Form Factors of Modeling Design Language with Improved Entropy Weight Based on Kaisen Engineering

Yunyun Wei*, Ye Zhang, Wansong Tong
School of Architecture and Design, Beijing Jiaotong University, Beijing, China
*Corresponding author (E-mail: yunyunwei@outlook.com)

Abstract
This paper utilized Kansei Engineering and entropy weight to analyze the correlation between guiding facility appearance and the architectural style of public space. Taking vertical signs as research target, this research divided the appearance factors of guiding facilities into seven types, each including several subclasses, and tested the users at different age by asking them evaluate on the fitness of guiding signs and the overall architectural style. Here the semantic differential method was employed to judging the fitness, and the Pearson correlation coefficient and entropy weight were adopted to analyze the test data, quantifying the correlation between the form factor evaluation of users at different age and the architectural style of public space, thereby the integrated result of form factor evaluation was obtained. Aiming at the difference of form factor evaluation of users at different age, this paper proposed a unique Pearson correlation coefficient matrix and improved the method of column-normalization entropy weight on the basis of traditional entropy weight for users’ cognitive evaluation on the uniformity of form factors and the architectural style. This research method also can be referred to by form correlation studies including product design and appearance design.

Key words: Signage System, Kaisen Engineering, Pearson Correlation Coefficient, Entropy Weight, Image Scale

1. INTRODUCTION
As an important element of large public space, signage system aims at helping people get to their destinations safely, efficiently and conveniently. With the purpose of guiding, all kinds of signs are made into a visual information system following certain relations (Kataoka and Hashiguchi, 2016). Signage system is not only the extension of space, keeping consistent with the spacial environment, but also the carrier of spacial environment information, conveying the information including environment, position and direction to people. The appearance of signage should be harmonious with the architectural environment, making itself and the environment be in good correlation as a whole. Furthermore, signage should be able to enhance people’s memory and feeling to improve their understanding and recognition of signage information, so that the information can be delivered effectively.

In the design of signage system for large public space, designers need to fully consider the overall style of the architectural space to make the signage and the style of the space to be uniform. The form factors of design language are basic for overall appearance style. With the knowledge of how to make the selection from many factors, rationally assess the weights of form language factors in the overall appearance, and quantitatively analyze and evaluate the function of key factors in the whole design, the design and development of product can be effectively guided and the regularities of people’s comments on the designed product can be accurately mastered, which is of great theoretical and application value for product design and development.

Meanwhile, when designing signage system, designers need to consider the cognitive differences among a variety of user groups. Especially, people with different age are much different in life experiences, and knowledge structure and cognition level, which directly impacts the design of signage system and increases the difficulty of the comprehensive evaluation of the design. How to balance the cognitive difference of users at different age is a huge challenge for the implementation of signage system design. In this paper, the Kansei Engineering (Bakaev and Gaedke, 2016) and Entropy Weight (Kim, 2016) are combined to integrate the evaluations on each form language factor from users of different age, thereby transforming qualitative indexes into quantitative ones. Thus, the selection and decision of form language factors in appearance design will be more scientific and objective.

2. THEORETICAL BACKGROUND
2.1. Architectural Style and Forms
Large public buildings can be divided into many types according to their function, such as transportation junction, museum, commercial complex, administrative office center, etc. The signage systems of large-scale rail traffic stations in China are taken as the research target. To some extent, this is a representative research
whose methods and results can be popularized to the design of signage systems of other large public spaces. In this research, a large number of representative images of typical large rail traffic junction buildings are assessed by experts and classified into seven classes by the time dimension of architectural style. In the classification, only one dimension is considered by the experts—the time presented by architectural style. The seven classes are: totally ancient, partially ancient, national, modern, contemporary, future, and unimaginable, gradually transforming from past tense to future tense.

Experts carried out morphological analysis on the forms of common signs to abstract major form factors of design language. Then they concluded seven types of key factors deciding the form of a sign, including style, repetition, main profile, position relationship, openwork, vertical view, and symmetry, which can be further divided into 29 subclasses. Thereby a database of form factors affecting the design of upright guiding signs was built (see Table 1).

Table 1. 7 types of design language form factors of guiding facilities

<table>
<thead>
<tr>
<th>Elements</th>
<th>Type1</th>
<th>Type2</th>
<th>Type3</th>
<th>Type4</th>
<th>Type5</th>
<th>Type6</th>
<th>Type7</th>
</tr>
</thead>
<tbody>
<tr>
<td>style ((x_1))</td>
<td>straight lines((x_{11}))</td>
<td>mostly straight lines((x_{12}))</td>
<td>mostly curves((x_{13}))</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>repetition ((x_2))</td>
<td>none((x_{21}))</td>
<td>once((x_{22}))</td>
<td>many times((x_{23}))</td>
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</tr>
<tr>
<td>main profile ((x_3))</td>
<td>square((x_{31}))</td>
<td>columnar((x_{32}))</td>
<td>knife shape((x_{33}))</td>
<td>geometry shapes and blocks((x_{34}))</td>
<td>irregular shape((x_{35}))</td>
<td></td>
<td></td>
</tr>
<tr>
<td>position relationship ((x_4))</td>
<td>none((x_{41}))</td>
<td>combined((x_{42}))</td>
<td>applied((x_{43}))</td>
<td>totally contained((x_{44}))</td>
<td>partially contained((x_{45}))</td>
<td>protruding((x_{46}))</td>
<td>side hanging((x_{47}))</td>
</tr>
<tr>
<td>openwork ((x_5))</td>
<td>none ((x_{51}))</td>
<td>openwork ((x_{52}))</td>
<td>sunken ((x_{53}))</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>vertical view ((x_6))</td>
<td>flat ((x_{61}))</td>
<td>columnar ((x_{62}))</td>
<td>many layers overlapping ((x_{63}))</td>
<td>vertical or protruding ((x_{64}))</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>symmetry ((x_7))</td>
<td>axysymmetric ((x_{71}))</td>
<td>one-side deformation ((x_{72}))</td>
<td>two-side deformation ((x_{73}))</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.2. Kansei Engineering

The term Kansei Engineering was firstly introduced by Kenichi Yamamoto, Japan, in 1986 (Nagamachi, 1995). Kansei Engineering is a science which combines sensibility and engineering. It aims at designing and making products according to people’s preference through analysis of people’s feelings and emotions, therefore the products will respect users’ psychological feelings without loss of physical properties. In Kansei Engineering, people’s obscure emotions that are hard to be caught and analyzed are transformed into...
quantitative data by exploring the factors of psychological perception (Razza and Paschoarelli, 2015). In this aspect, Kato, et al. (Kato and Miyamoto, 2012) proposed the methods of using conceptual image words to deduce the relevant theory, providing support to the design of sensitive autonomous robotic vehicles; on the basis of product semantic property research and usability test data analysis, Camargo et al. (Camargo, Wendling and Bonjour, 2014) the method of analyzing the correlation of product semantic properties through integrating user perceptions.

Image scale is the fundamental method of quantitative data collection in Kansei Engineering (Yukawa and Hayakawa, 2008). Using this method, image scale distribution value can be obtained through measuring, calculating and analyzing people’s hierarchical psychological quantities in their evaluation on a thing, and the distribution regularities also can be analyzed. Image scale method usually adopts image survey and semantic differential (Wilson, Haładewicz-Grzelak and Opolska, 2015) for systematic analysis and design guidance, to be more specific, it can quantify psychological preference and divide it into sections using most suitable antonymous adjective pairs, and thus carry out quantitative surveys and statistics on users’ psychological preference.

3. ALGORITHM ANALYSIS
3.1. Pearson Correlation Coefficient
Pearson correlation coefficient is a linear correlation coefficient, reflecting the degree of linear correlation between two variables. The larger the absolute value of Pearson correlation coefficient, the stronger the correlation (Socha and Miškovský, 2017; Sheugh and Alizadeh, 2015).

The definition of the Pearson correlation coefficient \( \rho_{X,Y} \) of two random variables \( X \) and \( Y \) is as follow:

\[
\rho_{X,Y} = \frac{\text{COV}(X, Y)}{\sigma_X \sigma_Y}
\]

Where \( \text{COV}(X, Y) \) is the covariance of variables \( X \) and \( Y \); \( \sigma_X \) and \( \sigma_Y \) is the standard deviation of \( X \) and \( Y \) respectively.

Aiming at different sample data and the needs of calculation time and data storage space, different forms of Pearson correlation coefficient can be adopted (Mohamed Salleh and Arif, 2015). By plugging the expectation and variance of the variables in Equation (1), the following Equation is obtained:

\[
\rho_{X,Y} = \frac{E[XY] - E[X]E[Y]}{\sqrt{E[X^2] - E[X]^2} \sqrt{E[Y^2] - E[Y]^2}}
\]

When calculating the correlation coefficient using the collected samples, replace \( \rho \) with \( r \). The data sets of the variables are \( X = \{x_1, \ldots, x_n\} \) and \( Y = \{y_1, \ldots, y_n\} \), where the number of samples is represented by \( n \), therefore, the calculation of Pearson correlation coefficient is as follow:

\[
r_{X,Y} = \frac{n \sum_{k=1}^{n} x_k y_k - \sum_{k=1}^{n} x_k \sum_{k=1}^{n} y_k}{\sqrt{n \sum_{k=1}^{n} x_k^2 - (\sum_{k=1}^{n} x_k)^2} \sqrt{n \sum_{k=1}^{n} y_k^2 - (\sum_{k=1}^{n} y_k)^2}}
\]

Aiming at the form design of guiding facilities, this paper employs Pearson correlation coefficient to analyze the uniformity correlation between the form factors and the architectural style of public space, and study the influence of form language factors on the form design by quantifying users' perceptual evaluations on products. Users at different age have different perceptual evaluations on form language factors. Therefore, a 2-dimensional Pearson correlation coefficient matrix is proposed in this paper to analyze the importance of form language factors aiming at different age groups.

The form factors are defined by random variable \( X = \{x_1, \ldots, x_u\} \), where \( u \) is the number of form language factors; age groups are represented by random variable \( Y = \{y_1, \ldots, y_v\} \), where \( v \) is number of age groups in the test. The correlation coefficient matrix \( R_{XY} \) of form factor evaluation is provided, and the calculation of the elements in the matrix is as follow:

\[
r_{X_i,Y_j} = \frac{n \sum_{k=1}^{n} x_{i,k} y_{j,k} - \sum_{k=1}^{n} x_{i,k} \sum_{k=1}^{n} y_{j,k}}{\sqrt{n \sum_{k=1}^{n} x_{i,k}^2 - (\sum_{k=1}^{n} x_{i,k})^2} \sqrt{n \sum_{k=1}^{n} y_{j,k}^2 - (\sum_{k=1}^{n} y_{j,k})^2}}
\]
In the equation, \( i = \{1, 2, \ldots, u\} \); \( j = \{1, 2, \ldots, v\} \); \( n \) is sample amount. Therefore, a \( u \times v \) correlation coefficient matrix \( R_{ij} \) of user conceptual evaluation is obtained.

3.2. Entropy Weight

Entropy weight is an objective weighting method. By this method, the information entropy of indicator is calculated, and indicator weight is determined according to the influence of indicator’s relative change degree on the overall system. The indicator with large relative change degree has large weight (Delgado and Romero, 2016; Wang and Yuan, 2015).

This paper puts forward the entropy weight of Pearson correlation coefficient based on column normalization for users’ conceptual evaluation on the uniformity of the designed form of a sign and the architectural style of public space. The purpose of column normalization is to set a standard value for the test data of different groups in the matrix. After calculation of Equation (4), the correlation coefficient matrix is normalized and the initial evaluation weight judgement matrix is obtained:

\[
P = \begin{bmatrix}
p_{11} & p_{12} & \cdots & p_{1v} \\
p_{21} & p_{22} & \cdots & p_{2v} \\
\vdots & \vdots & \ddots & \vdots \\
p_{u1} & p_{u2} & \cdots & p_{uv}
\end{bmatrix}
\]

(5)

Where \( p_{ij} = \exp\left(\frac{r_{x_i y_j}}{r_{\max,j}}\right) \); \( i = \{1, 2, \ldots, u\} \); \( j = \{1, 2, \ldots, v\} \); \( r_{\max,j} \), which normalizes the correlation coefficient values, is the max value of Pearson correlation coefficient in the \( j \)-th column of matrix \( R_{IT} \). Calculate the entropy of the \( j \)-th column:

\[
h_j = -k \sum_{i=1}^{u} p_{ij} \ln(p_{ij})
\]

(6)

Where \( k = \frac{1}{\ln(v)} \). From the entropy, the entropy weight of the \( j \)-th column can be obtained:

\[
w_j = \frac{1 - h_j}{\sum_{j=1}^{v}(1 - h_j)}
\]

(7)

Multiply the entropy weight \( w_j \) by the initial evaluation weight judgement matrix \( P \) and get the compound cognitive evaluation matrix:

\[
P' = \begin{bmatrix}
w_1p_{11} & w_2p_{12} & \cdots & w vp_{1v} \\
w_1p_{21} & w_2p_{22} & \cdots & w vp_{2v} \\
\vdots & \vdots & \ddots & \vdots \\
w_1p_{u1} & w_2p_{u2} & \cdots & w vp_{uv}
\end{bmatrix}
\]

(8)

Using Equation (8), the compound cognitive evaluation vector can be obtained:

\[
S = \sum_{j=1}^{v} w_p_{1j} \sum_{j=1}^{v} w_p_{2j} \cdots \sum_{j=1}^{v} w_p_{uj}
\]

(9)

4. APPLICATION ANALYSIS

4.1. Selection of Samples

Among the seven classes in Figure 1, the class of “contemporary” style is selected as the research object in this paper. Experts selected and numbered 30 representative guiding facility images which are closest to the “contemporary” style as the samples for the image scale test based on their experience.

Then the experts further built correspondence between every selected sample and the 7 types of form factors of guiding facilities, thereby establishing the sign form - design language database. This way, each representative image has seven retrievable form factor codes (refer to the columns of X1-X7 in Table 2). In Table 2, the first column shows the serial number of each guiding sign image; the second to the eighth columns demonstrate the types of form factors corresponding to the 30 guiding sign images.
These types of form factors are from Table 1. Therefore, the correspondence of the representative guiding sign images and the form factors is obtained.

**4.2. User Test Data**

There are 90 participants of different age in the test. They are divided into 3 groups by age with 30 in each group; the age range of each group is above 60, 59-15 and below 14 respectively. The 90 participants were divided into 3 groups by age with 30 in each group: 30 participants aged 14 or below, 30 participants aged 15-19, and 30 participants aged 20-30.

**Table 2. Numerical data statistics of the 30 guiding signs**

<table>
<thead>
<tr>
<th>No.</th>
<th>X₁</th>
<th>X₂</th>
<th>X₃</th>
<th>X₄</th>
<th>X₅</th>
<th>X₆</th>
<th>X₇</th>
<th>Average of F-U value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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<td></td>
<td>Age≥60</td>
</tr>
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<td>X₁₃</td>
<td>X₁₄</td>
<td>X₁₅</td>
<td>X₁₆</td>
<td>X₁₇</td>
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<td>X₁₄</td>
<td>X₁₅</td>
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<td>X₁₇</td>
<td>X₁₈</td>
<td>2.53</td>
</tr>
<tr>
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<td>X₁₄</td>
<td>X₁₅</td>
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<td>X₁₈</td>
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<td>X₄₄</td>
<td>X₄₅</td>
<td>X₄₆</td>
<td>3.23</td>
</tr>
</tbody>
</table>

Figure 2. 30 guiding facility samples
asked to evaluate whether the style demonstrated by the 30 guiding sign images fitted the architectural style of the “contemporary” type. There are 5 grades from Fit-Unfit: 1 grade for most unfit and 5 grades for fittest. Participants were asked to grade their psychological feelings according to that. Based on the grades given by the three groups of participants, the quantified values of average psychological intention were obtained. Table 2 shows the final statistic result. The last three columns demonstrate the average values of the test data of participants at different age.

4.3. Analysis and Result

To deepen understand the correlation between the seven types of form factors and the participants’ evaluations, and find the factor that has the greatest influence on users’ perception, further analysis using Pearson correlation coefficient will be needed. Equations (4) and (5) are utilized to determine the correlation coefficient matrix of user evaluation: the type numbers in Table 1 corresponding to the codes in Table 2 are plugged into the equations.

\[
R_{17} = \begin{bmatrix}
0.063 & 0.0581 & 0.0521 \\
0.0217 & 0.0281 & 0.1326 \\
0.2694 & 0.3863 & 0.3485 \\
-0.0424 & 0.0175 & -0.0515 \\
-0.1173 & -0.1072 & -0.2243 \\
-0.0141 & -0.093 & -0.2775 \\
0.1019 & 0.1148 & 0.103
\end{bmatrix}
\]  

The correlation coefficients in Equation (10) are transformed into curves of user evaluation on form factors in Figure 3. It can be seen that the factors that have relatively larger influence on the form design of guiding signs are mainly profile and symmetry. The influence of repetition varies greatly with the age of users.

![Figure 3. Curves of user evaluation on sign design language factors](image)

Then the correlation coefficient matrix of user evaluation in Equation (10) is plugged in equation (6), (7) and (8), thereby the compound user perceptual evaluation vector is obtained.

\[
S = \begin{bmatrix}
1.197 & 1.206 & 2.718 & 0.92 & 0.643 & 0.732 & 1.384
\end{bmatrix}
\]  

The compound user conceptual evaluation vector of each key factor can be obtained through the calculation, therefore, the evaluation results of different age groups can be integrated. It can be seen from the evaluation values that, in their influence on users of different age, the form factors are in a descent order of main profile, symmetry, repetition, style, position relationship, vertical view and openwork. Accordingly, the experts and designers need to consider the importance of these factors in the form design of guiding signs. Meanwhile, from the correlation coefficients of user evaluation from different age groups, as shown in Equation (10) and Figure 3, it can be known that main profile and symmetry of guiding signs are the key factors for a sign to be harmonious and uniform with the overall architectural style.

5. CONCLUSIONS

With the basic analyzing method of Kansei Engineering, this paper quantitatively analyzed the correlation between the form factors of guiding facility and the architectural style of public space, studied the difference of
form factor cognition of users at different age, integrated the evaluation coefficients of users at different age using the 2D Pearson correlation coefficient matrix and the column-normalization entropy weight, and obtained compound user conceptual evaluation value which objectively reflects the users’ cognition about the key form factors of guiding facility. The image scale method and analysis method adopted in this paper not only ensured the explicitness and reliability of the analytical result, but also avoided the subjectivity and randomness of evaluation. What’s more, this research provides a quantitative analysis method and proven technique for the design of similar product.

REFERENCES