for Extracting Sense Factors

Factor analysis is conducted to each group on the basis of sensory evaluation. Factor analysis can extract the potential factors from multivariate data. The number of common factor is four. Each common factor is named from the adjective after the analysis is conducted.

3.3. Relationship between the Factors and Beauty

This paragraph shows the method for analyzing the relationship between factors and beauty.

(a) Relationship between Beauty and Sense Factors

From the results for sensory evaluation and factor analysis, relationship between beauty and the sensory factors is analyzed. The weight of relation between the beauty and factors is calculated using multiple regression analysis. Multiple regression analysis is to construct a formula between one criterion variable and numbers of explanation variables. Explanation variable which is important for explaining criterion variable is found. In this study, criterion variable is the score of beauty obtained as a result of the sensory evaluation. The explanation variables are the factor scores of each factor obtained from the factor analysis.

Table 1: Quantity of Shape/Force Factors

	Area	Area Distribution		Maximum Value of Equivalent von Mises Stress	Thickness Distribution	
	(cm^2)	Coefficient of Standard Deviation	Degree of Skew	(~ 10^{-6}N/m)	Average	Standard Deviation
Bonsai 1	59.36	0.71	0.12	155.21	0.197	0.072
Bonsai 2	45.09	0.53	0.15	398.56	0.099	0.022
Bonsai 3	34.33	0.81	0.11	229.58	0.105	0.034
Bonsai 4	51.11	0.80	0.37	7.57	0.694	0.313
Bonsai 5	48.50	0.41	0.03	9.23	0.288	0.140
Bonsai 6	42.02	0.42	0.06	60.39	0.225	0.074
Bonsai 7	40.84	0.44	0.12	47.19	0.187	0.086
Bonsai 8	53.05	0.43	0.10	20.78	0.220	0.085
Bonsai 9	39.54	0.47	0.34	122.47	0.180	0.074
Bonsai 10	25.48	0.40	0.17	169.54	0.121	0.046
Bonsai 11	22.43	0.34	0.09	116.39	0.076	0.049
Bonsai 12	24.84	0.53	0.37	303.86	0.102	0.062
Bonsai 13	32.68	0.37	0.11	25.05	0.229	0.128
Bonsai 14	17.82	0.49	0.32	419.28	0.052	0.046
Bonsai 15	42.89	1.17	0.02	591.06	0.061	0.041

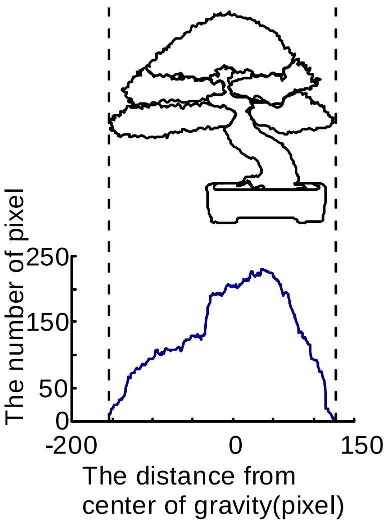

Figure 3: Distribution Map of Area

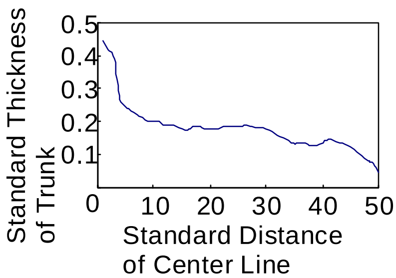

Figure 4: Distribution Map of Trunk's Thickness

(b) Relationship between Sense Factors and Shape/Force Factors

The correlation coefficient between the factor scores of each factor and physical quantity described in chapter 3.1 is calculated. When the correlation is large, the plot of the point diagram is represented in order to confirm the plot drawing a line correlation.

4.0. Results

4.1. Shape/Force Factors

The results of various experiments are shown in Table 1. The distribution of area and thickness are shown in Fig. 3 and Fig. 4, though this is simply a case in point.

4.2. Sensory Factors

(a) Result for Classifying Test Subjects

There are five *Bonsai* having two peaks for kurtosis of the distribution map represented from the score of beauty. So, cluster analysis is calculated from the beauty score of these five *Bonsai*s. As a result of the analysis, the test subjects are divided into two groups. One group (group 1) evaluates five *Bonsai*s to be beautiful. Another group (group 2) evaluates these to be ugly. The analysis which done after this is conducted to both groups.

(b) Result for Extracting Sensory Factors

(b.1) Group 1

From the factor analysis, four factors are extracted. First factor has many adjective pairs. Comparing the score of first factor and the model geometry, we can see that the symmetric model registers high score. We can conclude that the first factor represents the symmetry of the model. It is named “symmetry factor”. Second factor has many adjective pairs that represent internal force. The larger the size of model is, the higher the score is. So, the second factor is named “size factor”. Third factor is constructed from adjective pairs representing the curved line or shape. The model having high curvature shows high score. So, the third factor is named “curve factor”. It is difficult to explore the meanings of fourth factor. However, forth factor is constructed from adjective pairs representing movement. So, the forth factor is named “movement factor”.

Although the cumulative proportion is 62.57%, the eigenvalue is less than 1. So, the number of factor is appropriate.

(b.2) Group 2

From the factor analysis, four factors are extracted. First and second factor are the same as those in group 1. So, the first and second factors are named “symmetry factor” and “size factor”, respectively. The third factor is constructed from adjective pairs that represent the spread and the curved line. Furthermore, the score of factor changes due to the change of the trunk’s curvature and thickness of the model. In other words, the score of the factor changes due to the change in the stress in the model. So, the third factor is named “force factor”. Forth factor is constructed from adjective pairs that represent complexity. Furthermore, the model that has complex crop of leaves shows high score of the factor. So, the forth factor is named “complex factor”.

Although the cumulative proportion is 57.48%, the eigenvalue is less than 1. So, the number of factor is appropriate.

4.3. Relationship between Factors and Beauty

(a) Beauty and Sensory Factors

(a.1) Group 1

Standard partial regression coefficient obtained from the multiple regression analysis is as follows: symmetry factor: 0.706, size factor: 0.136, movement factor: 0.221, curve factor: 0.186. Standard partial regression coefficient is the value of the factor’s weight. In this study, the factor’s weight means effects on the beauty. There are no negative values for standard partial regression

Table 2: Correlation coefficient between factors and physical quantity (group 1)

	symmetry	size	movement	curve
quantity 1	0.200	0.814*	0.108	0.298
quantity 2	-0.641*	-0.224	0.672*	0.232
quantity 3	-0.293	-0.191	0.014	0.223
quantity 4	-0.391	-0.658*	0.394	0.638
quantity 5	-0.324	0.540	-0.087	-0.269

Table 3: Correlation coefficient between factors and physical quantity (group 2)

	symmetry	size	force	complex
quantity 1	0.062	0.895*	0.356	0.156
quantity 2	-0.693*	0.018	0.384	0.086
quantity 3	-0.319	-0.147	0.136	0.200
quantity 4	-0.543	-0.446	0.631*	-0.060
quantity 5	-0.094	0.531*	-0.409	0.378

coefficient. So, there is no multicollinearity in this analysis.

(a.2) Group 2

Standard partial regression coefficient obtained from the multiple regression analysis is as follows: symmetry factor: 0.462, size factor: 0.267, force factor: 0.365, complex factor: 0.022. There are also no negative values for standard partial regression coefficient. So, there is no multicollinearity in this analysis as well.

(b) Sensory Factors and Shape/Force Factors

(b.1) Group 1

The result of correlation analysis is shown in Table 2. Quantity 1 represents the area. Quantity 2 represents the coefficient of standard deviation of area distribution. Quantity 3 represents the degree of skew of area distribution. Quantity 4 represents the maximum value of equivalent von Mises stress. Quantity 5 represents the average of trunk's thickness distribution. A superscript, " * ", shows that the correlation coefficient are regarded to differ significantly from 0 at significant level of 1%. From this result, the symmetry factor has negative correlation to the coefficient of standard deviation of the area distribution. The size factor has positive correlation to the area and the average of trunk's thickness distribution. The movement factor has positive correlation to the coefficient of standard deviation of area distribution. However, the curve factor has no correlation to the shape/force factor. All the correlation is confirmed from the point diagram.

(b.2) Group 2

The result of correlation analysis is shown in Table 3. The quantities and the definition of the " * "in the table is the same as those in Table 2. From this result, the symmetry factor and the size factor has the same correlation as Table 2. The force factor has positive correlation to the maximum value of equivalent von Mises stress. The complex factor has no correlation to the shape/force factor. All the correlation is confirmed from the point diagram.

(c) Overall relationship

Figure 5 is the cognitive structure of beauty obtained by combining the results of (a) and (b). From this result, we can conclude as follows: First, the test subjects who belong to simple group (group 1) have simple cognitive structures. They judge beauty only from symmetry of shape. On the other hand, the test subjects who belong to complex group (group 2) have complex cognitive structures. They judge beauty from symmetry, size, and internal force of shape. It is confirmed that the three-layer linear model we constructed is useful for representing the cognitive structure of beauty of *Bonsai*. We believe that this method can be adapted for analyzing the beauty of other objects including industrial products in which the force/shape factors are important.

5.0. Conclusions

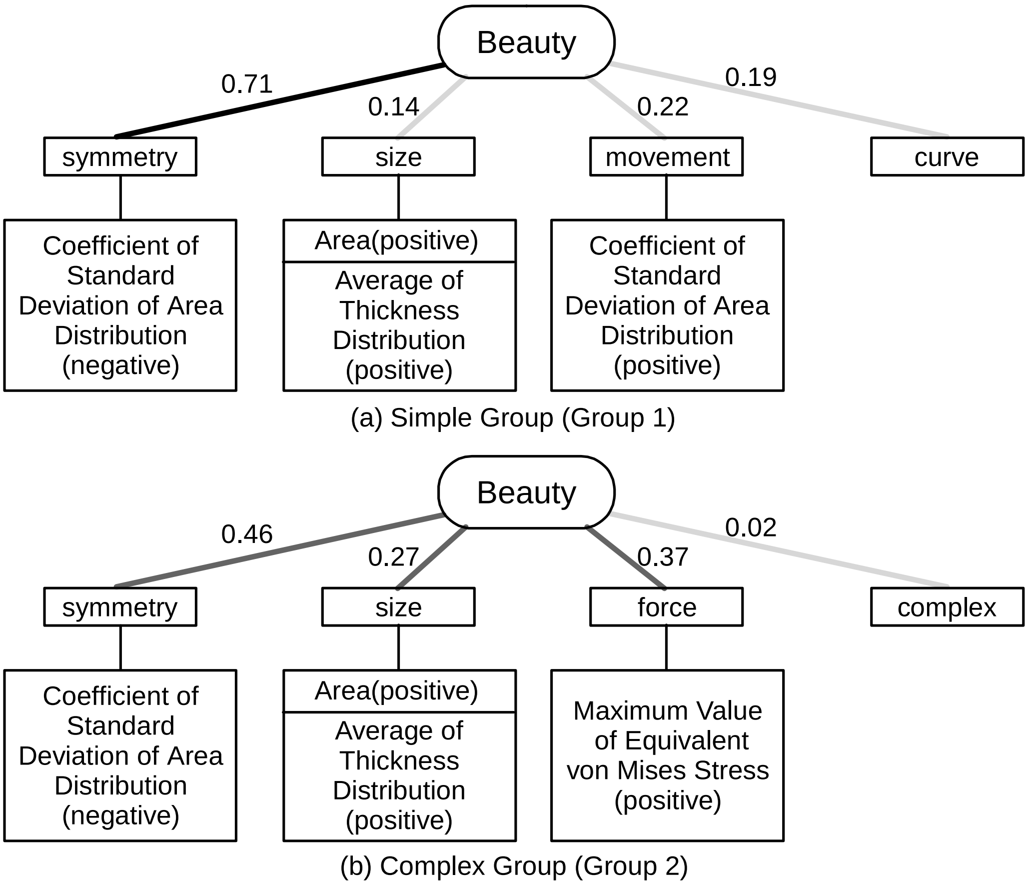

Figure 5: Combined Cognitive Structure of Beauty

The cognitive structure of beauty is constructed from the sensory factors and shape/force factors. First, shape/force factors that represent physical quantities of the models of *Bonsai* are calculated using FEM. Next, the test subjects are divided into two groups considering the difference of their cognitive structure. Then, the sensitive factors are extracted from each group. Last, the cognitive structure is constructed from the relationship of beauty, sensitive factors and shape/force factors. We found that the group, which we call “simple” group, judges beauty only by the symmetry of shape. Another group, which we call “complex” group, judges beauty from the symmetry, size and internal force of shape. So, we found that the human’s cognitive process of beauty can be modeled using three-layer structure. The method in this study is to find the physical quantity that affects the beauty of *Bonsai*. This method can be extended to other things. If the physical quantity affecting the beauty of artificial products is determined, artificial products that aimed to be beautiful can be designed in the future study.

References

1. Kubo, M., 1998, Stress Coherence in Intuitively Designed Shapes, China-Japan-Korea Design Symposium, pp211-216

2. Takashima, T., 1986, Consideration of Operativity of Keyboard Switches by Human Engineering, IPSJ, No.32, pp1807-1808
3. Verterasian, J.H., 1982, On Measuring Automobile Seat Ride Comfort, SAE Paper