ORIGINAL ARTICLE

Kansei Engineering Study for Streetscape Zoning using Self Organizing Maps

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Abstract: In this study, Kansei engineering was used to analyze people's subjective responses to a streetscape plan for a historic townscape. The Chofu area in Shimonoseki city was chosen for the Kansei analysis, and the appearance of the streetscape was evaluated on the basis of actual photographs by using the traditional semantic differential method. A guideline is often formulated to promote a landscaping plan in such historic towns. Generally, a landscape guideline established for a public purpose recognizes the anticipated loss of the worth to landowners and leaseholders resulting from the agreement, even if the plan is not legally binding or does not include penalties. The regulation, therefore, might be neutral in how it affects concerned residents or businesspersons in the area covered by the guideline. The different positions of people in the region, such as residents, tourist agents, or businesspersons, should be reflected in the views of the entire community. When building the plan, it is necessary to unify the concept and the image of the streetscape in the community. However, an issue sometimes comes up in such areas where the criteria for landscaping are not unified in the community. The principal concept of "Image held in the region and image of the individual place of the street" must be unified in advance. The Kansei engineering study proposed in this study revealed the representative design elements arising from the regional characteristics of the area and its people. The pilot investigation using self-organizing maps (SOMs) demonstrated the development of landscape image maps to consider the streetscape elements from observation points in the area. SOM has been used as an alternative analytical method that replaces factor analysis or PCA in recent Kansei engineering studies. This study employed a general SOM approach to illustrate streetscape zoning.

Keywords: *Kansei Engineering, Self-organizing map, Historic town, Streetscape, Zoning*

1. INTRODUCTION

This study illustrates Kansei data analysis for a historic streetscape. The Chofu area in Shimonoseki city is the subject of the study. Chofu has a historic streetscape that it is especially famous for its beautiful earthen walls. This study examines the Chofu street views in order to achieve streetscape preservation and conservation. The experimental results are transformed into an image map that can be used as a sample distribution of the semantic space. The streetscape elements and zoning of the observation points, which resulted from the estimated semantic space, are also considered for a preliminary finding to help with the conservation aspects of future landscaping.

Within the field of Kansei engineering, computing the semantic space has been an important research issue since it was pioneered by Nagamachi at Hiroshima University [1]. Kansei engineering aims to measure customers' subjective responses to products and to identify the properties from the responses by using mathematical models. Then, the results are applied to improve the design. The mechanism of human feeling is complex and hard to identify, so the use of semantic maps that have been computed from semantic differential data is a successful way to reduce the multidimensional semantic space into a few dominant components for representation. Factor analysis (or principal

component analysis) is one such methodology. It is often used in a traditional Kansei engineering study. The output of the analysis is a multidimensional semantic space estimated from semantic differential data, and the dimensions are usually a couple of latent factors. The adjectives are positioned, according to their loadings, on the space composed by the extracted factors. The factors also place the samples in the semantic space by the estimated factor score because the factor analysis relates the samples to the semantic meanings composed of reduced latent adjectives. Next, the samples' attributes are related to adjectives by using methods such as linear regression analyses or methods of quantification theory in the case of categorical data. The two-stage process is called a general Kansei analysis.

This study aims to use self-organizing maps (SOM) to analyze streetscape views [2]. SOM have been used to reduce multidimensional variables into a small number of axes. SOM performance has been confirmed in a previous study of Kansei analyses [3]. Our interest in the means of Kansei engineering methodology is to compute the position of attributes in a semantic space. This paper explores the prototyping of the Kansei analysis by using SOM for a case study on the analysis of a historic streetscape. The main purpose of the SOM analysis is to translate the large amount of data into two-dimensional mapping. SOM learning creates small, useful amounts of information by

gathering multidimensional data. Therefore, it is used as an alternative to factor analysis. SOM can analyze not only SD evaluation data but also numerical design attributes such as amounts, size, and color. It can also be used as a method like quantification theory type I [3]. This streetscape study only illustrates the use of maps to relate physical zones that are drawn according to human Kansei by using SOM. The study also explores the relationship between streetscape features and real allocations on the map. Therefore, it is recognized that the allocation of real designs to a map is the main advantage of our method. In order to confirm that SOM can be used to perform a streetscape analysis, an experimental proof is required from real case studies. In particular, adjusting learning parameters, such as setting an initial mapsize and determining the map topology, is not an established method because various SOM have been proposed. One purpose of our study is to demonstrate an example with a real streetscape.

2. EXPERIMENT USING A STREETSCAPE VIEW IN A HISTORIC TOWN

2.1 Objective Area of the Kansei Experiment

Chofu in Shimonoseki city is a tourist-frequented area [4]. It is popular because of its historic streetscape, which includes earthen walls built using the distinctive, traditional Japanese construction method. The walls imbue the streetscape with a strong sense of Japanese elements. The Chofu streetscape has a characteristic atmosphere that reflects its harmony with the daily life of the residents. Most of the houses are private properties, except for a few cultural ones; therefore, it is difficult to construct a landscaping approach that all residents can agree to, which can hinder the advancement of developing a plan for streetscape conservation. To set constraints on a private property typically declines the property's value. Consequently, an incentive for residents to adhere to the plan must be included in the plan to compensate for the residents' loss. For example, the regulations of the Shimonoseki city office have subsidized property owners' maintenance fees including reconstruction costs. The grant that was paid in exchange for maintaining private property in compliance with the landscaping plan was funded by the landscaping program and terminated at the end of fiscal year 2010, 14 years after it was established. Therefore, the streetscape in the area is no longer regulated by the rules set for residential properties. This raises concerns that the current properties face damage from changes to the streetscape. Therefore, the idea to conclude a streetscape-related agreement in the area was raised by the local government and residents [5].

In order to preserve a streetscape, the guidelines are required to establish common understandings. Instigated by the circumstances in Shimonoseki city, this project began attempting to define the zoning criteria for the landscaping regulations in order to restrict the plans to the minimum area necessary to conclude the agreement. To limit the area means that the plan appropriates the maintenance fund specifically for the zone of the street that should be maintained at this time.

The assigned task of this study is to collect basic data for zoning according to the geographical property environment [6]. The elements required for constructing the characteristics of Chofu are extracted by the study after specifying which areas should be maintained for the future, such as earthen-walled streets and garden plantings. This study undertakes a streetscape evaluation experiment in order to obtain the visual Kansei evaluation data of these representative points in the area. It is expected that the zoning maps will be identified from the streetscape evaluation data.

In previous studies, zoning methodologies were often used especially by city planning institutes. The city planning issues, however, have focused on a plan to solve the problem of establishing "use districts," which is a direction of how to use the land. Our study aims to develop streetscape planning, which is an approach to analyze the present situation from a city planning viewpoint. Therefore, it seems to be effective to apply the Kansei engineering approach to the streetscape analysis. On the other hand, architectural institutes traditionally try to research the streetscape evaluation by the SD method [7]. The studies are quite similar to the Kansei engineering approach; hence, the Kansei engineering institute has decided to deal with the landscape problem [8]. However, only a few cases have been studied in the field using the Kansei engineering approach. Streetscape issues could become one of the major fields of study in the Kansei engineering institute. The main advantage of our study is that it derives an actual problem-solving process to the specific field by applying the advanced Kansei engineering methodology.

2.2 Experiment of Streetscape Evaluation

A general semantic differential questionnaire was prepared for 25 persons (15 males and 10 females) who had been to Chofu before at least once [9-11]. The stimulus of this experiment was 39 photographs taken on the street of Chofu by using a compact digital camera. The targeted object area was the streetscape priority area in the Chofu district regulated by the city office. The photo locations were almost uniformly selected using the results for cumulative inspections, which included historic earthen-walled streets, contemporary residential areas,

and business districts. The photographs were taken at the same height as the viewpoint of the experiment's participants. In the experiment, the photo samples were projected onto a screen and evaluated on a five-point semantic differential scale for 15 adjective words (Table 1). The adjectives used as evaluation words were gathered from a previous study [12] and from the views of experts in the design and regional development. Then, the data from the questionnaire responses from the 25 subjects were averaged. As a result, a 39-times 15-element data matrix was obtained.

3. MULTIVARIATE ANALYSES

First, we carried out fundamental considerations by multivariate analyses. The results of the cluster analysis, which was computed the normalized data by Ward's method, are shown in Figure 1. The results provide a classification that is, when used in a Kansei evaluation, it forms clusters. The border was specified as a four-cluster line, considering the squared distance between the clusters. The clusters were used to derive common features in the relationship between the design and Kansei evaluation.

Next, the factor analysis results are given. Table 1 shows the factor loadings after performing a varimax rotation of the evaluation words. Two latent factors were extracted, which met the criterion of an Eigenvalue less than 1.0. These factors account for 84.6% of the cumulative contribution rate; therefore, the analysis gives sufficient results to explain 15 variables. The two-dimensional semantic spaces, defined as “fantastic-realistic” and “bright-dark” axes, compose the loadings of the 15 adjectives. In general, the latent factors, as well as the streetscape studies, compose the larger number of axes. In the case of Chofu, a historic viewpoint can strongly affect human identity. The influence of the image resulted in the two extracted

Figure 1: Dendrogram of the cluster analysis (Ward's method and normalized data) for 39 photo samples with 15 SD-scaled evaluation words.

Table 1: Factor loadings after varimax rotation.

Adjective words	Factor 1 fantastic-realistic	Factor 2 bright-dark
modern-classic	-0.96	-0.16
realistic-fantastic	-0.91	-0.33
tasteless-tasteful	-0.91	-0.38
indistinctive-distinctive	-0.89	-0.29
atypical-typical Chofu	-0.88	-0.36
wilderness-tidy	-0.83	-0.42
noisy-quiet	-0.82	-0.34
not high-grade-high-grade	-0.81	-0.50
ugly-beautiful	-0.79	-0.60
artificial-natural	-0.77	-0.42
senseless-smart	-0.75	-0.58
dark-bright	-0.14	-0.89
cold-warm	-0.49	-0.75
unfriendly-friendly	-0.26	-0.68
uneasy-easy	-0.50	-0.66
Contribution rate	56.9%	27.7%

latent factors. Figure 2 shows a factor-score mapping of the 39 samples. The marker denotes the kind of cluster to which it belongs. The relationship between the cluster and factor can be recognized as the sample distribution on the semantic map. The samples in Cluster 2, for instance, distribute around the upper-right area, so the meaning of the cluster is indicated as “dark” and “realistic” from the mapping. Then, the image of the streetscape that each cluster influences was found from the extracted semantic map.

Next, a zoning map, based on the multivariate analysis, is superimposed on the real road map to visualize the relationships between location and the Kansei results. Figure 3 shows where on the real road map the sample pictures were taken. An encircled number that identifies its cluster is marked at the place where the sample picture was taken. Then, the representative visual image of the area can be seen from the geographical location. Cluster 2, for example, signifies a set of photographs of views

Figure 2: Semantic mapping using the factor scores from the 39 samples on the axes of Factor 1 (realistic-fantastic) and Factor 2 (dark-bright).

Figure 3: Locations of the sample pictures with the number of clusters on the actual road map.

normally found in a commercial street, because both its semantic meaning and the geometric location are almost always found from the samples located around the shopping district. Therefore, considering the result of multivariate analyses, the streetscape of the commercial avenue is recognized as a “dark” and “realistic” image, and is consistent with our general feeling. The typical Chofu area, that is, residential streets with an earthen wall, mostly belongs to Clusters 3 and 4. Along the river-front area, there are many samples from Cluster 3. We can also recognize the features of specific sample streetscape images from the related pictures. The streetscape elements that are referred to establish the preservation guidelines must be derived by further considerations.

4. SELF-ORGANIZING MAPS

Self-organizing maps (SOM), developed by Kohonen, can visualize multidimensional data into a sheet-like neural-network array [2]. The units translate various input signals into certain reduced coefficients. SOM aims to acquire features of input data to classify unknown or unlearned data into proper classes. The basic SOM network is composed of an input layer, whose content depends on an input vector, and an output layer, formed as a two-dimensional array of units (Figure 4). An output unit has the same dimensions of an element within the input vector or the input layer. A unit of input layer corresponds to the element, or a variable, of the input vector,

Figure 4: SOM, showing connections of possible pairs in the input and output layers.

which means an evaluation word in the case of a Kansei analysis. Therefore, the relationship between the input unit and the element of input data is a one-to-one connection. Additionally, the connections from each input layer are connected to all output units by an arrow. Thus, the number of elements of the output unit is the same as the input vector or the array of the input unit. The learning process is an iterative competitive and cooperative learning, and is unsupervised (self-organized), which means no teacher is required for searching appropriate weights of the output units. In the basic version, only one nearest map node (the winner node) activates at a time, according to the distance from a just-entered input vector. The winner node adjusts its elements toward the input array (competitive learning). Neighboring units, which are located around the winner, also recompute the unit elements on the basis of the locational distance to the winner (cooperative learning). The formation of the unit on the input and output layers is static over the course of the learning process. A relationship between the output units, represented by Euclidian distance, is acquired by adjusting the weight vectors.

SOM is a kind of two-layered neural network, as shown as Figure 4. The first layer is the input layer $x(t)$ of an n -dimensional input vector. The second layer is the output (competitive) layer, and is generally two-dimensional, arranged in order to visualize the resulting two-dimensional plane mapping. The vectors of the competitive layer at discrete time t are expressed by model vectors $m_i(t)$, where i means the number of output units ($i = 1, \dots, u$). The model vector has n elements, depending on the dimension of the input vector $x(t)$. SOM performs a stochastic competitive learning algorithm. Initial values of the components of the model vector $m_i(t)$ might be decided randomly. Any input vector that would be mapped into a certain location by a winner-takes-all rules according to the distance between the input vector $x(t)$ and the model vector $m_c(t)$ of the winner unit. An input vector is compared with all the model vectors $m_i(t)$. The best-matching unit (winner) on the map, i.e., the unit where the model vector is most similar to the input vector, is identi-

fied according to the following minimum distance criterion:

$$|x - m_c(t)| = \min_i |x - m_i(t)| \quad (1)$$

Then, only one model vector $m_c(t)$ is identified as the winner vector. The model vectors of the winner and its neighboring nodes are recomputed toward the input vector according to the learning principle specified by the following equation:

$$m_i(t+1) = m_i(t) + h_{ci}(t) [x(t) - m_i(t)] \quad (2)$$

where $h_{ci}(t)$ is the neighborhood function defined over the map. Usually, the function is defined as ;

$$\text{if } i \in N_c(t), h_{ci}(t) = a(t) \text{ else } h_{ci}(t) = 0$$

where $a(t)$ is a scalar that is defined as the relative size of the learning step, and $N_c(t)$ specifies the neighborhood around the winner in the map array. The radius of the neighborhood is shrunk during the learning step.

Then, we intend to visualize the primary data matrix into a self-organizing map. Because, SOM consists of a two-layered network, it can visualize a two-dimensional mapping in which each output unit is connected to a scalar of an input variable depending on the weight implicit in the mapping information. Consequently, a map is composed of n sheets of the element map, such that the j th map is represented as a two-dimensional element matrix $l_j (j = 1, \dots, n)$. SOM combines a nonlinear projection from an input layer with an output layer and the clustering method in an ordered vector quantization graph.

5. RESULTING SOM MAP FOR STREETSCAPE

The next step involves learning an SOM map from the 39 sample pictures using the SD data gathered from the streetscape experience. Figure 5 shows the resulting SOM map on a 15×10 grid (unit size $u = 150$). The input data were obtained from 39 samples (images) of the 15-dimensional ($n = 15$) vectors (variables). A vector of the sample was used as an input vector for recomputing the model vectors of SOM learning. Each learning step is completed by recomputing the vectors, which takes a round of 39 samples. Therefore, 39 winners are identified as the nearest units to each image at each learning step. The network structure was a hexagonal topology, which is the most-used form for SOM construction. The number of learning steps was 10,000. The initial learning rate and neighborhood radius were 0.2 and 10, respectively. In Figure 5, a hexagon overwritten with a dot or a sample number (such as “s1,” which means the nearest unit to sample 1) indicates a unit on the output layer. All output units are characterized by the model vector m_i . Other hexagons represent the distance of the model vectors between the pair of neighboring units. The distance between the units on the map corresponds to the degree of the relationship in the semantic meaning. The model vector represents the characteristics of the SD evaluations; therefore, the larger distance of the model vector, which has a darker density of grey, shows the larger difference between the units. The lines on the map can be drawn to the dark blocks of the map. The distribution of the samples, which have been clustered on the basis of computation during the cluster analysis, is used as a semantic map, the same as that used for multivariate analyses.

Figure 5: Resulting SOM mapping, locating 39 samples within grouped clusters.

As shown by the resulting SOM map in Figure 5, the 39 samples can be divided into two groups by a diagonal line in the center that has been drawn using the boundary along the dark hexagonal units. The right-side group contains the samples in Clusters 3 and 4, and the opposite side contains Clusters 1 and 2. The other classifications are too ambiguous to form a separate cluster; therefore, conclusions cannot be drawn from the graded units on the map. However, the locational distances between the samples are also significant for the classification. It can be said that the comparison between the results of the multivariate analyses and the locational sample distribution using an SOM is useful when considering the advantages of our approach. In that case, the thin lines are intentionally drawn according to the cluster's classification. The thin line on the left side evenly divides the samples into Clusters 1 and 2 by the location. Clusters 3 and 4 distribute around the lower-right and upper-right parts, respectively. Additionally, a group that contains Clusters 3 and 4 is on the right side near the central line. As shown by the results of the multivariate analyses in Figure 2, the sample distribution using an SOM is similar to the semantic map resulting from the multivariate analyses, although it is distributed symmetrically. The partition through the center is the most considerable classification because most of the left-side samples belonging to Clusters 1 and 2 are located in commercial or recently resident districts, and most of the right-side samples belonging to Clusters 3 and 4 are located on the historic street (Figure 3). Thus, it is reasonable to conclude that the partition is affected on a distinction between the historic and contemporary features of the streetscape. The historic district on the actual road map is, therefore, available for zoning the covering area of the landscaping, which limits the area to specific properties.

Moreover, the samples in Clusters 3 and 4 are focused around the central triangular area. Figure 6 illustrates the

Figure 6: Mapping of the sample pictures using factor scores. The samples of Group 5 are marked on the corresponding samples in Clusters 3 and 4.

mapping of the sample pictures from Group 5 (marked by an asterisk on the cluster marker), which replace the samples on the triangular area. Additionally, as shown in Figure 3, these samples, denoted with outlined numbers, are located around the historic area. We can, therefore, assume that the features of Group 5 are attributed to the elements in the photographs. In this case, it is confirmed in the semantic map by multivariate analyses. Group 5 distributes around the boundary between Clusters 1 and 2, which means that Group 5 is an image intermediate to Clusters 1 and 2. Also, Group 5 is never distinguished by cluster analysis (Figure 1). This grouping appears only in the physical location when using an SOM.

The computed classifications from the Kansei evaluations are obtained from the specific design features in the sample images. Therefore, we compared typical sample images related to the divided sample groups, as shown in Figures 7–11, and extracted characteristic design features for defining the criteria used for zoning in the target area. First, the entire trend that was found from the photographs is examined. The pictures belonging to Cluster 1 are mostly residential streetscapes, such as a recent or western house on its property with a rebuilt earthen wall. This resident style is popular in the Chofu area. Therefore, Cluster 1 can be defined as a common residential streetscape. The primal image of the cluster was “dark.” The pictures belonging to Cluster 2 are photos along shopping avenues. The pictures are mostly of paved main streets and an old arcade. The primal image of the area is “realistic.” The samples in Cluster 3 show earthen walls, stone walls, stone pavement, and garden trees. The streets are well maintained. This cluster’s image is “fantastic” and “bright.” Cluster 4 shows features such as earthen walls, stone walls, and fewer garden trees than those in Cluster 3. This image is “fantastic” and “dark.” Group 5 shows earthen walls, stone walls, and garden trees, creating a streetscape either Clusters 3 or 4. The problem point of the group is that the street is not maintained well, and there are some blotches on the wall and disruption to the streetscape, such as electric cables and a tall factory building under repair. In this case, we obtained the location difference of the sample groups from our examination. Cluster 1 is a residential area, Cluster 2 is a commercial avenue, and Clusters 3 and 4 and Group 5 are located at the riverfront and along the earthen wall area, which is a so-called historic street. The distinguishable characteristics of Group 5 are found in the sample pictures that show the streetscapes that are typical of the Chofu atmosphere, but Group 5 images exhibit disrupting factors. This conclusion is not clear, but would be a concern for SOM classification. Because landscaping is expensive and requires a significant commitment to the affected people,

it is important to decide the border extend to each property that is to extract improper objects. Kansei engineering is a useful approach for including the participation people and is a reasonable method based on actual data.

6. CONCLUSIONS

This study analyzed historic streetscapes by using the Kansei engineering methodology. Multivariate analyses and SOM mapping were applied for the Kansei experiment.

We found that the SOM map mostly represented the two principal elements extracted from the factor analysis; therefore, it is evidenced that SOM was usable as a simplified version of factor analysis in the case of streetscape mapping. Additionally, a comparison with the results from the cluster analysis indicated a similar outcome as in SOM. It was also found that SOM gave an additional, interesting outcome, which was different from the results of the multivariate analyses with respect to extracting samples which have elements that disrupt streetscape viewing.

Figure 7: Sample pictures in cluster 1 which are mostly located on residential area(“realistic” image).

Figure 8: Sample pictures in cluster 2 which are mostly located on commercial street(“realistic” image).

Sample No. 10

Sample No. 2

Sample No. 9

Sample No. 15

Sample No. 18

Sample No. 20

Figure 9: Sample pictures in cluster 3 which are located on historic area(“fantastic” and “bright” image).

Sample No. 16

Sample No. 22

Sample No. 8

Sample No. 11

Sample No. 12

Figure 10: Sample pictures in cluster 4 which are located on historic area(“fantastic” and “dark” image).

Sample No. 3

Sample No. 4

Sample No. 19

Sample No. 13

Sample No. 14

Sample No. 17

Sample No. 25

Sample No. 24

Figure 11: Sample pictures in group 5 which are located on historic area and with factors of disturbance.

We found two viewpoints from these analyses. First, with both SOM and a cluster analysis, we could distinguish the location of the samples according to the characteristics of the streetscape image. This means that the Kansei engineering approach is sufficient for zoning a streetscape. Consequently, we defined three zones—a residential area, a commercial area, and a historic streetscape. Then, we obtained the streetscape conservation criteria. The resulting SOM map separated the specific sample images having disruptive elements from the images of the historic area. So, we found an approach for streetscape planning in the Chofu area.

In the future, we will attempt to extract items and categories to represent streetscape elements. The earthen walls are especially distinguishing features of property in Chofu. Some of the ancient earthen walls create a nostalgic atmosphere with their characteristic red-tinged surfaces. It is, therefore, required to unify the colors of the wall from one property to the next to maintain a typical Chofu streetscape. We are planning to measure color in order to formulate a streetscape guideline. To define the relationship between the guideline and Kansei results might be meaningful for streetscape planning. This study proposed a persuasive and objective approach to streetscape evaluation. Our final goal is to persuade residents with conflicting positions to agree on the streetscape guideline.

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