Interior Color Preference Investigation Using Interactive Genetic Algorithm

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Abstract
This paper presents an investigation of Beijing residents concerning their apartment interior color preference using an IGA interior design system. The investigation tested typical living room interiors consisting of five factors, the ceiling, walls, floor, interior door and sofa, and the participants were instructed to find ideal color combinations for the five factors using the IGA system. Through statistical analysis of the design results of 231 participants, it was found that they tend to use brighter materials for the walls and floor in darker interiors. It was also found that their age, gender and family income level has an influence on their preference concerning lightness and saturation of interior color. Through analysis of the evolutionary process of IGA, it is also revealed that the color of the ceiling, walls, floor and door tend to be similar to each other, while the difference of color of the sofa to the other colors tends to be more diverse.

Keywords: interior design; color harmony; Beijing residents; preference investigation; interactive genetic algorithm

1. Introduction
This research intends to explore associativities in interior color preference of Chinese residents through an investigation of Beijing residents using the method of interactive genetic algorithm (IGA).

Along with the growth of the Chinese housing market in recent years, residents are gradually paying more and more attention to the physical and aesthetic comfort of their living environment. When they move to a new apartment, the majority of them perform interior work after the developer has completed essential construction work (Li et al., 1999). Residents often design the interior space, purchase materials and furniture, and supervise any associated construction themselves, and the completed interior varies depending on their individual tastes and family demands. Understanding their interior aesthetic preference is helpful for them to improve their living conditions, for interior design practice, and is also useful for apartment project development and interior material marketing.

The interactive genetic algorithm (IGA) method combines the advantage of human subjective evaluation and that of the computer in searching to provide an interactive method of subjective design. In an IGA process, the designer evaluates a group of design proposals provided by the computer by scoring them, the computer then generates new design alternatives based on the scores through the crossover and mutation of a genetic algorithm (GA), and the designer then evaluates again. As the interactive process continues, some preferred designs can be achieved. (Fig.1.)

Huang, Matsushita and Munemoto (2006) tried to apply the interactive genetic algorithm (IGA) method in Chinese apartment interior design to help non-professional residents in performing interior design by themselves. An experiment was then carried out in Beijing, China to examine the usefulness of the system in assisting the residents in designing (Huang, et al. 2008). The experiment not only collected the participants' evaluations and comments concerning the IGA system, but also recorded the evolutionary IGA process and the design results. Since most of the participants thought the design results can answer

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their aesthetic preference, the experiment can also be considered as an investigation of the interior color harmony preference of Beijing residents. A correlation analysis of the color of different interior factors reveals that a certain relationship of colors has been gradually established through the IGA process\(^9\), which suggests that associativities could be explored through analysis of the investigation data.

Compared to traditional methods of color harmony research, there are limitations to IGA. For example, IGA may converge at some local optimal solutions, because of the limitation of GA. Secondly, IGA is a process of human-computer interaction, and is restricted by the human fatigue factor, which means people can only evaluate limited design proposals for limited generations. Finally, in an IGA interface, images are displayed side by side, so the colors of neighboring images will influence each other slightly regarding their perception. The above limitations lead to the fact that the design results are often not so accurate. But on the other hand, there are advantages to the IGA in terms of color harmony problems. One is that it is supported by the strong searching ability of GA, and the participants only need to evaluate several generations of design proposals to find some good results among numerous possibilities. So it is possible to explore complex color harmony problems using IGA, which were hard to deal with before. Another is that IGA is an iteratively evolving process, and its analysis can reveal how results are gradually achieved, and provide additional information on the associativities of color harmony.

2. Past Studies

Burchett (2002)\(^1\) carried out a content analysis on a selection of books from color science, art and design, color theory, and psychology, and identified categories of terms to be coincidental with color harmony, they are: order, tone, configuration, interaction, similarity, association, attitude, and area. It is understood from the paper that the problem of color harmony is related to the effect of a certain color, and also to the way in which the colors are combined together.

Chuang and Ou (2001)\(^2\) studied how a holistic color interval, i.e., the non-directional color difference between a pair of colors in the CIELab uniform color space, influences perceived color harmony. Statistical analysis confirmed the relationship: the degree of harmony is a cubic function of the color interval. Moreover, the interval for lightness may have a predominant effect on color harmony.

Zhou et al. (2006)\(^3\) studied the rules of Chinese interior decoration selection and its reason through the mining of association rules. It was found that the selection procedure of living room interior decoration was based on the coordination between plain and decorated, and this process led to a balance between them.

Huang and Matsushita (2006)\(^3\) applied IGA to interior design to help Chinese residents who were not design professionals to conduct interior design themselves. Seven interior factors of a typical Chinese apartment living room, primarily related to color and texture, were selected as parameters for the IGA system. In their later research (2008)\(^4\), an experiment was carried out in Beijing, and the developed system proved effective in assisting residents in interior design through an analysis of the evaluation of 231 participants regarding the system.

Newsham and Richardson (2005)\(^5\) applied an interactive GA to an investigation of peoples' preferences regarding surface luminance in office spaces. Forty participants viewed a series of grayscale images to find the ideal luminance combinations for six surfaces in a typical office space. The method effectively arrived at a participant's preferred luminance combination. The results were similar to the choices of people in actual office spaces, and suggested that a person's subjective evaluation of office spaces can be predicted, in part, from the luminance of the six surfaces.

To verify the possibility of evaluating architectural space lighting conditions via rendered images, Mahdavi and Eissa (2002)\(^6\) examined the extent to which subjective lighting evaluations of computationally rendered images of a space were consistent with subjective lighting evaluations of the actual space. Two groups of people were asked to evaluate several interior spaces; one group used actual locations and the other used computer-rendered images of the spaces displayed on a color monitor. A subjective lighting metric was used for the evaluation. The results showed that for the scenes and participants tested, the computer-rendered images could reliably represent certain aspects of the lighting conditions in the actual interiors.

The difference between the present research and the above-mentioned study is that it tentatively uses IGA in the investigation of color preference associativities, which is different from the traditional method in this area. The research is also significant because it tries to explore the color preference problem in Chinese interiors based on a large amount of original data and the findings are meaningful in practical terms.

3. Method

3.1 Investigation site and participants

The Lize shop, an oriental home construction and ornamental material chain store in Beijing, was selected as the investigation site. The shop provides a wide range of materials and is typical of where many people purchase their materials for interior work. The authors assume that the majority of customers in the Lize shop have experience or an interest in interior design. During the investigation, some customers were interested in the IGA interior design system and participated in the experiment.
3.2 The IGA interior design system

The IGA interior design system developed by Huang (2006)\(^3\) is improved and employed in this investigation. Fig.2. shows the interface of the system which displays 16 images of an interior scene viewed from a certain angle simultaneously for evaluation. At the beginning of the process, a set of interior scenes with random combinations of interior design factors was presented, and the users selected several scenes they preferred. A GA was then used to generate new scenes based on the user's selection, and the users then evaluated again. As the process continued, the results progressively approached the users' preference.

3.2.1 IGA objectives and material library

The IGA objectives are living-room interiors typical of Beijing apartments. The five factors involved in the IGA process (Table 1.) are the material and color of the main factors in interior aesthetics. Images of materials were collected to construct a library of the materials available in the Chinese interior work market. The above setting allows the investigation to have a common meaning for Beijing residents. For each of carpet, wood, and ceramic tile in the material library, the texture images were reduced to 1×1 pixels using the Bicubic method in Photoshop to obtain average RGB values. These values were used as coordinates of the materials in the RGB space. Different marks represent different categories of material.

Table 1. Construction of the Material Library

| Factors       | Category          | Number   |
|---------------|-------------------|----------|
| Ceiling material | Paint             | 60 colors|
| Wall material  | Paint             | 60 colors|
|               | Wall paper        | 138 textures|
| Floor material | Wood              | 103 textures|
|               | Ceramic tile      | 116 textures|
|               | Carpet (monochromatic) | 87 textures|
|               | Carpet (patterned) | 99 textures|
| Door material  | Paint             | 64 colors|
| Sofa material  | Textile           | 138 textures|
|               | Leather           | 96 textures|

Fig.2. Interface of the IGA Interior Design System

Fig.3. Material Sample Distribution in RGB Space

Fig.4. The IGA Process Flow
3.2.2 IGA process flow

The IGA interior design system is intended to be a heuristic approach to finding a user's aesthetic preferences rather than a means of identifying an exact design solution. The evolutionary process of IGA is arranged to increase the number of design alternatives in a certain generation of GA to make the system more efficient. (Fig.4.). The IGA process is intended to balance the trade-off between human fatigue and the quality of the results.

As lighting conditions affect the atmosphere of an interior space, rendered images of both day and night settings were provided in the process flow.

3.2.3 CG rendering

Radiance\(^1,\)\(^2\) is a highly accurate ray-tracing software used to handle complex interior lighting simulation and to provide dependable rendered images. The cloudy sky model of Radiance, which corresponds to a standard CIE overcast day, is employed to simulate the daylight condition.

4. Investigation

Customers of the Lize shop in Beijing were asked to participate in the investigation. As most of the customers were either performing or preparing for interior works, either for new apartments or in the renovation of old apartments, they all had design goals. IGA was introduced to the participants as an evolutionary process that would gradually lead them to their preferred design. The results may then serve as a reference for the interior design of their apartments. Interested customers participated in the investigation.

During the investigation, the investigator introduced the system and its operation to the participants, and then allowed them to use the IGA interior design system alone. The steps were as follows:

1) Participants were asked to choose which one of twelve different living room images was the most similar to the living room of their apartment. Although the plans of apartments in Beijing vary, they can be divided into a few general types. Six models are shown in Fig.5., and the other six are their mirror images. These models have the same-sized room with different arrangements of the window opening, as it affects interior lighting conditions.

2) The IGA process began. The interface was displayed on an adjusted 19-inch cathode-ray tube color monitor at a resolution of 1024 x 768 pixels. To make the IGA process more effective, the participants were asked to select three to five images from all images in each step of the first stage and two to three pairs of images in each step of the second stage. The participants worked on their own when evaluating images. The IGA process generally involved twelve steps, eight in the first stage and four in the second, as shown in Fig.4.

3) After completing the IGA process, participants were asked to complete a questionnaire, and to add some comments.

5. Investigation Results and Analyses

The investigation lasted for 22 working days, and the data of 231 participants (94 males and 137 females)
was successfully achieved, their ages ranged from 18 to 74 (average 35.6), most families consisted of 2 or 3 members, and their income was between 2,000 RMB and 20,000 RMB (Fig.6.).

The 231 participants achieved 1,307 design results altogether. By analyzing the questionnaire, it was found that generally the system works well in helping non-design-professional participants carry out interior design, and the design results can represent the participant's aesthetic preference.

In order to explore the interior aesthetic preference of the participants, CIELab color values' of the design materials proposals and results of the IGA process were analyzed. The CIELab color system was selected because it describes all the colors visible to the human eye and was created to serve as a device-independent model.

In the IGA process, every participant achieved multiple design results (average 5.66). These design results are all possibilities in terms of the participant's aesthetic preference, and could be used to represent the preferences of other people who have similar taste. Therefore the 1,307 design results are all considered useful in terms of statistic analysis. On the other hand, because the design proposals evolve through the crossover and mutation of IGA, a certain participant's design results may contain the same material for a certain interior factor, so the design results are not independent. In order to avoid this effect in statistic analysis, when analyzing a certain factor, if the same material is used in multiple design results of a certain participant, it is considered as only one independent sample.

5.1 Influence of lighting condition on material lightness preference

In the experiment, 6 living room interior models with different lighting conditions were provided (Fig.5.) which resulted in a significant difference in the lightness of the rendered interior scenes. It was found through the one-way ANOVA test (Table 2.) that the participants' selection of models has a significant influence on the lightness (L*) of the materials of their IGA design results, especially the material lightness of the wall.

Table 2. One-way ANOVA Test Results of Material Lightness L* Grouped by Model Selection

|       | Ceiling | Wall | Floor | Door | Sofa |
|-------|---------|------|-------|------|------|
| Total df | 833  | 812  | 764   | 791  | 784  |
| F      | 0.863 | 2.564| 1.437 | 2.057| 0.421|
| Sig.   | 0.522 | 0.018| 0.198 | 0.056| 0.866|

Table 3 compares the mean value and standard deviation of the lightness of wall materials of different models. It is found that as the brightness of the scene decreases from model 1 to model 4, the mean value of the lightness of the wall material gradually increases, and for model 5 and 6, the mean value of the lightness of the wall material is similar, and is close to that of models 2 and 3. If we calculate the person's correlation coefficients of lightness for all five materials with the model number (the data of participants who selected models 5 and 6 are not included), it can be found that the lightness of the wall material has a significant correlation with models number 1 to 4 (Table 4.). Although the lighting condition of each model cannot be represented linearly by model number, the general tendency is clearly revealed. Since the wall material has a great influence on the brightness of the scene, the participants may try to adjust the lighting condition of the scene by using brighter wall materials in darker scenes to achieve an ideal lighting environment.

5.2 Influence of family income level on material lightness preference

The family income level distribution of 231 participants mainly falls in 3 groups as shown in Fig.6., which are 2,000–5,000RMB, 5,000–10,000 RMB and 10,000–20,000RMB.

Table 5. shows a person's correlation coefficients regarding the material lightness (L*) of the IGA design results with family income group number. It is found that for female participants, the lightness of the ceiling and wall has a significantly positive correlation with the family income group. However, for male participants, there is no significant correlation for any of the interior factors. The one-way ANOVA test also reveals that for female participants in different family income groups, the lightness (L*) of the ceiling and wall material of their IGA design results has a comparatively significant difference. (The significant value is 0.131 and 0.021), but for male participants, the same test shows no significant difference. It could be concluded that as the family income level increases,

Table 3. Material Lightness (L*) of Wall of Different Models

| Model No. | Participants number | Mean | Std.dev |
|-----------|---------------------|------|---------|
| Model 1   | 28                  | 83.48| 16.30   |
| Model 2   | 80                  | 86.31| 11.69   |
| Model 3   | 42                  | 87.90| 9.70    |
| Model 4   | 21                  | 89.70| 5.87    |
| Model 5   | 34                  | 88.41| 8.21    |
| Model 6   | 25                  | 86.79| 7.85    |

Table 4. Person's Correlation Coefficients of Material Lightness (L*) with Model Number (Model 1 to 4)

| Person Correlation | Ceiling | Wall | Floor | Door | Sofa |
|--------------------|---------|------|-------|------|------|
| Sig.(2-tailed)     | 0.032   | 0.113| 0.038 | -0.050| -0.024|
| Sig.(2-tailed)     | 0.834   | 0.001| 0.297 | 0.161 | 0.504|

Table 5. Person's Correlation Coefficients of Material Lightness (L*) with Group Number of Family Income

|           | Ceiling | Wall | Floor | Door | Sofa |
|-----------|---------|------|-------|------|------|
| Male      | Person Correlation | 0.027 | -0.078 | 0.007 | -0.056 |
| Sig.(2-tailed) | 0.620 | 0.167 | 0.202 | 0.907 | 0.324 |
| Female    | Person Correlation | 0.090 | 0.110 | -0.018 | 0.037 | 0.069 |
| Sig.(2-tailed) | 0.052 | 0.017 | 0.079 | 0.436 | 0.143 |
female participants tend to select brighter materials for ceilings and walls, while for male participants, there is no such tendency.

5.3 Age influence on material saturation

Age has a great influence on people's cultural background, mind, and physical and psychological condition, etc., and thus may greatly affect their aesthetic preference.

A saturation value $C'_{ab}$ is calculated in CIELab color space to test the influence of age on saturation preference. The $C'_{ab}$ is defined by the following formula.

$$C'_{ab} = \left[ (a'^* )^2 + (b'^* )^2 \right]^{1/2} \quad (1)$$

Fig.7 shows the mean of material saturation value $C'_{ab}$ of participants of different ages. Compared to other interior factors, it is found that the saturation of the floor is more affected by a person's age. The one-way ANOVA test also supports this finding (Table 6.). Starting from an average level from age 18~29, the mean of floor saturation reached a high level between age 30~39, then gradually decreased. But the highest mean of floor saturation appears over the age of 60. It is not easy to find an explanation for this kind of change because it is a result of many factors, but for participants over 60, since the color sensitivity of their eyes has decreased, they are more probably inclined to material with higher saturations. In addition, since the means of saturation of other interior factors do not vary greatly, it could be said that saturation of the floor is more important for the older participants.

5.4 Holistic color interval between factors

Chuang and Ou (2001) employed the holistic color interval for exploring the problem of color harmony, and it is also employed in this paper. The holistic color interval is defined as the Euclidean distance of two colors in CIELab color space as follows:

$$\Delta E'_{ab} = \left[ (\Delta L'^* )^2 + (\Delta a'^* )^2 + (\Delta b'^* )^2 \right]^{1/2} \quad (2)$$

Where the $\Delta L'$, $\Delta a'$, $\Delta b'$ denote the difference in $L'$, $a'$ and $b'$ values, respectively, between the two colors. The holistic color interval can be interpreted as the perceived color difference between the two colors.

In this research, the holistic color intervals of every two factors in a certain design proposal are defined as ten $\Delta E'$ values as in Fig.8. and calculated for statistical analysis.

In an IGA process, design proposals evolve iteratively for generations. The evolutionary process demonstrates how a general tendency of aesthetic preference emerges gradually. The mean and standard deviation of the $\Delta E'$ values in each generation are

![Fig.8. Holistic Color Intervals between Colors of Interior Factors](image)

![Fig.9. Evolution of Mean and Standard Deviation of Holistic Color Interval of Selected Design Proposals](image)

| Table 6. One-way ANOVA Test Results of Material Saturation $C'_{ab}$ Grouped by Age |
|---------------------------------|---|---|---|---|---|
| Total df | Ceiling | Wall | Floor | Door | Sofa |
| F        | 0.502  | 1.713 | 6.546 | 0.906 | 0.408 |
| Sig.     | 0.734  | 0.145 | 0.000 | 0.460 | 0.803 |
calculated and shown in Fig.9. (The generation here is defined as Fig.4.) It is found that for the holistic color intervals from the color of the sofa to other factors (the 4 graphs with thicker frame), the mean value decreases from generation 0 to 1, and then gradually increases. At the same time, its standard deviation continuously increases from generation to generation. On the other hand, for the remaining holistic color intervals, the mean values continuously decrease, and the standard deviations also have a general decreasing tendency. The findings suggest that the colors of ceiling, walls, floor and door have a tendency to become similar to each other. On the other hand, the color of the sofa is different from them, and the continuous increasing standard deviation suggests that the difference from sofa color to other colors tends to become more diverse.

In an IGA process, as the evolutionary process continues, the design proposals gradually become closer to people's ideas. So it could be said that the evolutionary tendency of design proposals in the IGA process is closely related to people's aesthetic preference. For the tested scenes, the sofa is the main furniture, while the other factors could all be considered as its background. The findings suggest that the participants tend to prefer a background of similar colors, while tending to choose a sofa color that differs greatly (some are similar, some are more different) to other colors in the interior according to their taste.

6. Conclusion

In order to explore the associativities of the interior color preference of Beijing residents, this research tries to employ an IGA interior design system which has the advantage of being able to search through numerous possibilities and achieve multiple results concerning problems related to sensibility. Typical living room models of Beijing apartments were tested which involved five interior factors, the ceiling, walls, floor, interior door and sofa. The data of 231 participants were collected, and statistical analysis performed to explore the associativities between colors and that of colors based on the participants' personal information. A certain procedure has been taken to deal with the dependency of the IGA design results.

Analysis reveals that the participants tend to use brighter wall materials as the lighting condition of the interior worsens. It is also revealed that female participants tend to use brighter materials for walls and ceilings as their family income level increases, but for male participants, there is no such tendency. The age of the participants is found to have a significant dependency of the IGA design results.

Through an analysis of the evolutionary process of the holistic color interval in the IGA process, it is found that the colors of the ceiling, walls, floor and interior door have a tendency to become similar, but in the case of the color of the sofa, its difference to other colors tends to be more diverse. The result suggests that the sofa, the main furniture in the interior has a different meaning for the participants compared to other factors.

Although it is still hard to predict the color preference of people based on their personal information alone, the findings in this paper could be meaningful in interior design practice and interior material marketing. The IGA method has also proved to be useful in such color preference investigation. Further researches could be carried out based on a larger number of participants to explore more detailed color associativities in more complex interiors.

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Notes

1. Radiance, developed by Lawrence Berkeley National Laboratory (http://radsite.lbl.gov/radiance/HOME.html)
2. The CIELab color space developed by Commission Internationale d’Eclairage, which is the most complete color model conventionally used to describe all the colors visible to the human eye. The CIELab system is also an attempt to linearize the perceptibility of color differences.
3. Analysis of variance (ANOVA) is a general method for studying sampled-data relationships. The method enables the difference between two or more samples to be analysed achieved by subdividing the total sum of squares. One-way ANOVA is used to test for differences among two or more independent groups. Typically, however, the One-way ANOVA is used to test for differences among at least three groups, since the two-group case can be covered by a test.
4. http://www.visionaware.org/how_does_vision_change_as_i_get_older

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