Development and Evaluation of an Intelligent Colour Planning Support System for Townscapes

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Abstract. Aesthetics of townscapes have been a main factor in urban development. This paper introduces *IroKage*, an intelligent colour planning support system. The system offers improved colour schemes for existing townscapes based on three elements: colour harmony, impressions of the townscape, and cost for the change of colours. The system is constructed using an evolutionary algorithm and the *Kansei* engineering approach. After the construction, system evaluation is conducted. The subjects evaluate fifteen colour schemes output from the system in terms of colour harmony and the ideal impressions for the townscapes using the semantic differential method introduced by Osgood et al. The results of the evaluation demonstrate that the system has sufficient ability to propose appropriate colour schemes for the ideal town impressions.

1 Introduction

The problem of how to live in a comfortable environment has attracted attention with the changing expectation of residents, and the townscape is a central factor in urban-development problems. Aesthetics of townscapes have been studied in various fields [1, 2], and the colour scheme of the buildings is one of the most influential factors. In considering colours of the buildings, each nearby colour in the row is a key point. Proper evaluation of colours has to consider the whole street, not only individual buildings. Several colour studies have been reported as colour harmony principles [3]. Using one of those principles may enable evaluation of the colours in the whole street and allow a better colour scheme for the townscape to be found. However, characteristics of the target town also need to be respected throughout the colour planning process. In addition to the form and material of the buildings in the town, the climate and the historical background of the town are also elements affecting the characteristics, and these elements evoke particular impressions as well. Although several previous colour plans have included characteristics and impressions of towns, most of them have been based on anecdotal reports or experience and have been conducted for individual localities.

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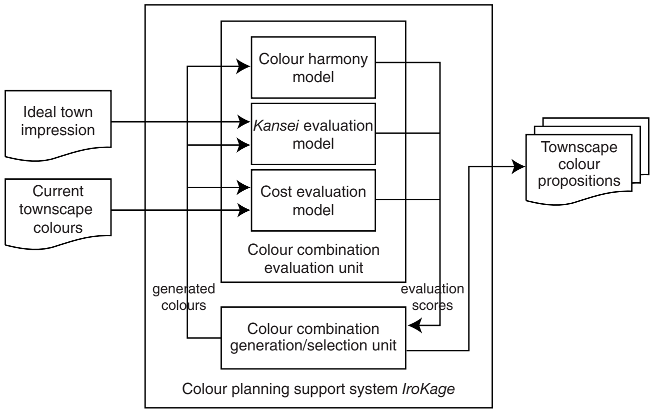


Fig. 1. Block diagram of the colour planning support system

In our studies, an intelligent colour planning support system for townscapes, called *IroKage*, was developed [4]. The system helps to improve existing townscapes by considering colour harmony as well as the town impressions. This paper focuses on the system evaluation based on townscape colour schemes output from the system.

2 System Overview

The inputs to the colour planning support system are the current townscape colours and ideal town impressions expressed by adjectives. The system offers several colour propositions for the townscape, as shown in Fig. 1. In the system, the colour combination generation/selection unit generates a large number of colour combinations. The colour combination evaluation unit evaluates the colour combinations generated from the generation/selection unit one by one.

First, the colour combination generated is evaluated from the approach of colour harmony. Moon and Spencer brought together the concepts in previous colour harmony principles and proposed equations to calculate aesthetic measure for colour harmony [5–7]. We expanded their aesthetic measure for townscape colours and constructed a colour harmony model [4] using Takagi-Sugeno type fuzzy reasoning [8]. The inputs to the model are townscape colours and the output is the aesthetic measure.

In addition to colour harmony, impressions of the generated colour combination are evaluated in respect of their suitability when compared to the ideal impressions of the townscape. The differences between the ideal impressions of the townscape and the psychological response for the generated colour combination is calculated. The combination having the smallest difference is evaluated as the appropriate combination. Handling the impressions of the townscape requires quantification of psychological responses. A *Kansei* evaluation model to quantify the human responses is constructed by linking town impressions and townscape colours [9]. *Kansei* is a Japanese term which means human sensibility or impression.

The targets of this system are mostly townscapes that already exist. A critical issue is finding the most effective colour scheme changes at the lowest cost. The cost evaluation model calculates the cost to convert the current townscape colours to the generated colours. In terms of the colour changing cost, the repaint cost is assumed to be almost the same even if the new colour is similar to the original colour. The number of colour changes is therefore simply applied for the cost evaluation.

Based on scores obtained by the evaluation unit, the generation/selection unit selects several colour propositions for the output of the system.

3 Quantification of Town Impressions

3.1 Evaluation Experiments of Town Impressions

In order to manage town impressions in the system, psychological responses to townscape colours are quantified from the *Kansei* engineering approach [10]. This technique translates target psychological responses into perceptual design elements.

First, evaluation experiments were conducted to investigate the relationship between town impressions and townscape colours. Adjectives allow expression of the psychological responses. In this study, adjectives express the impressions of the townscape. Approximately 470 adjectives related to the town impressions were collected from dictionaries and previous studies. After the collection, similar adjectives were combined and they were paired with opposite meanings. Finally, the number of adjectives was reduced to sixteen pairs. One hundred colour picture samples were prepared for the evaluation experiments. The pictures show the front side of a row of houses. The samples were made by altering the same picture while maintaining all the other conditions. The wall and roof colours of the houses were selected from a wide variety of chromatic and achromatic colours, and the window frame colours were selected from a set of achromatic colours.

Computer-based evaluation experiments were conducted for 20 subjects, four females and sixteen males, using the semantic differential (SD) method [11]. One picture sample and the sixteen adjective pairs are placed on the computer screen. In the experiments, the subjects select a suitable response on the five-step SD scale for each pair of adjectives. The subjects evaluated all of the 100 picture samples, which were shown at random.

3.2 Selection of Adjectives

After the experiments, appropriate adjectives were selected based on the results of the above experiments. An evaluation in the centre of the SD scale implies that the adjective was evaluated as neutral. The adjectives with many neutral evaluations may be irrelevant for expressing town impressions. Four adjectives

Table 1. Pairs of adjectives related to townscape impressions

adjective No.	adjectives
1	cold – warm
2	unrefined – refined
3	restless – calm
4	unfriendly – friendly
5	uncomfortable – comfortable
6	artificial – natural
7	typical – individualistic
8	conservative – progressive
9	quiet – lively
10	old-fashioned – modern
11	awkward – elegant
12	western – eastern

were excluded for this reason. Variance of evaluation scores is also a factor to be considered. We checked the variance for each sample but every pair of adjectives showed low variance. No adjective was excluded in this process. Consequently, the twelve adjectives shown in Table 1 were selected.

3.3 Construction of *Kansei* Evaluation Model

With the selected adjectives, a *Kansei* evaluation model is constructed. The behaviour of *Kansei* response is usually non-linear and it is difficult to manage *Kansei* data using conventional methods. Some previous studies adopted neural networks for *Kansei* data [12, 13]. Neural networks are one of the best methods for modelling non-linear data. The model was constructed using a neural network for each pair of adjectives. Sixty-two experimental results were selected as the training data for the neural networks and 20 results were selected as the testing data for the model validation. Both training and testing data were selected to consist of various, dissimilar colour combinations. Each colour in the data was selected to have unique hue, brightness or saturation attributes.

The input items to each neural network are the wall colours, roof colours, and window frame colours of the houses in the picture samples. Every colour is expressed in the CIELAB colour system [14]. The three CIELAB values, L^*, a^* and b^*, are used for the wall colours and roof colours, and only L^* is used for the window frame colours because the use of chromatic colours is generally limited. Since there are three buildings in the sample picture, the input data becomes 21 values. The output from each neural network is the SD scale response for the town impression. Every value is given in [0, 1]. Each neural network has three layers and the numbers of units are 21, 30, and 1 on the input, hidden, and output layers, respectively. Every network was trained using back-propagation learning to an accuracy of 3.125×10^{-4} mean square error, which is equivalent to 0.1 on the SD scale of 1 to 5.

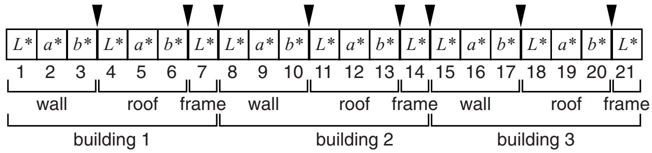


Fig. 2. Encoding of individuals. Black arrows represent candidate crossover points.

3.4 Performance Test

After the model construction, a performance test was conducted. The 20 testing data were input into the constructed model, and the errors between the output from the model and the average of the experimental results were calculated. The average accuracy of the twelve neural networks was 7.321×10^{-3} mean square error, 0.374 on the SD scale of 1 to 5. This result indicates that our *Kansei* model has adequate ability to evaluate the town impressions.

4 Townscape Colour Generation and Selection

4.1 Approach

For the implementation of the colour combination generation/selection unit in the system, the problem is the method to select appropriate combinations under the evaluation scores with the three different objectives: colour harmony, impression and cost. For selecting appropriate colour combinations to output from the system, we focuse on Pareto optimal solutions.

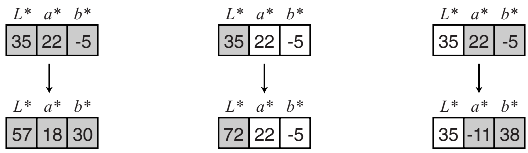
In a maximization problem, a is said to *dominate* b when

$$f_e(a) \geq f_e(b) \quad (\forall e \in \{1, 2, \ldots, n\},\ a \neq b) \tag{1}$$

where f_e represents a vector function, and a and b represent two decision vectors. The decision vectors that are not *dominated* by any other vector are called Pareto optimal solutions. In this study, those solutions are searched from an evolutionary algorithm approach [15].

4.2 Encoding

The system uses wall, roof and window frame colours of three buildings, nine colours in total. In the evolutionary algorithm, the colours are expressed in the CIELAB colour system and encoded by value encoding. Each wall colour and roof colour consists of the three CIELAB values, L^*, a^* and b^*. Each window frame colour consists of L^* value only. Seven values therefore express the colour scheme of one building. In total, one individual includes 21 values, as shown in Fig. 2. Every L^* value is given in [10, 90] while a^* and b^* values are given in [-40, 40].



(a) all of L^*, a^* and b^* (b) L^* only (c) a^* and b^* only

Fig. 3. Wall colour alteration patterns in the initialization and mutation processes. Pattern (a) alters all attributes of the target colour while pattern (b) only alters the lightness attribute. Pattern (c) alters the hue and saturation attributes.

Table 2. Candidate roof colours

colour	L^*	a^*	b^*
grey	45	0	0
brown	35	20	25
green	30	−15	10
red	45	40	25
blue	45	0	−35

Fig. 4. Configuration of the townscape samples

4.3 Colour Search Algorithm

The generation/selection unit generates the population of the first generation by altering several colours in the current townscape input. First, up to three colours are chosen as the target(s) for alteration. When a wall colour is chosen as the alteration target, one of the three alteration patterns shown in Fig. 3 is randomly applied. When a roof colour is chosen as the target, the colour is randomly replaced with one of the five candidate roof colours shown in Table 2. For a window frame colour, the target L^* value is randomly replaced with either '10' or '90.'

The individuals generated are evaluated based on the three evaluation models. Based on the evaluation scores, individuals are selected as the parents of the next generation. For the selected parents, single point crossover is executed at one of the eight crossover points shown in Fig. 2. After that, each of nine colours in an individual mutates with a given probability. The target colours are altered in the same manner as the initialization processes. Finally, those individuals will be the population of the next generation.

The system stores all individuals through all generations and selects the highest-ranking individuals for output.

5 System Evaluation

5.1 Townscape Colour Development

Townscape colour development is conducted using our system, *IroKage*. Three townscape samples are prepared as the targets of the colour development. Every

Table 3. Colours in the townscape samples

sample No.	building No.	wall L^*	wall a^*	wall b^*	roof L^*	roof a^*	roof b^*	frame L^*
1	1	80	0	−10	45	0	0	10
	2	50	20	−20	45	0	0	90
	3	80	0	15	30	−15	10	10
2	1	80	−10	−10	45	0	0	90
	2	45	0	0	45	0	0	90
	3	30	0	−20	45	0	0	90
3	1	80	0	0	45	0	0	10
	2	75	20	20	45	0	0	90
	3	65	0	0	45	0	0	90

Table 4. Parameters for the evolutionary algorithm

population size	100
crossover probability	0.9
mutation probability	0.03
number of generations	300

sample consists of three buildings in a row. Fig. 4 shows the configuration of the samples and Table 3 shows colours in the samples. Here, *natural*, *warm* and *lively* are selected as the ideal impressions for Samples 1, 2 and 3, respectively. The system searches for Pareto optimal solutions using the evolutionary algorithm with the parameters shown in Table 4.

Tables 5, 6 and 7 show examples of the system output for Samples 1, 2 and 3, respectively. The bold face numbers in the tables indicate modified colours. For Sample 1, the system modified the wall colour of Building 1, light blue, and/or the wall colour of Building 2, purple, in most cases. Those colours were replaced with brownish, greenish and yellowish colours. For Sample 2, the system output warm colours, yellowish and reddish colours. These match to the ideal impression *warm*. For Sample 3, the system mainly output colour schemes with high saturation and high lightness colours.

5.2 Evaluation Methods

In order to make sure that the system output is appropriate, evaluation experiments are conducted. The participants of the experiments evaluate colour schemes output from the system in respect of colour harmony and the ideal impressions using the SD method. As the targets of evaluation, a set of samples is prepared. The sample set consists of fifteen samples repainted in the output colour schemes shown in Tables 5, 6 and 7 and three original colour schemes shown in Table 3. However, the participants are not informed that the sample set includes the original colour schemes. For the evaluation of colour harmony, a pair of adjectives, disharmonious—harmonious, is used. For the evaluation of impression, one pair of adjectives is selected from Table 1 depending on the ideal impressions (e.g., artificial—natural for Sample 1). In total, the participants therefore evaluate eighteen samples with the two pairs of adjectives.

The experiments were conducted in a computer-based environment. The participants sit 70 cm away from a CRT display. The participants sit 70cm away from a CRT display. Fig. 5 shows the screen appearance of the experiments. One of the samples is placed at the centre of the screen with a black background, and one pair of adjectives is placed on the lower part. There is a five-step scale

Table 5. System output examples for Sample 1 with the ideal impression *natural*

result	building	wall			roof			frame
No.	No.	L^*	a^*	b^*	L^*	a^*	b^*	L^*
1A	1	80	0	−10	45	0	0	10
	2	50	**4**	**30**	45	0	0	90
	3	80	0	15	30	−15	10	10
1B	1	80	0	−10	45	0	0	10
	2	**39**	**16**	**13**	**30**	**−15**	**10**	90
	3	80	0	15	30	−15	10	10
1C	1	80	**−12**	**13**	45	0	0	10
	2	50	**−1**	**15**	45	0	0	**10**
	3	80	0	15	**45**	**0**	**0**	10
1D	1	80	0	−10	45	0	0	10
	2	**40**	**−9**	**27**	45	0	0	90
	3	80	0	15	**45**	**0**	**0**	10
1E	1	**62**	**1**	**37**	45	0	0	10
	2	**46**	**11**	**30**	45	0	0	90
	3	80	0	15	30	−15	10	10

Table 6. System output examples for Sample 2 with the ideal impression *warm*

result	building	wall			roof			frame
No.	No.	L^*	a^*	b^*	L^*	a^*	b^*	L^*
2A	1	80	**13**	**15**	45	0	0	90
	2	45	0	0	45	0	0	90
	3	30	0	−20	45	0	0	90
2B	1	**81**	**1**	**19**	45	0	0	90
	2	45	0	0	45	0	0	90
	3	**67**	**7**	**27**	45	0	0	90
2C	1	80	**8**	**16**	45	0	0	90
	2	**68**	**15**	**30**	45	0	0	90
	3	30	0	−20	45	0	0	90
2D	1	**86**	**2**	**2**	45	0	0	90
	2	45	0	0	45	0	0	90
	3	**67**	**23**	**24**	45	0	0	90
2E	1	**78**	**11**	**22**	45	0	0	90
	2	45	**19**	**19**	**35**	**20**	**25**	90
	3	**68**	**15**	**28**	45	0	0	90

between the adjectives and one value is highlighted as the current selection. The participants move the selection and choose a suitable response using arrow and space keys on a keyboard. The samples and adjectives are shown in random sequence to reduce influence from the order of the presentation.

Table 7. System output examples for Sample 3 with the ideal impression *lively*

result	building	wall			roof			frame
No.	No.	L^*	a^*	b^*	L^*	a^*	b^*	L^*
3A	1	**87**	**10**	**−7**	45	0	0	**90**
	2	75	20	20	45	0	0	90
	3	65	**−33**	**12**	45	0	0	90
3B	1	80	0	0	45	0	0	**90**
	2	75	20	20	45	0	0	90
	3	65	**−33**	**2**	45	0	0	90
3C	1	80	0	0	45	0	0	10
	2	75	20	20	45	0	0	90
	3	65	**11**	**34**	45	0	0	90
3D	1	80	0	0	45	0	0	10
	2	**34**	**22**	**−12**	45	0	0	90
	3	**71**	**8**	**29**	45	0	0	90
3E	1	80	0	0	45	0	0	**90**
	2	**74**	**−23**	**−17**	**45**	**0**	**−35**	90
	3	**42**	**−32**	**−4**	45	0	0	90

5.3 Results and Discussion

The experiments were conducted for seventeen participants, fourteen males and three females. Figs. 6, 7 and 8 show the average evaluation scores of the experiments for Samples 1, 2 and 3, respectively.

In Fig. 6, Sample 1, with the original colour scheme, was evaluated as 1.88 for colour harmony (standard deviation 1.05) and 1.35 for the *natural* impression (standard deviation 0.49). Those scores indicate that the sample had poor colour harmony and no ideal impression. This kind of townscape is the main target of our system. Compared to the original sample, all the results output from the system, 1A–1E, achieved good evaluation scores for both colour harmony and the *natural* impression. Especially, Result 1E was evaluated as 4.12 for colour harmony (standard deviation 0.78) and 3.71 for the *natural* impression (standard

Fig. 5. Screen appearance of the experiments

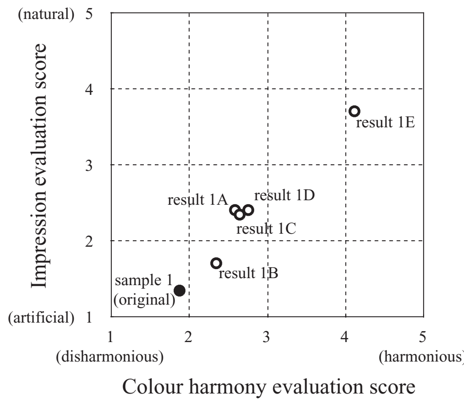


Fig. 6. Evaluation results for Sample 1

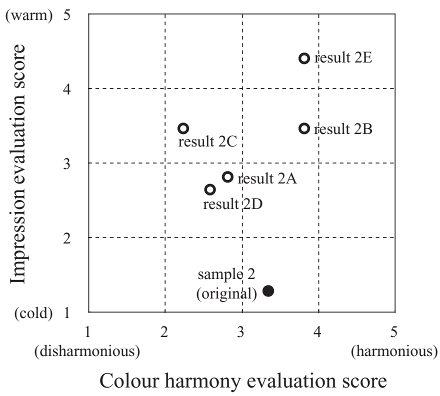


Fig. 7. Evaluation results for Sample 2

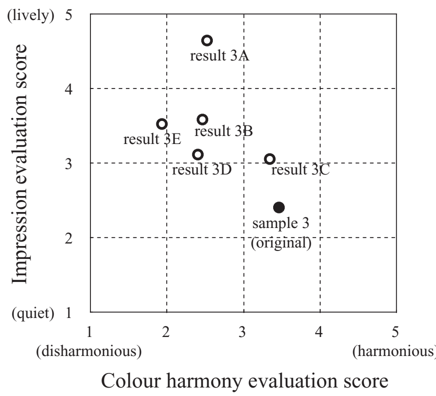


Fig. 8. Evaluation results for Sample 3

deviation 1.05) with the two colour changes. The system successfully improved colour harmony and realized the ideal impression.

In Fig. 7, Sample 2 was evaluated as 3.35 for colour harmony (standard deviation 1.27) and 1.29 for the *warm* impression (standard deviation 0.47). It represents that the original sample already had good colour harmony. Although this kind of townscape is not the target of our system, the results from the system, 2A–2E, showed high scores for the *warm* impression. Not only for the impression, Results 2B and 2E even achieved better colour harmony. The colour harmony score for Result 2E was 3.82 (standard deviation 1.01) while the impression evaluation score was 4.41 (standard deviation 0.62). For some results, colour harmony scores were somewhat decreased. However, the decreases were not significant compared to the improvements in the *warm* impression.

Like Sample 2, Sample 3 also had good colour harmony but did not have enough *lively* impression. For this sample, colour harmony score was getting decreased concurrently with increasing of the impression score. Here, the relationship between colour harmony and the *lively* impression can be considered a *trade-off* where it is difficult to improve the two objectives at the same time. In this case, the system is expected to output the optimal colour schemes with variety. The output from the system included *lively* impression samples, such as Result 3A as well as harmonious samples, such as Result 3C, as shown in Fig. 8. The use of the evolutionary algorithm helped to obtain a variety of results as Pareto optimal solutions.

6 Conclusions

In this paper, the intelligent colour planning support system for townscape, *IroKage*, was introduced. The system was constructed using an evolutionary algorithm with colour harmony, impression and cost evaluations. The evaluation of *IroKage* demonstrated that the system has sufficient ability to improve colour harmony and realize ideal impressions. The system successfully proposed appropriate colour schemes.

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