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Research on Multidimensional Characterization of Interior Design and Architectural Decoration Styles Based on Clustering Algorithm

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Abstract In the field of architectural interior design, color matching technology, as an important tool for shaping spatial aesthetics, will have an impact on the emotional and psychological feelings of the occupants. The article takes the color characteristics of interior design and architectural decoration style as the entry point, and constructs an interior design layout optimization model from the utilization rate of effective indoor activity space and indoor distance accessibility as the objective function. A small habitat algorithm is introduced to improve the genetic algorithm, so as to realize the solution of the interior design layout optimization model. On the basis of interior design layout optimization, the color matching of interior architectural decoration styles is carried out through IPSO algorithm and light effect rendering processing in combination with the interior layout model. The simulation results show that the improved genetic algorithm of SCT can achieve the optimal interior design layout scheme, and the color style feature score of architectural decoration reaches 4.11 points, which is only 0.02 points lower than that of the professional designer team. Making full use of the advantages of the algorithm can help users better plan the interior space, and fully improve the diversity of interior architectural decoration styles on the basis of meeting the dual needs of users' material and spiritual needs.

Index Terms interior design, small habitat algorithm, genetic algorithm, IPSO algorithm, color style

I. Introduction

Since the reform and opening up, the living standard of Chinese residents has made great improvement, especially in recent years, after people satisfy the basic living conditions such as food, clothing, housing and transportation, they begin to gradually enhance the pursuit of higher material and spiritual aspects [1]-[3]. Interior design as a continuation of architectural design, interior design contains a number of aspects, interior decoration is mainly based on the perspective of visual art to explore the selection of materials, artistic treatment of the interior interface, the decoration of common components, the setup of furniture, the choice of indoor greening and other issues [4]-[7].

For the sustainable development of construction enterprises, interior design and architectural decoration style play an important role that cannot be ignored. The design purpose of interior design and architectural decoration style is the same, both are on the basis of limited material resources, so that the building to play a better function, but the essential difference lies in the difference of the design object, interior design is the internal structure of the building, while architectural decoration style is the whole of the building for the construction of the design, and the relationship between the two is the whole and the local [8]-[11]. In order to complete the progress and development of the construction industry, the first step is to harmonize and balance the relationship between interior design and architectural decoration style, so that they can be integrated with each other. In this process, analyze the contradictory points appearing in interior design and architectural decoration style, so as to summarize the correct combination method, in order to be able to improve the level of architectural design on the whole, and complete the whole intention of interior design and architectural design [12]-[15]. Interior design has certain independent characteristics, the surface analysis of the link between interior design and architectural design is not large, but in fact the two are closely integrated [16], [17]. According to the diversified needs of people, safety, comfort and other points need to be well controlled in the structural design of buildings [18].

Based on the continuous progress of contemporary architectural design, color matching technology occupies an important position in architectural interior decoration, and has become a key technical means to enhance the aesthetics and functionality of architectural space. Based on the knowledge of living space, color relationship, architectural decoration style representation and color application in interior design, the article establishes an optimization model of interior design layout based on the optimization objectives of effective indoor space utilization rate, indoor distance and furniture influence. The genetic algorithm is improved by using the pre-selection mechanism, exclusion mechanism and sharing mechanism of the small habitat algorithm to obtain the optimal interior design layout scheme. On this basis, the 3D model of the interior layout is further created, and the IPSO algorithm and light effect rendering processing method are introduced, which then realizes the color style matching of the interior architectural decoration, and provides support to meet the user's color visual comfort. For the application feasibility of the above methods, this paper carries out a quantitative analysis of data through multi-angle simulation experiments.

II. Stylistic features of interior design and architectural decoration

In interior design, Chinese decorative color as a form of decorative language, is an important part of the interior environment, in addition to bring the user visual enjoyment, but also allows the user to experience traditional Chinese culture and art in a comfortable environment. Nowadays, people's demand for art has risen from the basic material level to the spiritual level, interior design should not only meet the needs of people's material life, but also become a part of modern life.

II. A. Interior Design Color Relationship Exploration

II. A. 1) Living space in interior buildings

The space of indoor buildings is mainly divided as shown in Figure 1, i.e. living space, common space and auxiliary space. Among them, living space is an important place for people's leisure and rest, and is the basis for people to enjoy life. The living space exists in the form of indoor units, and the internal division of the area is determined by the behavioral activities of the user, according to the different behavioral needs of the user, the living space is divided into the rest area, entertainment area, hygiene area and activity area. Among them, the activity zone runs through the whole living space [19]. There are many factors affecting the design of living space, such as the limited and complexity of the space itself, and the existing theoretical methods can not effectively deal with these difficulties, so intelligent environment-related technologies and theories should be integrated into the design to solve these problems.

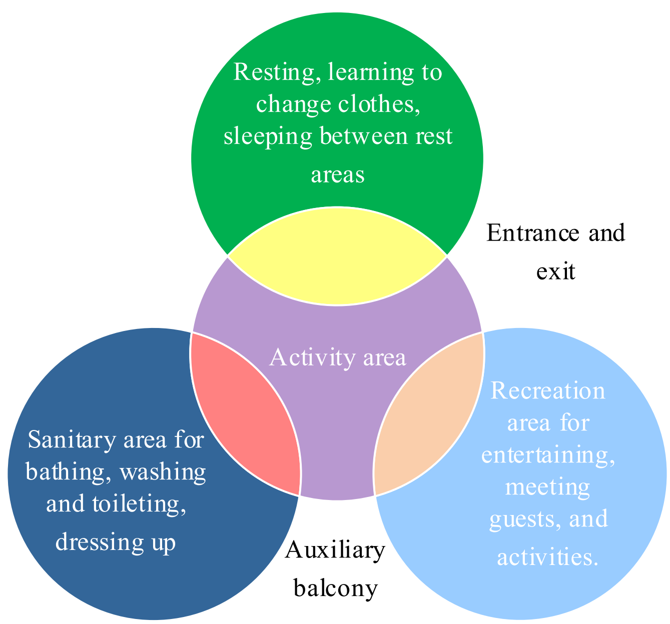


Figure 1: Main division of residential space

The living space of indoor buildings is generally difficult to change its spatial layout on the original structure, which can be changed by adding partitions, changing the location of furniture, using smart home products and lighting area division. The reasonable layout of living space can not only increase the utilization rate of space, but also improve the comfort of users.

II. A. 2) Color relationships in interior design

The interior structure unites the building, but the color is independent. The rational use of the interaction of color can be used to achieve a perfect transition of the lines and structure, and to visually depict a building with the color itself. Color can extend the walls and raise the height of the ceiling, making the whole interior space look tall and bright.

(1) Consider the interior as space. Floor and ceiling colors influence the perception of the height of a space, and the color of the walls defines the extent of the space. Usually the larger the room or the larger the window area, the less cramped and confined it feels. All the high-colorful colors in a room (e.g., warm colors such as red, yellow, and orange) give a sense of prominence, accentuating the visual effect of objects and magnifying their visual effect in the overall pattern. While the low chroma colors (such as blue, blue-purple and other cold colors) give the feeling of concave, the visual effect of the object smaller, the viewer's attention back in the furniture and equipment, artwork, the structure and function of the room and so on.

(2) See the interior as a flat surface. When designing, designers can view the interior building structure as separate, bounded vertical planes and horizontal surfaces, and then they are free to design each surface separately. Vertical surfaces: First, all the vertical planes in the building are independent, choose the desired color, and then when combining these planes into a whole, fine-tune the color scheme in detail so that the colors interact harmoniously in the whole. Horizontal planes: Horizontal planes mainly refer to ceilings and floors, and the color of horizontal planes is measured by visual weight. Ceilings are made lower in height with high chroma colors and higher with low chroma colors. The colors of white, cream, or the ceiling itself have the lightest visual weight and hue and lightness relationships, and these colors are the most expansive elements in the environment.

II. B. Multi-dimensional characteristics of architectural decoration style

II. B. 1) Stylistic characterization of decorative themes

For the architectural decoration style of interior design, its theme design is mainly based on the user's main needs, the era environment and other aspects to determine. Usually, the architectural decoration theme of interior design can be divided into five main types, culture, nature, nostalgia, art and era. Among them, the cultural theme includes simple culture, regional culture and other themes, the art theme includes classicism, baroque, eclecticism and other styles, nostalgia and culture and art themes and nested. Figure 2 for the interior design of architectural decoration theme style interpretation, relying on five decorative themes reflecting nine different types of decorative style. These theme styles are concentrated in the plane form of the interior space, the interface of the decorative style and details, such as decorations, lamps, patterns, colors and other aspects.

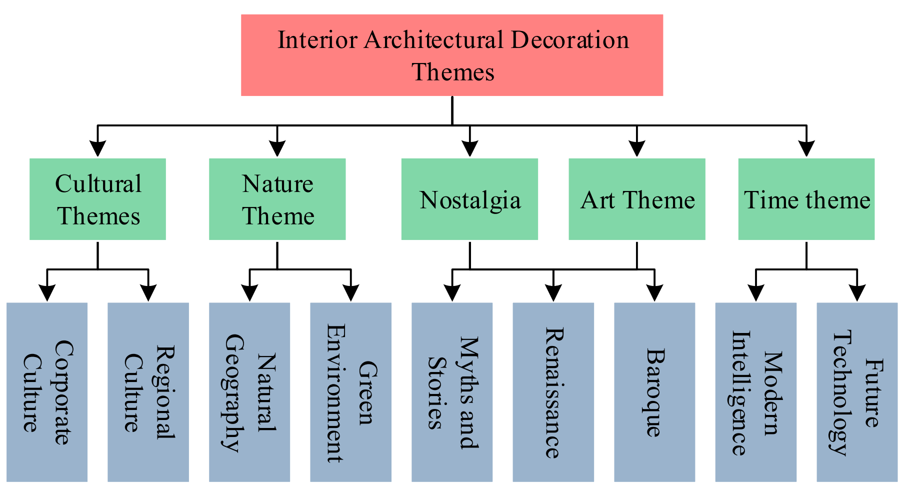


Figure 2: Architectural decoration theme style deduction

II. B. 2) Color application in interior design

In residential interior design, the design of color needs to consider the following three factors:

(1) External environmental factors, such as climate, light and so on.

(2) Factors of the building itself, such as layout, orientation, materials, etc.

(3) Occupant factors, such as color preferences, artistic preferences.

On this basis, it is also necessary to consider the symbolic meaning of color, expressive power and collocation. Interior design is to re-create the space in the form of art and realize creative expression. Interior design not only focuses on the material surface of the innovative design, but also focuses on the spiritual needs of the level of demand, and its fit with the functional aspects of the region. In interior design, color is one of the most important design elements, the visual impression brought by color on people's influence can not be ignored, color vision is also an important form of expression of emotion. Therefore, the expression of color can create a richer sense of hierarchy and emotion for the interior space, and color is the soul of interior design. The application of color in residential interior design is strategic. In interior design practice, color design is about innovation, the designer should give full play to the imagination, rather than simply mechanical application of ready-made formulas [20].

III. Interior design layout optimization and color design

Color is a very expressive emotional language, in interior design is an important element that can give people a strong visual feeling, all things contain their own color, color can directly stimulate people's visual response, while color is also a commonly used language, with its own content and characteristics. The application of color matching technology in architectural interior design can change the interior environment and improve the design effect. The main reason is that color can determine the interior design style to a certain extent, so in the process of interior design need to ensure the consistency of color and style, while paying attention to the reasonableness of the color collocation, so as to create a good indoor living environment for people to improve their quality of life.

III. A. Interior Design Layout Optimization Model

III. A. 1) Effective space

Effective living space refers to the continuous and spacious space for daily activities after the completion of the living space arrangement. Specifically refers to the removal of those who can not be utilized due to the placement of furniture and equipment space (including the space occupied by furniture and equipment as well as furniture and equipment around the narrow space can not be utilized), the size of the effective activity space can be used to express the corresponding area, in general, indoor furniture and equipment placed differently, the corresponding area of the effective living activity space will also be different.

Let a living space corresponding to the total area of A, indoor effective activity space corresponding to the area of S, the indoor effective activity space utilization rate E can be expressed as:

$$E=\frac{S}{A} \tag{1}$$

From equation (1), the value of E ranges from 0 to 1, and the larger the value of E, the higher the indoor effective activity space utilization rate of the arrangement scheme. In the case of arranging the same amount of furniture and equipment, the higher the effective activity space utilization rate, the better the arrangement plan. The corresponding total area A of the indoor space can be obtained from the geometric dimensions of the indoor space, and the corresponding area S of the effective activity space of the cabin can be expressed as follows:

$$S=A-S_1-S_2 \tag{2}$$

where S_1 is the sum of the areas corresponding to the space occupied by each furniture and equipment, and S_2 is the sum of the areas corresponding to the narrow corners that cannot be utilized due to the arrangement of each furniture and equipment.

III. A. 2) Objective function

In the layout optimization of interior design, designers usually need to reasonably arrange various furniture and equipment in certain positions to meet their functional requirements according to certain design guidelines and design experience. Due to the polymorphism and ambiguity of the evaluation indexes of the layout scheme of interior design, it makes the evaluation of the scheme very difficult, and it is difficult to evaluate the goodness of an interior design layout scheme with a precise data, so it is always based on the designer's experience and intuition to judge in the evaluation of the layout scheme of interior design.

In this paper, through the analysis of interior design and layout optimization guidelines, the weighted method is used for multi-objective optimization, and the multi-objective decision-making problem is transformed into a single-objective problem to be solved, so as to establish the mathematical model of interior design layout optimization as follows:

$$\min f(X)=w_1\frac{f_1(X)}{f_1^0(X)}+w_2\frac{f_2^0(X)}{f_2(X)}+w_3\frac{f_3(X)}{f_3^0(X)}+w_4\frac{f_4(X)}{f_4^0(X)}+w_5\frac{f_5^0(X)}{f_5(X)} \tag{3}$$

$$s.t.\begin{cases} g_i(X)\geq 0 \\ h_j(X)=0 \end{cases} \tag{4}$$

(1) $X=\left\{X_1,X_2,\cdots,X_p\right\}=\left\{(x_1,y_1,z_1),(x_2,y_2,z_2),\cdots,(x_p,y_p,z_p)\right\}$, p is the number of furniture devices in the room, $x_i\left(i=1,2,\cdots,p\right)$ is the x-coordinate of furniture equipment i, $y_i(i=1,2,\cdots,p)$ is the y-coordinate of furniture equipment i, and $z_i\left(i=1,2,\cdots,p\right)$ is the z-coordinate of furniture equipment i.

(2) In the objective function, $f_1\left(X\right)$ describes the indoor distance, $f_2\left(X\right)$ describes the indoor interference distance, $f_3\left(X\right)$ describes the internal people circulation distance, $f_4\left(X\right)$ describes the indoor man-machine efficacy index, and $f_5\left(X\right)$ describes the effective area of the interior and its integration. $w_i\left(i=1,2,\cdots,5\right)$ is the importance weighting coefficient of each indicator, and its value is determined by AHP method, and $f_i^0\left(X\right)\left(i=1,\cdots,5\right)$ is the value of indicator of initial program.

III. A. 3) Constraints

When establishing the constraints for optimal arrangement of interior design layout, three types of constraints are mainly considered as follows:

(1) Layout guidelines to be followed when arranging furniture. Mainly the layout container constraints, that is, the layout can not exceed the boundaries of the cabin, as well as the distance to the requirements of the two genera furniture location relationship, the following equation can be established:

$$\frac{s_i}{2}\le x_i\le L-\frac{s_i}{2}\ Or\ \frac{q_i}{2}\le y_i\le W-\frac{q_i}{2} \tag{5}$$

The point to consider here is that since the interior space is not a rectangle in many cases, but rather has one or both sides with curvature variations, it is generally the edges in the x direction that will be in this situation. Therefore, for such constraints they should be expressed in the following form:

$$\frac{s_i}{2}\le x_i\le L-\frac{s_i}{2}\ Or\ \frac{q_i}{2}\le y_i\le f(x_i)-\frac{q_i}{2} \tag{6}$$

$$\left|x_i-x_j\right|=d_{xij} \tag{7}$$

$$\left|y_i-y_j\right|=d_{yij} \tag{8}$$

where x_i and y_i are the position parameters of the furniture, $f(x)$ is the fitting function of the curved edge, d_{xij} and d_{yij} are the distance requirements in the x and y directions between the generics i and j, respectively, and L and W are the length and width of the room, respectively.

(2) Non-interference between furniture. That is, each furniture layout position two by two cannot intersect, then the constraint is:

$$\left|x_i-x_j\right|\ge\frac{s_i+s_j}{2}\ Or\left|y_i-y_j\right|\ge\frac{q_i+q_j}{2} \tag{9}$$

where x_i, y_i are the cardinal heart position parameters of device i, s_i, q_i are the x, y direction dimensions of device i, and d_x, d_y are the minimum distances in the x, y directions of device i and device j due to functional requirements.

(3) Ensure that each furniture does not conflict with the entrance and exit door. The door of the room is a channel for people to enter the room, the furniture naturally can not conflict with it, the requirements of the furniture does not interfere with the closest to his furniture, the basic space in and out of the door is also regarded as a furniture, the problem will be converted into a non-interference problem of furniture, the constraints are expressed as follows:

$$\left|x_i-x_d\right|-\frac{s_i+L_d}{2}\ge 0\ Or\left|y_i-y_d\right|-\frac{q_i+W_d}{2}\ge 0 \tag{10}$$

where x_d, y_d are the positioning parameters of the feeding gate hypothesis generator, L_d, W_d are the length and width.

III. B. Interior Design Layout Optimization Solution

III. B. 1) Genetic algorithms

The basic idea of genetic algorithm (GA) comes from molecular genetics and biological evolution theory, is a kind of stochastic global search optimization algorithm that draws on the doctrine of natural selection and genetic mechanism. The basic principle of genetic algorithm is to first generate an initial population, which consists of initial candidate solutions to the problem, and bring each candidate solution into the evaluation function to find the value to reflect the goodness of the solution. According to the principle of nature that high-quality populations will be retained and low-quality populations will be eliminated, the higher the evaluation result of the candidate solutions in the initial population, the higher the possibility of generating offspring. Next, various types of genetic operations are performed on the candidate solutions to generate new population candidate solutions, inheriting the characteristics of the previous generation of high-quality solutions, and this is repeated iteratively until the optimal solution that meets the requirements is generated [21].

(1) Coding method. Selecting the appropriate coding method will make the selection, crossover and mutation steps in the algorithm relatively simple, which will improve the computational speed and also increase the probability of convergence to the optimal solution. On the contrary, if the selected coding method is not suitable for the actual problem, it will lead to the computational difficulties of the other steps of the algorithm, which is easy to produce undesirable individuals, and ultimately affect the convergence of the algorithm.

(2) Adaptation function

The fitness function in a genetic algorithm is usually a quantitative measure of individual goodness and usually takes the value of a positive function. Its value is converted from the objective function of the optimization problem. The objective function is a specific mathematical function established for a specific real optimization problem. There are two forms of objective functions for solving optimization problems in general. One is to solve the maximum value problem and the other is to solve the minimum value problem. Assuming that the objective function sought is $f(x)$ and the fitness function is $F(x)$, the conversion formula is:

$$Fit(x)=\begin{cases} f(x)+D_{\min} & f(x)+D_{\min}>0 \\ 0 & f(x)+D_{\min}\le 0 \end{cases} \tag{11}$$

$$Fit(x)=\begin{cases} D_{\max}-f(x) & D_{\max}-f(x)>0 \\ 0 & D_{\max}-f(x)\le 0 \end{cases} \tag{12}$$

where Eq. (11) is for the maximum problem, where $D_{\min}$ denotes a relatively small number. Eq. (12) is for the minimum problem, where $D_{\max}$ denotes a relatively large number.

The role of the fitness function is to evaluate the strengths and weaknesses of the chromosomes and to combine with the crossover variance to eliminate the poorer chromosomes. At the beginning of the algorithm, the chromosome direct differences are large and the fitness values are also large, so that the elimination process progresses smoothly. At the end of the algorithm, the chromosome difference decreases, and the direct difference in fitness value decreases, which not only slows down the optimization process, but also makes the algorithm fall into a local optimal solution easily. Therefore, at the end of the algorithm, the fitness function value is enlarged to improve the difference and ensure that the solution goes smoothly.

(3) Genetic operator

In the iterative process of the algorithm, the individuals with high fitness should be retained into the next generation as much as possible, and this strategy is similar to the process of survival of the fittest in biological evolution, which is known as the selection operator in the genetic algorithm. The common strategy of selection operator is roulette strategy, this selection method solves for fitness and sums it over all contemporary individuals of the population, and determines the probability of the individual being selected based on the size of the fitness of each individual.

Let the population be M and the value of individual fitness be F_i, then the probability that the i th individual is selected into the next generation is:

$$P_i=\frac{F_i}{\sum_{i=1}^{M}F_i}\left(i=1,2,3,\cdots,M\right) \tag{13}$$

The crossover operator plays a very important role in the generation of new individuals, especially at the beginning of the algorithm iteration when the differences between individuals are obvious. The crossover operator mainly includes three types: single-point crossover, multi-point crossover and arithmetic crossover.

The variation operator is to ensure that the algorithm does not fall into the local optimum during the iteration process, as the evolution proceeds, the excellent individuals in the population increase, and this state is not conducive to the global search, the variation operator can play a role in jumping out of the local optimum at this time.

III. B. 2) Solution flow

The traditional GA algorithm retains genes in the solution composition, which makes the diversity of the population lower and lower, and will eventually converge to a certain section gradually. Therefore, the traditional GA algorithm for solving the interior design layout optimization may bring the problem of multiple peaks worth. In order to be able to get multiple peaks through the calculation, the idea of microhabitat needs to be introduced, and microhabitat is used to improve the genetic algorithm to solve the interior design layout optimization model.

Habitat refers to a kind of survival environment in a specific environment, and in the process of evolution, organisms usually live with their own similar organisms and reproduce their offspring together in a specific geographic environment. Genetic algorithms based on the idea of microhabitats are used to maintain the diversity of the population by partitioning the evolving population into several microhabitats, which in turn leads to multiple peaks. Depending on the mechanism utilized, microhabitat-improved genetic algorithms can be classified into three main categories, i.e., pre-selection mechanisms, exclusion mechanisms, and sharing mechanisms.

In small habitat genetic algorithms, the Hemming distance is utilized to measure the coding variability between individuals.

Let there be M individuals in the population, then the Hemming distance between every two individuals among these M individuals is:

$$\left\|X_i, X_j\right\| = \sqrt{\sum_{k=1}^{M}\left(x_{ik} - x_{jk}\right)^2} \begin{pmatrix} i = 1, 2, \cdots, M-1 \\ j = i+1, i+2, \cdots, M \end{pmatrix} \tag{14}$$

(1) The main idea of the pre-selection mechanism is to let the parent and offspring form a small habitat environment, and through the comparison of the fitness function, the individuals with better performance in the small habitat environment are selected to enter the new population.

(2) The basic process of the crowding mechanism is to set up a crowding factor and select individuals in the population to form a crowding set proportionally, and the individuals in the crowding set are called crowding individuals. Then the newly generated individuals after genetic evolution and the crowded individuals are compared for similarity, and the comparison can be carried out by calculating the Heming distance. If the similarity is too high, the newly generated individuals are discarded. On the contrary, the newly generated individuals are retained.

(3) The sharing mechanism is to use the sharing function to modify the fitness function of individuals, and then create the environment of small habitats to influence the evolution of the population. The sharing function is a function that expresses the degree of similarity between individuals, the higher the similarity, the larger the value of the sharing function. Conversely, the smaller the value of the sharing function. Sharing degree is the sum of the sharing function values of the individuals in the population, and the individual fitness function value is modified by the value of sharing degree. Then:

$$S_i = \sum_{j=1}^{M} S(d_{ij}) \quad \left(i = 1, 2, \cdots, M\right) \tag{15}$$

where M denotes the number of individuals in the population and $S(d_{ij})$ denotes the value of the sharing function of individuals. After finding the sharing degree, the individual fitness value is corrected, and the correction formula can be expressed as:

$$F_i'\left(X\right) = \frac{F_i\left(X\right)}{S_i}\left(i = 1, 2, \cdots, M\right) \tag{16}$$

Since the individual genetic probability is mainly determined by the individual fitness function, by using the sharing degree to modify the individual fitness function, which in turn affects the genetic probability of the individual, maintains the diversity of the population, and creates an evolutionary environment of small habitats.

In this paper, the small habitat improvement genetic algorithm is used to solve the layout optimization problem of interior design, and its specific solution process is shown in Figure 3.

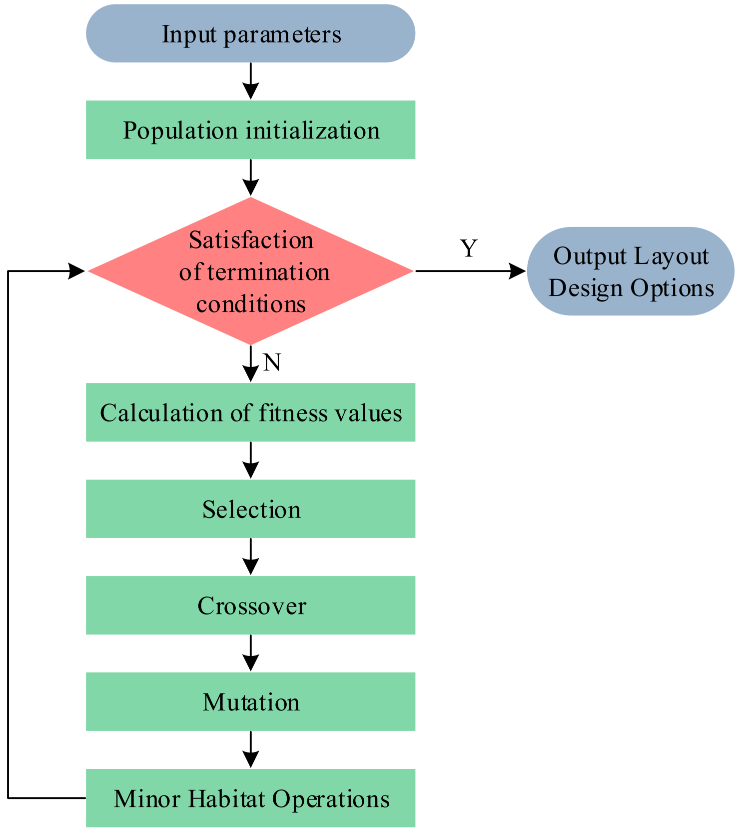


Figure 3: The solution process of interior design layout optimization

III. C. Architectural decoration style color matching

III. C. 1) Indoor Model Creation

After obtaining the layout optimization results of the interior design using the small habitat improvement genetic algorithm, the geometric features of the indoor space layout are then analyzed using Bayesian network. By setting the spatial coordinate system in the indoor environmental space, it is stipulated that the direction of the indoor entry door is parallel to the y-axis direction of the coordinate axis, the origin of the coordinate system is set as the minimum coordinate of the vertex of the indoor environmental space, and the x-axis and y-axis directions are the width and length of the indoor environmental space, respectively.

Firstly, the entrance position of the indoor environmental space is normalized to obtain the normalized entry door coordinates $\left(E_x, E_y\right)$ of the indoor environmental space, and the width and length of the indoor space are W and L, respectively, and then the normalized entry door coordinates are:

$$E_x = \frac{E_{x_0}}{W} \tag{17}$$

$$E_y = \frac{E_{y_0}}{L} \tag{18}$$

Let the area of the indoor environmental space be S, the ratio of the length to the width of the indoor environmental space be R, and the extension of the indoor environmental space be C. It is usually described by using the covariance matrix of the center point of the indoor rectangle in the x-axis and y-axis of the coordinate system, then the two-dimensional covariance matrix of the indoor environmental space can be expressed as:

$$C_{2\times 2}=\begin{bmatrix}\mathrm{cov}(x,x) & \mathrm{cov}(x,y)\\ \mathrm{cov}(y,x) & \mathrm{cov}(y,y)\end{bmatrix} \tag{19}$$

$$\mathrm{cov}\left(x,y\right)=\mathrm{cov}\left(y,x\right) \tag{20}$$

Analyzing the above two equations, the covariance matrix of the indoor environment space can be expressed as $\mathrm{cov}\left(x,x\right)$, $\mathrm{cov}(x,y)$ and $\mathrm{cov}\left(y,y\right)$. Assume that the geometric characteristics of the indoor environment space is F, denoted as:

$$F=\left(E_x,E_y,S,R,C\right) \tag{21}$$

Based on the geometric characteristics of the indoor environment space, the indoor environment space layout model is built by optimizing the indoor environment space layout attributes. Assume that the location coordinates of the indoor environment space are (x_p,y_p), denoted as:

$$x_p=\frac{x}{W} \tag{22}$$

$$y_p=\frac{y}{L} \tag{23}$$

where x denotes the coordinate value of the location point of the indoor functional area in the x-axis of the indoor environmental space layout coordinate system, and y denotes the coordinate value of the location point of the indoor functional area in the y-axis of the indoor environmental space layout coordinate system, and the location coordinate attributes of the indoor environmental space, x_p and y_p, are usually taken in $[0,1]$. Suppose θ_p represents the orientation attribute of the indoor environmental space, denoted as:

$$\theta_p=\theta\cdot\frac{2}{\pi}+1 \tag{24}$$

where θ denotes the facing angle of the indoor functional area in the indoor environmental space. Assume that (l_p,w_p) denotes the scale of the indoor environmental space, denoted as:

$$l_p=\frac{l_y}{L} \tag{25}$$

$$w_p=\frac{l_x}{W} \tag{26}$$

where l_y denotes the length of the indoor functional area in the indoor environmental space and l_x denotes the width of the indoor functional area in the indoor environmental space.

III. C. 2) Color matching algorithm

We use a method based on IPSO algorithm and IVR to obtain the best color match, which is a human-computer interactive process to find the best color match.

First, a preliminary color matching scheme is generated, rendered and displayed in a virtual reality environment. Users can fully explore the virtual properties of the colors and provide feedback on their preference for the presented color matching scheme. At the same time, the sum of the two scores, visual harmony score and subjective preference, is fed back to the IPSO algorithm as the overall target value. The IPSO algorithm then generates a new color scheme based on the feedback and sends it to the VR interface for another iteration. It is worth emphasizing that once the color scheme is generated, the rendering of the 3D environment can be presented to the user in real time. The method proposed in this study is embedded in the game engine Unity through the C# language, and when the IPSO algorithm generates a new color scheme, the game engine retrieves the corresponding color parameters and textures from the database and renders the interior decoration model in real time. The iterative process continues until the IPSO algorithm reaches one of the termination criteria, e.g., completing a specified number of iterations without further improvement in user satisfaction.

In order to enhance the user experience in color product selection, we developed an optimization model for interior architectural decorative color matching in IVR environment, which maximizes user satisfaction with color matching aesthetics and helps users and designers to explore design options efficiently. The objective function proposed in this study is expressed as:

$$Objective\left(I_x\right)=\underset{I_x}{\arg\max}\left\{\theta_1 \cdot b\left(I_x\right)+\theta_2 \cdot u\left(I_x\right)\right\} \tag{27}$$

where I_x represents the xth material matching scheme consisting of 5T decision variables, and $5T$ refers to the product of each material product based on its 5 aesthetic characteristic parameters (brightness of color, spectral position of the color between red and green, spectral position of the color between yellow and blue, glossiness, and metallicity) and the number of material types T in interior design, the The total number of decision variables obtained. The θ_1 and θ_2 are the weights of the sub-objectives of visual harmony and passenger preference, respectively.

The IPSO based on small populations employs three methods, namely mutation operation, DE-acceleration algorithm, and migration operation, to enhance the diversity of small population search, accelerate the convergence of the operation process, and avoid the crowded diversity of the population that causes it to fail to reach the desired level of diversity. In addition, this study employs a Euclidean distance-based approach to facilitate the convergence of the optimization and measures the distance between the current color scheme and the historical schemes rated by the users in order to predict the unrated schemes without additional user interaction.

III. C. 3) Light rendering processing

After the completion of the indoor color mixing and matching, in order to achieve a better optimization of indoor color, choose to make further light rendering treatment on this basis. Indoor color matching is usually divided into three parts, namely, auxiliary lighting in the interior space, the main light lighting and background lighting. By the Boolean principle is easy to know, in these three types of light, the main light for the whole indoor home is more critical to the impact of the main lighting is often able to determine the tone of the brightness of the indoor space as well as the lighting atmosphere of the space. Therefore, in the light rendering processing part, mainly on the main light for the interior color rendering research.

By calculating the light refraction, light reflection and direct radiant brightness corresponding to the main indoor light, the main light rendering of the whole indoor scene can be realized. The corresponding formula of radiant brightness is as follows:

$$W\left(x,\rho\right)=W^s\left(x,\rho\right)+\int_\phi W\left(\vartheta\left(\left(x,\rho'\right),\rho'\right)\cos\beta' f_r\left(x,\rho'\right),\rho\right)d\rho' \tag{28}$$

where $W^s(x,\rho)$ denotes the direct radiation from the same point in the same direction, and $W(x,\rho)$ denotes the radiance corresponding to a specific point x along the direction of ρ in indoor space, $\int_\phi W\left(\vartheta\left(\left(x,\rho'\right),\rho'\right)\cos\beta' f_r\left(x,\rho'\right),\rho\right)d\rho'$ describes the indirect light corresponding to light refraction and light reflection.

At the same time, the corresponding lighting array is set up in the corresponding lighting rendering model, and the specific requirement is to keep the same distance with the floodlight. Define u as the distance from the floodlight to the plane, k as the radius of the attenuation distance of the long-distance light, and g as the distance of the corresponding display light. If there exists a line segment n perpendicular to the light source on the x-axis, and the corresponding number of light sources is m, then the corresponding light brightness can be expressed as:

$$W\left(x_j\right)=\sum_{j=1}^{m}W_j\left(x_j,\rho_j\right) \tag{29}$$

In summary, the simulation effect corresponding to indirect light is obtained to achieve the feeling of light with perfect color brightness in interior design architectural decoration style.

IV. Interior design layout and decorative color optimization

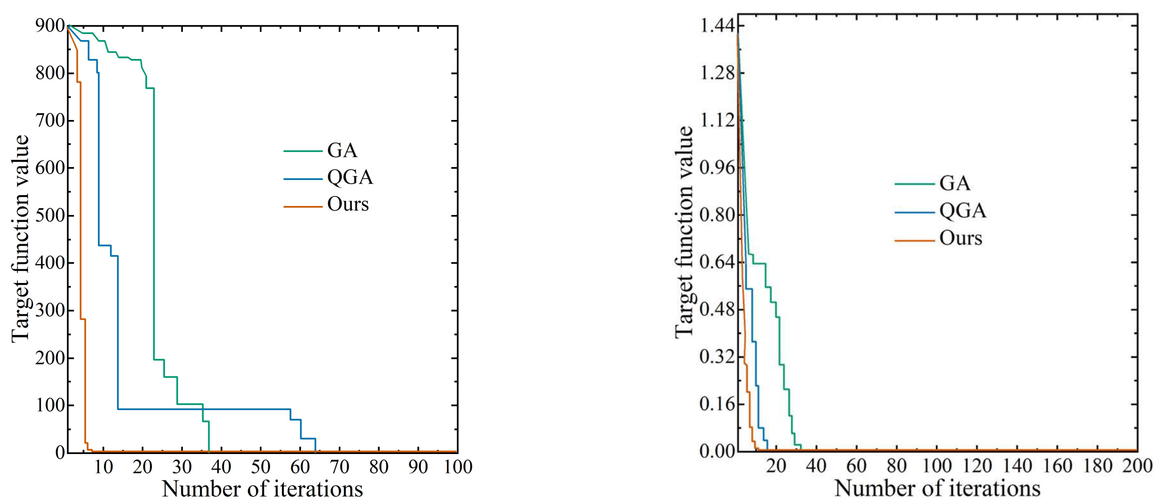
Interior design can meet the material requirements and spiritual requirements of people's daily life and work, can enhance the comfort of people's life, to provide people with a better spatial environment, therefore, people attach great importance to interior design. With the rapid development of social economy and the continuous improvement of people's living standards, people's demand for interior design is getting higher and higher. In interior design, the use of color has a pivotal position, because the appropriate color matching can bring a new visual feeling and emotional experience for the interior space.

IV. A. Simulation of interior design layout optimization

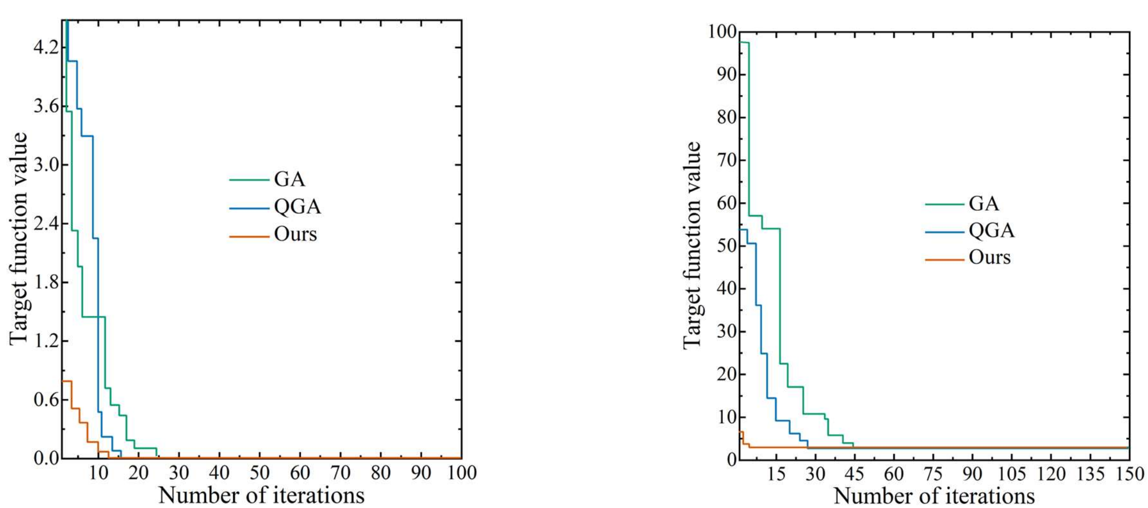
IV. A. 1) Algorithm Optimization Performance

In order to verify the effectiveness of the genetic algorithm proposed in this paper for small habitat improvement, several commonly used continuous functions are selected to evaluate the performance of the algorithm in solving multi-objective optimization problems, and the GA algorithm and the Quantum Genetic Algorithm (QGA) are chosen as comparisons. The three algorithms are implemented using MATLAB software and the iterations are observed up to the point where convergence is completed to assess the optimization seeking ability. Each function was run 100 times to find the optimal solution, the number of iterations to reach convergence, and the average running time. The results of the optimization curves for one randomly selected run are shown in Fig. 4, where Figs. 4(a)~(d) show the iteration results for the Schaffer, Sphere, DeJong, and Goldstein functions, respectively. Table 1 shows the performance comparison results of the algorithms with different functions.

Through 100 times of experimental analysis and evolution curve display, we can find that under the four optimization functions, the genetic algorithm improved by this paper using Sphere is better than the traditional genetic algorithm and ordinary quantum genetic algorithm in terms of convergence speed as well as the adaptability of the optimal solution. However, it is slightly higher than the ordinary quantum genetic algorithm in terms of time cost, which is due to the inclusion of the small habitat co-evolutionary strategy to update the population, occupying a certain algorithmic time cost. It is not difficult to conclude that the improved algorithm proposed in this paper has practical effects and outperforms the traditional methods in solving the problem of dealing with multi-objective optimization.



(a) Schaffer (b) Sphere



(c) DeJong (d) Goldstein

Figure 4: Convergence optimization of three algorithms

Table 1: Comparative analysis of algorithm performance

Functions	Algorithm	Optimal value	Means	Average frequency	Average time /s
Schaffer	GA	10948	12251.4	60	0.64
	QGA	10594	12821.5	35	0.45
	Ours	10611	11028.9	12	0.96
Sphere	GA	10753	12406.5	45	0.65
	QGA	10689	12867.9	14	0.38
	Ours	10632	10986.3	8	0.72
DeJong	GA	10867	11687.6	22	0.64
	QGA	10752	12065.2	14	0.51
	Ours	10691	11241.8	8	0.83
Goldstein	GA	10856	11476.3	50	0.45
	QGA	10714	12115.7	30	0.37
	Ours	10663	10693.1	6	0.51

IV. A. 2) Interior design optimization

In this paper, the small habitat improvement genetic algorithm is proposed to be used in the layout optimization problem solving of interior design, which simplifies the interior design layout problem into a two-dimensional layout optimization problem. In a rectangular interior layout space, five furniture modules, namely, double bed, bathroom, sofa, writing desk and closet module, are laid out. In order to make the effectiveness of each furniture module effective, its plan dimensions are synthesized from the static space and the required gesture space of each furniture module.

Based on the solution process of the small habitat improvement genetic algorithm given in the previous section, the relevant algorithm is compiled under the MATLAB software environment, and in the simulation calculation, combined with the rasterized space to be laid out, the dimensions of the furniture modules are all calculated with the raster dimensions in the process of the optimization of the interior design layout.

Set the simulation parameters of the small habitat improvement genetic algorithm, in which the cluster size is 1000, the number of iterations is set to 500, and the crossover probability and variance probability are 0.45 and 0.15, respectively.The simulation calculation is realized by MATLAB autonomous programming, and the results of the optimal layout of the indoor design are outputted in the form of matrix after the simulation optimization calculation. And AutoCAD is used to further translate into the plan layout diagram, and finally the optimal layout scheme of the interior design is obtained as shown in Figure 5.

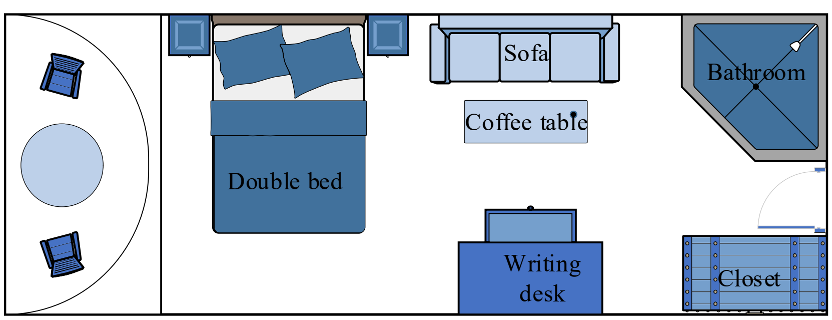


Figure 5: Optimal layout scheme of Interior design

In the establishment of the interior design layout optimization model, the furniture modules have been given the necessary gesture space required for human activities, so after using the small habitat improvement genetic algorithm to optimize the layout of the interior, it is only necessary to verify that the indoor flow line of the resulting optimal layout scheme meets the accessibility requirements. The indoor flow line of the indoor space should run from the entrance to the balcony door, and the specific verification process of the indoor flow line of the optimal layout scheme of the indoor design obtained from the simulation experiment is shown in Figure 6. In particular, according to the remaining free activity space in the scheme, a balcony door is configured on the balcony side that opens outward from the balcony room chamber to the balcony, and the width of its door diameter is consistent with the entrance of the balcony room. Then, a flow line running from the entrance door to the balcony door was drawn, which is complete, smooth and meets the interior accessibility requirements.

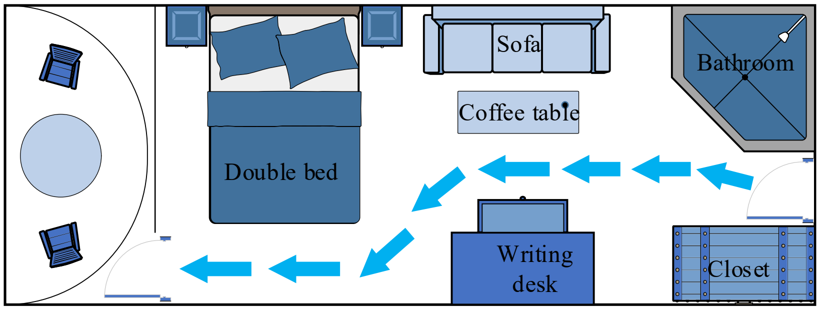


Figure 6: Indoor flow verification results

In summary, the optimal layout scheme for interior design obtained by layout optimization basically meets the layout requirements of the living space, and has high consistency with the layout examples of the existing living space, verifying the effectiveness of the intelligent layout optimization method for interior design proposed in this paper.

IV. B. Color verification of architectural decoration styles

IV. B. 1) Color matching performance

In order to verify the validity and superiority of the color matching algorithm proposed by the study, 3000 sets of interior design architectural decoration color images were collected and randomly assigned into 600 color mixing combinations containing five images to form a visual stimulus set. The study recruited 50 students with normal visual function and no color recognition disorder as volunteers to wear eye-tracking devices for the experiment, and calculated the average eye-movement response in each region. And the visual aesthetic parameters were calculated based on the visual behavioral data. Figure 7 shows the visual behavioral data and visual aesthetic parameters of some color mixing combinations.

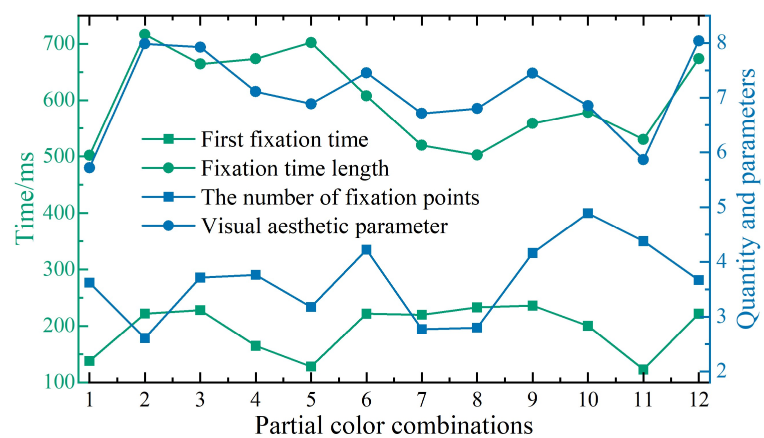


Figure 7: Visual behavior data and visual behavior parameters

As can be seen from the figure, the highest visual aesthetic parameter among the twelve color style matching combinations of interior design architectural decoration is 8.04, and the mean value is 7.07. 600 color mixing combinations of interior design architectural decoration styles are used as a training set to train the image translation model in the color matching algorithm, and the number of training rounds is 500. The study chooses the image translation model without integrating eye tracking technology and the professional designer team pairing as the comparison algorithm for exploring the proposed color matching algorithm for experiments, and invites 25 college students majoring in design as volunteers to make subjective evaluations of the color matching scheme. Figures 8 and 9 show the objective comparison results and subjective evaluation results, respectively.

As can be seen from Fig. 8, the average value of the minimum color difference of the color combinations of the interior architectural decorative styles obtained by the image translation model without integrating eye tracking technology is 0.258, while the average value of the normalized minimum color difference between the professional designer team and the color matching algorithm proposed in this paper is 0.202 and 0.171, respectively.Combined with the subjective evaluation results in Fig. 9, it can be seen that, the use of the image translation model without integrating eye tracking technology After the optimization and improvement of the extracted color matching scheme, the average score of the color characteristics of its interior architectural decoration style is 3.76. And after the team of professional designers matched the extracted colors in the interior design layout optimization model, their color style feature scores generally exceeded 4 points, with an average score of 4.13 points. Finally, after using the color matching algorithm designed in this paper to match the extracted colors, the scores were similar to those of the matching scheme designed by the professional designer team, with an average score of 4.11. It can be seen that under the existing interior design layout optimization model, applying the color matching algorithm to the optimization of architectural decoration color style characteristics can significantly improve the color expression effect of interior architectural decoration, and the quality of its color matching scheme can be further improved to approach the level of professional designers.

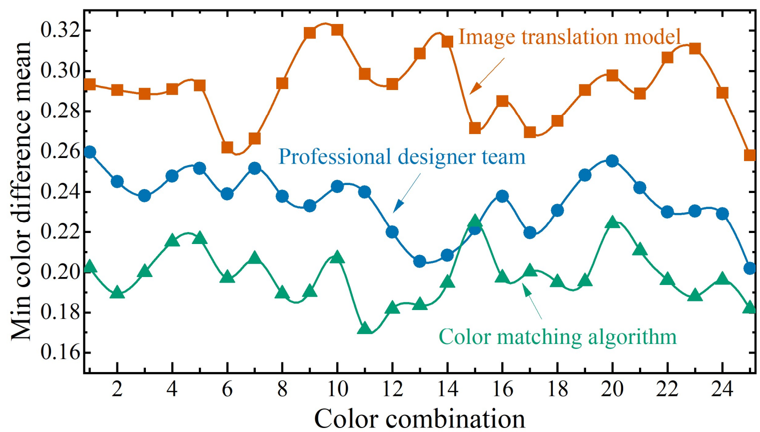


Figure 8: Objective evaluation result

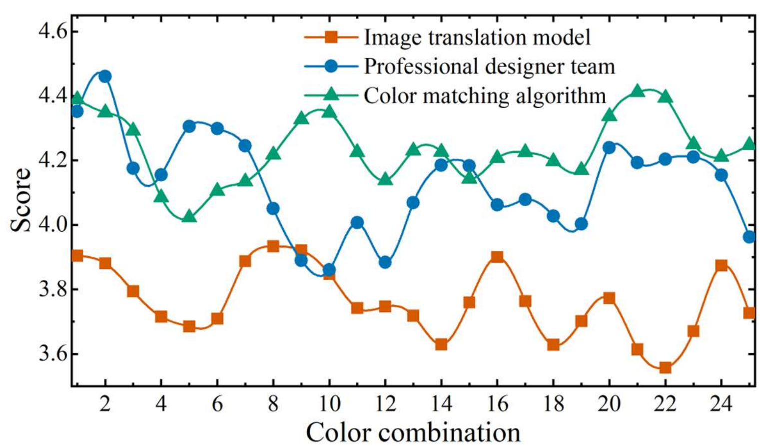


Figure 9: Subjective evaluation result

IV. B. 2) Color visual comfort

The purpose of optimizing the color style characteristics of interior design and architectural decoration is to create a more suitable color for the user's residence and better meet the user's physiological needs. In order to further analyze the impact of the optimization results obtained by the color matching algorithm given in this paper on the user's visual comfort, pupil diameter data was introduced to carry out a difference analysis on the basis of the eye movement experiments in the previous section.

In the 25 subjects selected, gender (male and female) as the intergroup variable, under the premise of the same hue as well as brightness, saturation (low, medium, high) as the intragroup variable, in order to verify the pupil diameter index, male and female groups in the three saturation conditions, the size of the pupil diameter of the experimental picture area of interest. Table 2 shows the mean values of pupil diameters for different genders at the three levels of saturation. As the saturation level increases, the pupil diameter gradually decreases, and the trend is basically the same for the male and female groups.

Table 2: Mean pupil diameter

Sex	Saturation	Means (mm)	SD
Male	Low	3.463	0.315
	Medium	2.872	0.226
	High	2.448	0.164
Female	Low	3.218	0.219
	Medium	2.649	0.208
	High	2.273	0.137

On this basis, a repeated measures ANOVA was carried out, and simple effects multiple comparisons were corrected for LSD. Table 3 shows the results of the ANOVA effects and multiple comparisons, and Table 4 shows the results of the ANOVA simple effects of pupil diameters of different genders at three levels of saturation.

Based on the data in Tables 3 and 4, the following results were obtained:

There was a significant main effect of gender (F=5.895, Sig.=0.019<0.05), with males being larger than females on the mean of pupil diameters for the three saturation conditions, Sig<0.05. There was a significant main effect of saturation (F=5.726, Sig.=0.005<0.01), and post hoc multiple comparisons showed that pupil diameters were significantly larger when gazing at the low-saturation pictures than the medium saturation and high saturation, both with Sig. less than 0.05, and the pupil diameter of those who gazed at the medium saturation pictures was significantly larger than that of the high saturation (Sig. < 0.05). The gender*saturation interaction effect was significant (F=4.938, Sig.=0.012<0.05). Simple effects analyses showed that in males, there was a significant two-by-two difference in pupil diameter across the three saturation conditions, with pupil diameter significantly larger than medium and high saturation when gazing at low-saturation pictures, both with Sig. less than 0.05, and significantly larger than high saturation when gazing at medium-saturation pictures, with Sig. <0.05. In females, there was a significant two-by-two difference in pupil diameter across the three saturation conditions, with Pupil diameter was significantly larger when gazing at low saturation pictures than at medium and high saturation, both Sig. less than 0.05, and significantly larger when gazing at medium saturation pictures than at high saturation, Sig. < 0.05.

Table 3: Variance analysis effect and multiple comparison results

Effect	Sum of squares	Mean square	*F*	Sig.
Sex	2.847	2.835	5.895	0.019
Saturation	6.726	3.427	5.726	0.005
Sex* Saturation	5.519	2.814	4.938	0.012
Contrast condition		Mean difference	Standard error	Sig.
Low - Medium		0.580	0.354	0.028
Low - High		0.980	0.382	0.000
Medium - High		0.400	0.296	0.043
Male - Female		0.214	0.187	0.019

Table 4: Analysis of variance simple effect results

Saturation	Horizontal contrast	Mean difference	Standard error	Sig.
Male	Low - Medium	0.591	0.351	0.015
	Low - High	1.015	0.428	0.000
	Medium - High	0.424	0.279	0.021
Female	Low - Medium	0.569	0.361	0.028
	Low - High	0.945	0.384	0.005
	Medium - High	0.376	0.275	0.043

In summary, it can be seen that in the interior design of architectural decoration color style features, high saturation color features will cause the user's pupil diameter to narrow, fully attract the user's eyes, to a certain extent, can meet the user's visual comfort. That is, the interior design of architectural decoration color style features need to fully optimize the expression of color features in order to meet the visual needs of users, to better ensure that the spiritual needs of users can be comforted.

V. Conclusion

The article proposes an interior design layout optimization model, solves the optimal interior design layout scheme by using the small habitat improvement genetic algorithm, then combines the IPSO algorithm with the optimization results for the architectural decorative style color matching, and designs the light effect rendering processing method, so as to enhance the architectural decorative color expression of interior design. Simulation results show that the small habitat improvement genetic algorithm can obtain the optimal interior design layout optimization scheme, which can meet the requirements of indoor accessibility. The average value of the minimum color difference of IPSO algorithm combined with light effect rendering is only 0.171, and the overall architectural decoration color style feature score is only 0.02 points different from that of the professional designer team. Relying on the algorithm to obtain the interior design architectural decoration color style features can fully meet the visual comfort of the user, and there is the same impact on users of different genders. Therefore, making full use of the advantages of the algorithm can realize the layout optimization of interior design, and can also give the color style of interior architectural decoration more diversified.

The research in this paper has achieved certain results, but also has certain shortcomings. For example, only the layout optimization of interior design is considered, and the layout positioning accuracy under the influence of different furniture is not further explored. Such as indoor architectural decoration styles of diverse characteristics only dissected the color characteristics of the change situation. In the subsequent research, we will further explore the optimization path of interior design under the characteristics of different architectural decorative styles, in order to provide conditions to meet the material and spiritual needs of modern users.

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