Interactive Evolutionary Computation (IEC) Method of Interior Work (IW) Design for Use by Non-design-professional Chinese Residents

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Abstract

This paper presents an interactive evolutionary computation (IEC) method for interior design, intended to help non-design-professional Chinese residents conduct interior work (IW) themselves. Seven interior design factors, which are typical of a Chinese apartment living room, primarily color and texture, were selected for adjustment by this IEC method. A material library, coding method, user interface, and different evolutionary processes were developed in this paper. Three experiments were carried out to test this method. It was concluded that the IEC method may facilitate non-design-professional residents determine IW designs for themselves according to their own preferences.

Keywords: Interior Work (IW); chinese habitation; CG simulation; IEC; subjective evaluation

1. Introduction

1.1 Background

Due to recent sustained economic growth in China, vast housing production has taken place throughout the country. From 2001 to 2004, a continuous annual increment of approximately 30% has taken place in investment in the apartment market in China¹. Along with improved living conditions and increases in individual income, people have started to pay more attention to the physical and aesthetic comfort of their living environment. Beginning in 1990, residents started to do interior work (IW) when they moved to a new apartment, after the developer completed essential construction work.

An investigation of habitation in Beijing carried out from 1990 to 1992 (Zhao and Lin 1995 cited in Zhou et al. 2005)² showed that 1 in every 5.1 households performed IW, while in 1997, the same investigation (Li et al. 1999 cited in Zhou et al. 2005)³ revealed that all households performed IW in their apartment living spaces. Presently, many Chinese residents take an active part in IW; they design, purchase materials and furniture, and supervise the construction themselves. The completed IW displays a variation in individuality and in family demand. However, lacking professional knowledge and design experience, this IW is not an easy task for most residents. It is particularly hard for them to visualize the interior aesthetic that they wish in advance.

Furthermore, a great deal of IW materials come from all over the world, and are now available in Chinese IW material markets. This availability provides numerous choices for residents, thereby making the comparison and selection of material difficult.

Interior space is an integration of form, material, color, and lighting. Generally, interior design is based upon experience and intuition. Today, however, because of the development of computer hardware and lighting simulation software, computer graphics (CG) have been widely applied to represent the performance of interior space. Although CG images of an interior space cannot convey the exact feeling of the real space in its entirety, it is still an effective way to help people view the performance of a space before it is constructed.

The interactive evolutionary computation (IEC) method optimizes systems based on human evaluation. It has been applied in many studies in recent years and been proven to be an effective method in searching through a large number of choices and finding creative solutions that are applicable to generating an aesthetic area, especially for nonprofessional designers. It is expected that the IEC method will work well for nonprofessional Chinese residents in developing ideal interior designs among numerous choices of material combinations, without the help of designers.

1.2 Purpose

In this paper, the searching capabilities and creative ability of the IEC method and the simulation ability of CG were integrated into an IW design method.
This research intends to provide a practical interior design method for Chinese residents to participate in the design of IW, which can effectively search through a great deal of materials, predict visual effects of interior space, while at the same time ensuring the individuality of each resident. While improving the interior environment of their apartment, the IW method should save time, costs, and energy for residents.

2. Previous Studies

There have been several recent studies on Chinese IW. Zhou et al. (2004) studied the characteristics of IW and customer evaluations of IW realization and satisfaction based on investigation. A second study (2005) focused on the effects of a transformation of developers' completion standards and management regulations on IW. To date, no research on the aesthetic aspects of Chinese IW has been reported.

The IEC, including interactive GA (genetic algorithm), has been successfully applied in many subjective problems. Aoki and Takagi (1997) applied interactive GA to 3-D CG lighting design. They found that the method effectively worked to assist amateur designers, especially those with limited experience or capabilities. This result suggests that applying the IEC method may help nonprofessional designers.

Matsushita and Munemoto (2004) applied IEC and CG in searching for façade glass attributes, which perform ideally both day and night. The color, reflectance, and transmittance of glass were adjusted according to the designer's subjective evaluation. Images that highly satisfied the customer's expectation were chosen.

Tagawa and Kawamura (2003) used the IEC method for interior design. Different textures were mapped to an interior space, and the Web3D technique was used to visualize the space.

To verify the possibility of evaluating architectural space lighting conditions via rendered images, Mahdavi and Eissa (2002) tried to determine if and to what extent the subjective lighting evaluation of computationally rendered images of space is consistent with subjective lighting evaluations of real space. Two groups of people were asked to evaluate several interior spaces and the computer-rendered images of these spaces were displayed on a color computer monitor, respectively. A subjective lighting metric was used for evaluation. The result showed that for the scene and participants tested, the image could reliably represent certain aspects of the lighting conditions in real space.

In order to provide a dependable image to represent the architectural space, a scientific visualization tool that combines photo-realistic rendering with detailed photometric computation is needed. In the research of Mehlika N. Inanici (2001), two physically based software programs, Lightscape and Radiance, were compared. Radiance was found to be more accurate than Lightscape, and highly accurate for a range of realistic sky conditions.

The difference of this research to that of the above-mentioned study is that the present study applies the IEC method to Chinese IW design areas, and intends to help non-design-professional residents do the designing. Furthermore, the IEC method was tested in these experiments, and was developed based on the findings of the experiments.

3. Methods

3.1 Model

Interior space is composed of many factors, and all factors influence the aesthetic evaluation of the space. But the design process is accomplished step-by-step, with the forms, materials, and furniture being adjusted gradually, and details added in sequence. The IEC method cannot account for every factor of interior space in one process, just as the designer cannot decide everything at one time. Each IEC process can only include a limited number of factors, and is thus considered as one step in a completed design process. Subsequent design steps can be carried out based upon these previous results.

The living room of a typical apartment in Beijing was selected as the design objective. The room model (Fig.1.) is oriented in the south–north direction with a balcony at the south end. Because many apartment buildings in Beijing are of shearing-wall structure, two buttresses and a beam are placed between the living room and the balcony.

Because of the different lighting conditions during day and night, the atmosphere changes, and it is therefore necessary to adjust the factors under both conditions. Images of day and night were rendered for evaluation.

Sofas, standing lamps, plants, interior doors and ceiling lamps are part of the scenario. These are important features in the living room of a Chinese apartment, and greatly influence the resulting aesthetic feel. As the method is intended to be used by Chinese residents inexperienced in interior design, it is easier
for them to make an aesthetic evaluation, without the
necessity of imaging.

The factors involved in the IEC process (Table 1)
are primarily material- and color-related factors. It is
assumed that these are the main factors influencing the
interior aesthetic feel. The light color of a ceiling lamp
is also involved because it influences the interior space
greatly during nighttime. The IEC searching results of
these factors and the achieved images can be used as a
basis of further interior designs for the residents.

### 3.2 Material library

A material library was constructed for this study
in the context of the actual Chinese IW. The material
categories in the material library were selected
according to the typical choices of Chinese residents.
Some of the materials' properties, such as the color of
paint and textiles, were obtained from manufacturers'
catalogs. Other material properties, including the
texture of carpets, wood, and ceramic tiles, were found
in images used in CG simulation of interior designs
in China; they are assumed to represent real materials
available on Chinese market (Table 2).

### 3.3 Radiance

Radiance is a photo-realistic and photometric
ray tracing software, which has been widely used in
lighting simulations. It is well-known for its accuracy
in lighting simulation both in daylight and under
artificial lighting conditions. Radiance was used to
provide dependable simulations of interior space in the
research.

The material properties, such as specularity fractions
and roughness values, were decided upon by referring
to the standard radiance material library, and through
trial-and-error as recommended in the book "Rendering
with Radiance".

### 3.4 IEC coding and process

In order to optimize the interior design by the IEC
process, materials in the material library had to be put
in a coordinate system. In this research, RGB space
was selected as the coordinate system. The paints and
textiles were entered according to their color values.
For each of carpet, wood, and ceramic tile, 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 RGB space.

The materials were identified as discrete points in
RGB space. When the GA-generated coordinates did
not have a corresponding material, the gene fraction
was replaced by one of the coordinates of the nearest
material point. This was based on the assumption
that the nearer the RGB values, the more similar the
subjective evaluation. Fig.2 shows the distribution of
sofa colors in the material library in RGB space and a
gene relocation process that occurred in that space.

The gene of the IEC method has a length of 80 bits
(Table 3). The gene bits corresponding to certain RGB
values were shortened to make the GA search among
sparse material points more effective.

The first population of the IEC process was
generated randomly. After the rendering process and evaluation by the user, the next population was generated by crossover and mutation as in the usual GA process. Afterwards, new individuals are compared by the program. If any two individuals are identical, mutation is applied. This process eliminates identical individuals and makes the GA search more effective.

3.5 Mutation-only evolution

After generations of evolution, the population of an IEC process may converge around some local optimal solution, and it would be difficult to generate a better solution even if the evolution continued. This also occurs during the IEC process. A previous study showed that it is much more effective during early generations than in the latter ones.

A mutation-only evolution method called "variation" was employed (Fig.4.) to enhance the IEC method in latter generations. In this method, the user can specify one individual he/she prefers in a certain generation as the parent. The next generation will be variations of the parent. The user can also specify factors manipulated in the mutation, and the mutation range: "small," "medium," and "large" (Fig.3.).

3.6 Interface

The interface of the IEC program (Fig.5.) was constructed with Visual BASIC. The interface is of the resolution of 1,024×768 pixels and displayed on a color computer monitor. Rendered images during day and night of eight individuals were displayed in pairs on the interface. The user can start the IEC process by clicking "start," evaluate each individual by selecting scores from 0 to 7 in the ComboBox at the bottom right corner of the image, and produce the next generation of individuals by clicking on "next generation." The mutation-only process can be accessed by the button "variation."

4. Experiments

Three experiments were designed and carried out in this study. In experiment 1, a goal individual was set to test the searching efficiency of the IEC method. In experiment 2, two users were asked to find an ideal interior design using the IEC method, without any set goals. Based on the findings of experiment 2, a new method was developed by increasing the population size, and a corresponding test was performed in experiment 3.

4.1 Searching efficiency (experiment 1)

A Chinese student in Kyoto University was asked to use the IEC program to verify the searching effectiveness of the IEC method.

Two images were rendered according to an individual in the search space of the IEC program. These two images (Fig.6.) were set as the searching goal of the IEC process.

The experiment consisted of two parts: the traditional IEC search of the goal without the "variation" process (experiment 1-1), and the IEC search of the goal.
including the "variation" process (experiment 1-2).

During the experiments, the student was asked to evaluate each individual displayed in the interface by comparing each with the goal images displayed on the same computer monitor. Both tests lasted for ten generations and resulted in two individuals as results, respectively (Fig.6, and Table 4).

The optimization process of experiment 1-1 demonstrates the characteristics of the GA method. In early generations, the population evolved greatly, while in latter generations, it did not change very much.

In experiment 1-2, after two generations of crossover and mutation evolution, the user started to employ "variation" to generate successive generations. One or two factors were selected to participate in each mutation process. The best individual in each generation, which the user selected as the parent of the next generation, became incrementally closer to the final goal. The result of experiment 1-2 was found to be visually and numerically closer to the goal than that of experiment 1-1.

The correlation coefficient can be used to analyze the proximity of two data sets, and in this research, it was calculated to compare the goal individual with the best individuals and generation average values for each generation (Fig.7). The results indicated that experiment 1-2 evolved into individuals having a higher correlation coefficient with that of the goal individual. The IEC with "variation" was found to be more effective than the traditional IEC method in searching for a certain design goal, especially in the latter stages of the evolution.

4.2 Efficiency in design (experiment 2)

Although the searching ability was improved by the mutation-only process and verified in the above experiments, the real design process is different from searching for a designated goal individual. Further experiments were conducted to test the efficiency of the IEC method for design problem solving.

Two Chinese students at Kyoto University, who were not architecture or design majors, were asked to participate in the experiment. The experiment consisted of three steps as follows. The interior model of a living room employed in this research was introduced to the user. After that, the user was asked to select materials for different factors of an ideal interior space by directly viewing the material texture images and color samples displayed on the computer screen. This process was considered to be similar to the usual material searching and selecting activities conducted in material markets in China. Two images of daytime and nighttime interior space were rendered for the selected individual. In step 2, the user was asked to use the IEC program tentatively to search for an ideal interior space according to his/her subjective evaluation of the displayed images. In step 3, the user was asked to evaluate both individual results from steps 1 and 2 by viewing the rendered images of each. The user was also asked to evaluate the IEC method.

It took four and eight generations for user 1 and user 2 to obtain results from the IEC process, respectively. The images generated from step 1 and step 2 for both users are shown in Fig.8.

In step 1, user A selected materials based on her experience at home and some furniture shops, but she was not satisfied with the result. Comparing the results of step 1 and step 2, the user preferred the individuals in step 2 because "the materials in the room are more..."
The population size (number of individuals in a certain generation) is critical for the searching ability and efficiency of a GA optimization process. Increasing the population size will enhance the searching ability of the GA process, but increase the computation time.

The IEC population size was limited by the image number that could be displayed simultaneously on a computer screen; in this case, the image number was 16. Since daytime and nighttime images are both important for evaluation, they are displayed in pairs in the interface, which reduces the population size to 8.

From experiment 2, it was suggested that the IEC method still had some problems: it converged too quickly and could not display sufficient choices, which can be explained by an insufficient population size. Based on this assumption, the method was developed by increasing the population size, and an experiment was performed.

Two new developments were applied to the IEC process flow to increase the population size (Fig.9.). The IEC search process for daytime and nighttime was performed separately in the first step, with the resulting individuals from these two processes designated as first generation of a day and night (D&N) IEC process, from which the final results were determined. This development was based on the assumption that people will give a similar evaluation of a day image and night image of a certain individual, so that day or night processes will evolve toward results that perform well in both day and night. In the D&N step, the day and night images were displayed simultaneously for precise evaluation of the effect. The result of step 1 was evaluated as "ordinary, not special." She explained that "because it is hard to imagine the effect, I selected common materials, which are safe. And I was therefore restricted by conventional ideas." The IEC process was evaluated as "heuristic, interesting" and the result was better. But the user was not very satisfied with the result from step 2. She said that "some of the ideas I was imagining were not shown during the process."

From the users' evaluations, it was suggested that the IEC method can provide more possibilities to the user than the usual design process, and is "heuristic" in finding new ideas different from what the user was thinking. But the method still has the following problems. The evolution converges too quickly and the evolution cannot present sufficient choices to the user.

The users evaluated the direct selection of material as "difficult" and the IEC-searched design as "more harmonious," which may have been because the users could view the rendered CG images and make an evaluation directly and easily.

4.3. Increasing population size (experiment 3)
Due to this development, 16 individuals could be displayed simultaneously in the day or the night processes, so the population size was double that of the original method. Also the population size increased since two groups of individuals evolved in the separated day and night IEC processes independently. (The latter D&N process obtained the results from both of the former processes and evolved into the final results.)

The population sizes of all three IEC processes were doubled again. The population size of daytime or nighttime process was increased to 32, and the D&N process to 16. The individuals of a certain generation were generated from all selected individuals of the parent generation, and were displayed on the computer screen in two successive steps.

Although the individuals of a certain generation were not displayed simultaneously, since they were generated from the same group of parent individuals, it was assumed that the user's evaluation of them was similar to his/her evaluation in the situation when all individuals could be viewed simultaneously.

Considering that the evaluation method of scoring individuals is not an easy task for non-design-professional users to use, a new "selection" method was employed in the experiment to reduce user fatigue. The user only needed to click on the individuals he/she prefers, and these individuals were marked and became parents of the same importance of the next generation. Although this "selection" method is not as precise as the scoring method, it is easier for non-design-professional users in evaluating a large number of individuals.

User B in experiment 2 was asked to tentatively use the newly developed IEC method. The IEC process consisted of 16 steps (day: 6; night: 6; D&N: 4) and the last generation of the D&N process (Fig.10.) was considered the design result.

When evaluating the results, the user felt "satisfied with the results," and she "liked many results" in the final generation. Compared to the former experiment, she stated that "this method was much more heuristic, and the results were better." She mentioned that "I have never imagined a green sofa before, and it seems to be a good idea," and "the results can be good reference in interior design." She also evaluated the "selection" evaluation method as "easier" to use than the scoring method.

For user B, two statistic values were calculated for experiment 2 and experiment 3. One was the amount of materials that appeared in each generation (sum of all factors; Fig.11.). The other was the average of AVEDEV (average of absolute deviation, function provided by Microsoft Excel) of materials' RGB values of each generation (Fig.12.). These two statistical values could be used to represent the material variation.
in a certain generation with respect to the aspects of amount and dispersion. It was found that both values of experiment 3 were generally much higher than that of experiment 2. Experiment 3 was found to be more effective in presenting more possibilities to the user.

It was concluded from this experiment that increasing population size improves the effectiveness of the IEC method in searching for individuals that the user prefers.

5. Conclusions
In this study, an IEC method was applied to Chinese IW design areas. This method was intended to facilitate the interior design activities of non-design-professional residents. An IEC program and a graphic interface were developed, and a material library was constructed in the context of the actual situation of Chinese IW. The rendering program Radiance was used to provide reliable simulations of interior space.

Three experiments were performed in this study. In experiment 1, the IEC method was tested in searching for a designated goal, and a "variation" method was found effective in enhancing the IEC searching capabilities. Experiment 2 was intended to test the method for solving a problem for which no design goal had been set. The method was found useful for the two users who participated in the experiment, and some weak points of the method were exposed. Based on the findings of the second experiment, the method was further developed by increasing the population size, and the effect was tested in experiment 3. It was discovered that the development of the method might enhance the IEC search process by presenting more variations.

It was concluded from the experiments that the IEC method helps non-design-professional residents in easily finding IW designs according to their own preferences, and thus improves the interior environments of their apartment living spaces.

In an IEC process, a set of randomly generated individuals gradually evolve into a population, which the user evaluates. Behind the interface, on the gene level, the genes of the user's own preferences were approached by the program (supported by the fact that user B liked many individuals in the final generation of experiment 3).

Professional designers use architectural language, which can be interpreted as an integration of design rules, in their design practice. Non-design-professional residents, however, have difficulties in finding an ideal design because they have not mastered this language. The genes of the user's preference found by the IEC program can be interpreted as the user’s own architectural language. Since this language, which was difficult for the user to express and hard for professionals to understand, was revealed, the design ability of non-design-professional residents was greatly improved.

Finally, seven factors of the living room interior space were selected and used in the design problem. Although it was assumed that these factors were the primary ones that influence the aesthetic appearance of interior space, there may be other important factors in living room environments. For example, user A in experiment 2 mentioned the influence of the form of the sofa on her evaluation. This indicates that the problem of an IEC process should be designed carefully to provide sufficient freedom to the user, and at the same time allow the IEC process to evolve efficiently.

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Notes
1. National Bureau of statistics of China (2001-2004) China Statistical Yearbook. Beijing: China statistics press.
2. Radiance, developed by Lawrence Berkeley National Laboratory (http://radsite.lbl.gov/radiance/HOME.html)

References
1) Aoki Ken and Takagi Hideyuki (1997) 3-D CG Lighting with an Interactive GA. In: vol.1 of the Proceeding of the 1st Int. Conf. on Conventional and Knowledge-based Intelligent Electronic System (KES’97), May 1997, Adelaide, Australia.
2) Larson, Greg Ward and Shakespeare, Rob (1998) Rendering with Radiance. California: Morgan Kaufman Publisher.
3) Mahdavi, Ardeshir and Eissa, Hesham (2002) Subjective evaluation of architectural lighting via computationally rendered images. Journal of the Illuminating Engineering Society, Summer 2002, pp.11-20.
4) Matsushita Daisuke and Munemoto Junzo (2004) A study of a search method of façade glass attributes by an aesthetic evaluation of CG images applying an interactive evolutionary computation, Journal of Architecture, Planning, and Environment Engineering, AJJ, No.584, pp.187-192.
5) Mehlika N. Inanici (2001) Application of the state-of-the-art computer simulation and visualization in architectural lighting research. In: Seventh International IBPSA Conference, 2001, Brazil.
6) Targawa Kazumasa, Kawamura Hiroshi and Tani Akinori (2003) Architectural interior design supporting system by interactive evolutionary computing. In: Proceedings of the 26th symposium on computer technology of information, systems and applications, AJJ, 2003, Japan.
7) Zhou Xiaohong, Yoshida Tetsu and Mumemoto Junzo (2004) A study on the characteristic of interior works in units of apartment houses and customers' realizations and satisfaction. Journal of Architecture, Planning, and Environment Engineering, AJJ, No.575, pp.1-6.
8) Zhou Xiaohong, Yoshida Tetsu and Mumemoto Junzo (2005) Study on residents' apartment interior works effected by transformation of developers' completion standards and residents' apartment interior works management regulations. Journal of Architecture, Planning, and Environment Engineering, AJJ, No. 592, pp.1-8.