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The innovative model of interior design under the integration of housing functional zoning and environmental art

Yichen Li[1,*], Feifei Liu[1] and Ze Wang[1]
[1] Beijing City University, Beijing, 101309, China
Corresponding authors: (e-mail: 18639244965@163.com).

Abstract Integration of environmental art design concepts for housing interior space design, improve space utilization, so that the interior space is effectively utilized to form a large space sensory experience. In order to enhance the effective integration of housing functional zoning and environmental art design in the interior design process, this paper proposes an interior design model based on BIM technology. The indoor floor plan design of housing is regarded as a multi-objective optimization problem through floor plan layout constraints, and the WFC algorithm is used to establish an adaptive evolutionary generation algorithm of indoor floor plan layout for floor plan layout solving. Based on the simulation and example verification, the time consumption of this paper's algorithm grows slowly under the increasing sum of the number of rooms and design constraints, but the time consumption of this paper's algorithm is about 87.5% compared with SAA algorithm after the sum exceeds 50. And the use of WFC algorithm can realize the generation of the floor plan layout of different housing types, and the user's satisfaction with the functional zones such as dining room, master bedroom, kitchen, master bathroom and balcony is relatively good, and its score is between 0.65 and 1.0 points. Therefore, the application of BIM technology in interior design can effectively improve the efficiency of interior design, realize the effective integration of housing functional zoning and environmental art design, and fully satisfy the diversified needs of residents for housing functions.

Index Terms BIM technology, WFC algorithm, plan layout constraints, housing functional zoning, interior design

I. Introduction

In recent years, people's living standards have been improving, so people have unprecedented changes in the concept of life, the quality of life and taste for life has new requirements. Therefore, people's interior space design is also constantly updated and progress. Designers for interior decoration design how to innovate has become a hot topic. Many designers lack the concept of environmental awareness, and the understanding of interior decoration, architectural design and management mechanism is not perfect, there are also many problems in the creation of interior design [1], [2].

Interior design is a comprehensive discipline that integrates art and science, and is committed to creating comfortable, beautiful and functional interior spaces, so the constant pursuit of innovation and breakthroughs is the inevitable trend of its development. Interior design should not pursue the designer's personal style, to learn from the public taste, do not make the design passive, or the design of the whole will show pale and powerless. Designers should have a sense of innovation, independent play ingenuity, to keep pace with the times using different methods of style to create a different style of home. And this kind of creation can be natural elements, science and technology, history and culture into the interior design, and in consideration of the user's comfort, sensory and aesthetic and other appropriate to the indoor space partition and the integration of environmental art, only then can get rid of the traditional design concepts, to realize the innovation of interior design in the ever-changing society and the needs of life, innovation in interior design will continue to promote the development of the industry, and to create a more comfortable, aesthetic and environmental art for the people. Create a more comfortable, beautiful and functional interior space [3]-[6].

Literature [7] examined the use of artwork in interior design, noting that using artwork in interior design is a more complex process. Artwork plays an important role in interiors by displaying certain visual forms and creating a harmonious and aesthetic living space. Literature [8] highlights the fact that in recent years interior designers have gradually become aware of the importance of innovation and development, which has led to a phenomenon characterized by new design technological innovations. It is pointed out that most of the research in the field of interior design is aimed at realizing the functionality and aesthetics of interior spaces. The role of the products of formal innovations in interior design is also proposed with the aim of informing applications and experts in this field.

Literature [9] reveals the importance of interior design as an innovation in the hotel industry. Reports of tourists' experiences with hotel design were analyzed in order to understand the innovation path of hotel management. Based on the analysis of tourists' review data, it reveals that the interior design of hotels largely affects travelers' rest and comfort, and the tourists' experience reports play an important role in the interior design of hotels. Literature [10] introduces a new interior design innovation system based on big data and virtual reality technology. Based on the opportunities and challenges facing interior design, innovative solutions are proposed in terms of constructing virtual architectural space using virtual reality technology. The results indicated that the innovative system can solve the problems of traditional interior design methods. Literature [11] describes an eco-innovation approach to interior design, and through a study of relevant experts, it is shown that eco-creativity supports teams to share a common vision of interior design and generates several original joint workspace concepts. Literature [12] examined the innovation path of architectural interior design in terms of digital design and sustainability. It also created a digital interior design framework that integrates technologies such as artificial intelligence and the Internet of Things. The results revealed that the framework can improve design efficiency and spatial performance, and promote collaborative optimization and sustainable development of the design process. Literature [13] illustrated the application of regional culture in interior design. It is pointed out that regional culture is closely related to interior design, regional culture provides rich materials and inspiration for interior design, and design concepts promote the innovative application of regional culture. Literature [14] aims to contribute to a larger footprint of interior design in social innovation programs. A study of the literature related to social innovation landscapes, methods and socially responsible design was conducted using an exploratory nature. A conceptual framework for integrating social innovation into interior design is proposed. Literature [15] used case studies of different populations in order to discuss the artistic innovation of color psychology in interior art and innovation design. The feedback on the emotional expression and symbolism of color is indicated as its main innovation.

In this paper, an interior design model based on BIM technology is proposed, and the WFC algorithm is used to realize the adaptive evolution generation of the indoor layout of the housing functional partition under the support of BIM platform.

When designing the indoor space layout of housing, applying the concept of environmental art can enrich the visual sensation of the indoor space of the functional partition of housing, so that the space can be reasonably applied and the living experience of the living environment can be enhanced. On the basis of sorting out the environmental art and housing functional zoning, the article combines the specific requirements of environmental art design into housing functional interior design, and constructs a housing interior design model based on BIM technology. The layout constraints of the interior design of housing functional zoning constructs the multi-objective optimization problem of plane layout, and then introduces the WFC algorithm to design the adaptive evolution generation algorithm of plane space layout, so as to realize the optimization of the plane layout of interior design. Based on the above method, this paper carries out evolutionary comparison and example verification to explore new paths for realizing the integration of housing functional zoning and environmental art in interior design.

II. Interior design models integrating environmental art

Residential construction is closely related to thousands of families, and it involves the immediate interests of each resident. The planning and design of residential indoor functional zoning is ultimately to provide a good environment for people, so that they can better realize their various personal and social activities. Therefore, to adapt and satisfy the needs of people is the basic requirement of the planning and design of residential indoor functional zoning. The combination of housing indoor functional zoning and environmental art design, fully explore the environmental art characteristics of housing functional zoning, in order to make the housing indoor functional zoning more distinctive.

II. A.Functional zoning of housing and environmental art

II. A. 1) Functional zoning of housing

Interior design is a comprehensive discipline to shape the overall architectural space environment, it is under the overall guidance of the design ideas and the integration of the internal space of the building each other, inseparable from a whole, they have a close internal connection and external extension, both rely on each other, each other's influence. Interior design is the re-creation, extension and deepening of the internal space of the building, and is the necessary means for the personalized creation and rational development of the internal space of the building. The basic function of housing indoor living space is shown in Figure 1. The development of the current era makes people's pursuit of housing living space is no longer limited to the living room, more emphasis on interior design style and personalization.

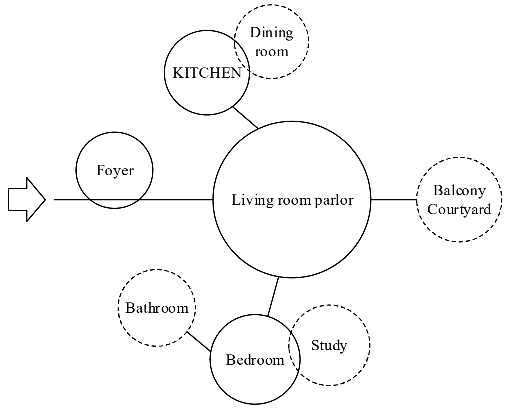


Figure 1: Basic function of residential space

Living space is the expression of family life and living, it can also be seen as a manifestation of social civilization. Living space interior design is simply the owner commissioned home furnishing designers and home furnishing construction personnel, the use of specific design concepts, comprehensive functional configuration, artistic space treatment, appropriate furniture and furnishing arrangement, artistic space treatment, reasonable economic input and correct construction technology and scientific construction organization, the owner of the original home space decoration.

II. A. 2) Environmental art design

The application and promotion of environmental art design in the field of architecture plays an important role in the development of modern architecture and the improvement of people's living environment quality. Environmental art design is a form of design that combines natural, humanistic, scientific and technological factors, aiming to create architectural spaces that are harmonized with the surrounding environment through spatial design, decoration, sculpture and other means. By applying a variety of artistic elements to the interior design and exterior design of the building, the designers make the whole construction project have high artistic and aesthetic value, and enhance the aesthetics and ornamental of the building.

Environmental art design takes people's living and working environment as the starting point, and uses a variety of artistic means to carry out creative processing of space layout, material, color, form and structure, etc., so as to achieve the purpose of improving the quality of space, strengthening the functionality of the building, creating a harmonious atmosphere between human beings and nature, digging out the emotional connotation of the architectural design, and improving people's living environment [16]. This design can realize the effective combination of art and architectural functions, and design a more comfortable, beautiful, connotative and emotionally enhancing architectural environment for people.

II. B. Design of interior environmental art for housing

II. B. 1) Interior design requirements

Housing functional zoning and environmental art combined to carry out interior design, the overall effect of its indoor environment is determined by all of its constituent elements, determined by the shape of the space, enclosing the interface, lighting setup, supporting facilities, etc., they all have an impact on the overall effect of the environment. Therefore, when carrying out interior design after the integration of housing functional zoning and environmental design, the overall need to pay attention to the following requirements:

(1) Reasonable space layout. To give full consideration to the rationalization of the spatial layout, to provide good ventilation and lighting environment for people's various spaces. In the design of the indoor environment should study and analyze the use of indoor space, environmental requirements, etc., combined with the spatial characteristics of each part of the space layout design and combination.

(2) Comfortable space atmosphere. To meet people's aesthetic standards, suitable for people's lifestyles, with the times, regional, cultural, etc., with the new era of aesthetic, appreciation standards for the design and construction of the indoor environment.

(3) Convenient living facilities. The arrangement and combination of living facilities should take into account people's living patterns, behavioral habits and design, and at the same time to consider the relationship between facilities and equipment and the scientific and reasonable design of pipelines, to avoid mutual interference and influence between facilities and equipment.

(4) Artistic indoor environment. Improvement of living standards makes people's spiritual and cultural requirements for housing indoor environment will be gradually strengthened, requiring the indoor environment with

artistic expression and infectious, with a strong sense of visual pleasure and cultural connotations, to enhance people's cultural and artistic enjoyment, to meet the people's spiritual pursuits.

II. B. 2) BIM forward design

Building Information Modeling (BIM) is a design mode that applies three-dimensional digital technology to the field of architectural design, realizing the transformation of computer-aided design from two-dimensional to three-dimensional.BIM technology can simulate the architectural design scheme, improve the quality of the design and efficiency, meet the needs of multi-disciplinary collaborative work, and effectively reduce the errors in the design work.BIM forward design refers to the use of BIM technology for preliminary preparatory work in the planning stage of the building, and then rely on BIM-related software to complete the scheme design, and simultaneously carry out performance simulation and analysis until construction, and later operation and maintenance. The use of BIM technology in the planning stage of the building to carry out the preliminary preparatory work, and then rely on BIM-related software to complete the program design, the relevant professionals in accordance with the program for structural, utility design, construction drawings, simultaneous performance simulation and analysis, until the construction, the latter part of the operation and maintenance stage are using BIM technology [17].

BIM technology has the characteristics of visualization, synergy, optimization, simulation, and chartability, etc. The use of BIM forward design can express the designer's intention in real time and clearly, which is convenient to carry out the work of program deduction, performance simulation and analysis. Part of the complicated and repetitive work can also be handed over to the computer for processing, which can greatly reduce the repetitive work and thus improve the quality and efficiency of program design.

II. B. 3) Interior design patterns

In order to better realize the effective integration of housing functional zoning and environmental art, and to innovate the housing interior design mode, this paper introduces the concept of BIM forward design, and optimizes the overall design process by using the digital design method of BIM [18]. BIM-based housing functional zoning and environmental art integration interior design process shown in Figure 2, which fully combines the design requirements of the traditional housing functional zoning, follow the environmental art design of deepening the principle of layer by layer, to realize the innovation of the interior design model.

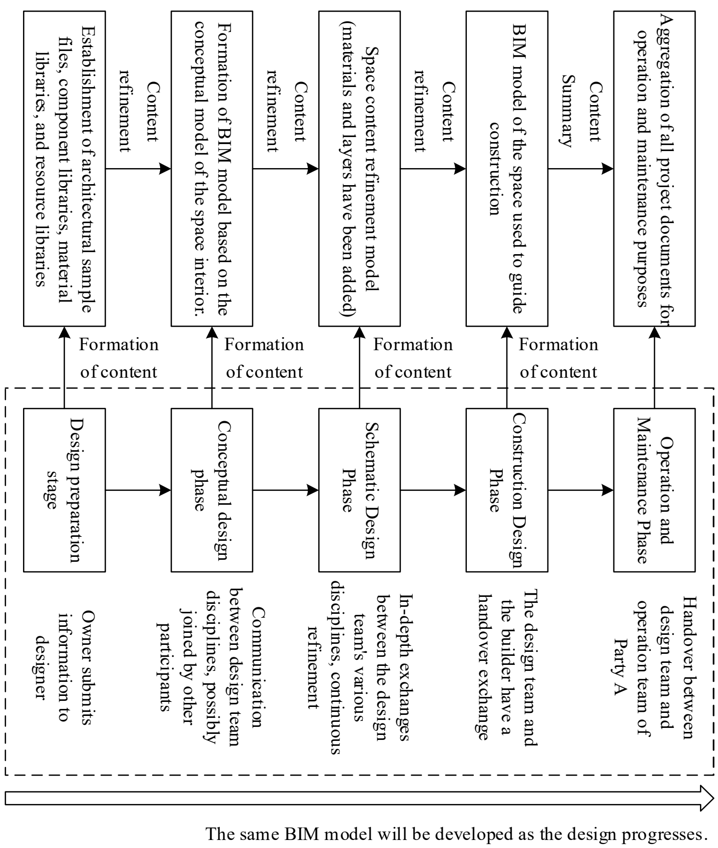


Figure 2: The overall design of housing interior design

The interior design process of housing functional zoning is divided into five phases: design preparation, concept design, scheme design, construction design, operation and maintenance, and BIM technology will be involved in the five design phases of interior space design, to optimize and update the digital design process, so as to further improve the efficiency of interior design.

In the design preparation stage, the interior design team needs to analyze and interpret the interior space design mission statement of the housing, review and analyze the BIM models of other professions, and build a collaborative design structure with other professions to make appropriate preparations. In the conceptual design stage, the BIM model can play its three-dimensional visualization advantages to assist in the design, the design team needs to discuss to determine the design concept of the office space design and preliminary ideas to carry out a certain design ideas sorting. And according to the actual design needs to establish the housing interior space BIM design of the relevant family library, in a timely manner, the necessary family file saved in the family library, easy to access. In the program deepening stage, the designer should summarize the relevant information of the previous design stage. And combine with the design elements related to the interior space such as functionality, visual effect and crowd demand to enrich the design details of the deepened model. In the construction design stage, the designer will establish the BIM housing interior construction design model based on the content of the previous stage, for the refinement of the model within the refinement of the model, such as specific decorative surface practices, node details, the layout of indoor furniture, and so on. In the operation and maintenance phase, Party A will analyze and sort out the design information based on the previous operation and maintenance requirements. It will be recorded into the simulation operation and maintenance system for checking, and if there is a lack of certain aspects of the design information, it will notify the designer in time to make up for it. When the design project is finished, it will be used for daily intelligent operation and maintenance.

III. Generation of floor plans for functional subdivisions of housing

Rapid economic development has accelerated the pace of urbanization, and people's needs for housing interior design are further changing. Relying on effective housing functional zoning design can help people better experience life, fully integrated with environmental art design can give housing interior design more artistic and personalized. How to effectively realize the integration of housing functional zoning and environmental art design, this paper aims to introduce BIM technology to realize. In the BIM technology-supported interior design, intelligent algorithms can be combined with the optimization of housing interior layout, so as to achieve the deep integration of housing functional zoning and environmental art design, and further enhance people's dual demand for housing function and environmental art.

III. A. Indoor Floor Plan Layout Constraints and Algorithms

III. A. 1) Indoor floor plan layout constraints

To ensure high-quality interior scene modeling, a collection of 3D models is not enough. Both the semantic function and layout structure of the indoor scene layout are indispensable. As the core and foundation of indoor scene modeling, indoor space layout design can be regarded as a constraint satisfaction problem. In indoor space layout, there are specific requirements in terms of positional relationships between different indoor objects, geometric dimensions, and specific functions to be realized. In indoor scene design, the constraints focused on are mainly:

(1) Boundary constraints. That is, in the indoor space layout, the boundary constraints of walls and buildings need to be considered, and the boundary constraints include indoor walls, floor slabs, doors, windows, and other inherent architectural elements.

(2) Bubble diagram constraints. Bubble diagram is usually composed of a group of interconnected bubbles (or circles), each bubble represents a functional area, and their size and location indicate the spatial dimensions of different functional areas. In plan layout design, the bubble diagram can be used to represent the relationship between indoor areas, such as spatial location, size, semantics and topological relationships.

(3) Load-bearing wall constraints. Load-bearing wall is the wall that supports the building's own structure and load, and is one of the basic structural components of the building. In the interior layout design, the location and number of load-bearing walls often directly affect the structural stability and safety of the building.

Interior design based on BIM modeling, with full consideration of the above spatial layout constraints, can transform the indoor layout design of housing into an optimization problem. Namely:

$$\begin{cases} \min_x f(x) \\ s.t. g_i(x) \le 0, i = 1, \cdots, m \\ x_j \in D_j, j = 1, \cdots, n \end{cases} \tag{1}$$

In this problem, the goal is to minimize the objective function $f(x)$, $g_i(x)$ represents the i rd constraint, x_j is the j th element of the decision variable x, which takes values in the domain of definition D_j, where n denotes the dimension of the decision variable x, and m denotes the number of constraints.

III. A. 2) Wave function collapse algorithm

The Wave Function Collapse (WFC) algorithm uses a meshed generation idea, where its basic generating units are slots, which are divided by a 3D mesh containing the spatial location of a primitive. The user needs to import the produced model prototype and develop constraint rules for each face orientation of the model prototype. During the generation process, the interior of the slot is continuously filled with primitives that satisfy the constraint rules to realize the procedural generation of the space [19].

Different primitives are connected based on the constraint rules, which are based on the cross-section shapes and functional roles of the model in each direction. The algorithm computes a combination of primitives that can become neighbors for each face orientation of a primitive based on the constraint rules. Slots are created at each location in the scene where primitives need to be generated, and each slot corresponds to a collection of optional primitives. The slots contain an entropy value that is positively correlated with the number of optional primitives, and the formula for finding the entropy value is expressed as:

$$H(x) = -\sum_{i=0}^{n-1} P(i)\log_2[P(i)] \tag{2}$$

where n is the number of optional primitives, $P(i)$ is the customized probability parameter of the i rd optional primitive, and $H(x)$ is the entropy value of the slot.

The main loop of WFC algorithm is based on three steps of collapse-constraint propagation-backtracking, and the specific algorithm is as follows:

(1) Collapse. Calculate the entropy values of all slots to be collapsed, and collapse the slot with the lowest entropy value. The final primitive selection probability of this slot can be expressed as:

$$R(i) = \frac{P(i)\log_2[P(i)]}{H(x)} * 100\% \tag{3}$$

where $R(i)$ represents the probability that the primitive is selected, $P(i)$ represents the probability parameter of the primitive, and $H(x)$ represents the entropy value of the slot where it is located.

(2) Constraint propagation. In the slot, each optional primitive corresponds to a group of potential neighbor primitives in each face orientation. When the optional primitives are deleted, the possibility of potential neighbor primitives appearing in the neighbor slots decreases or even disappears. The algorithm needs to delete the optional primitives that are not allowed to appear in each slot one by one with the help of the constraint propagation step, which ensures that the rule constraints brought about by the collapse are propagated to each slot.

(3) Backtracking. In the process of constraint propagation by the algorithm, it sometimes leads to the rule constraints of optional primitives of multiple neighboring slots contradicting each other in a certain piece of slot, and the number of optional primitives of that slot drops to 0, and no primitive can be generated. This is when the backtracking mechanism needs to be introduced. During the collapse-constraint propagation step for each slot, the deleted optional primitives for each slot are saved as history information. This history information is read and restored, and the collapse progress is regressed to the state before the most recent steps were performed, after which the collapse of this part of the slots is repeated.

III. B. Adaptive evolution of floor space layout

III. B. 1) Adaptive layout evolution

For a reasonable spatial layout planning scheme of a housing interior scene under boundary constraints, the subspace needs to fill the complete layout area, and the area containing the subspace is kept in a reasonably moderate proportion considering the utility and functionality of the space. In addition, in order to better serve the designer's design process, planning control is realized in the form of parametric scaling. In order to generate a reasonable spatial layout plan for the housing interior scene, the calculation results of the method should satisfy three points, i.e., the model needs to fit the constraint contours, the subspaces do not overlap each other, and the area of each sub-area accounts for a reasonable proportion of the complete area.

Based on the above objectives, the WFC algorithm defines three kinds of constraints, boundary fitting constraint L_b to induce the mesh primitives to evolve to fit the input constraint contours, mesh primitive overlap penalty constraint L_o to induce the different primitives in the mesh primitive group not to overlap, and deformation weight constraint L_w to control the degree of deformation of the mesh primitives. In addition, in order to solve the problem of co-computation of multiple mesh primitives in graphic design, differentiable rendering evolution is performed for each mesh primitive in the input model separately for the input mesh primitive group. Then:

$$L_b(m) = IOU\left(I_m^l, I\right) \tag{4}$$

$$L_o(m) = \frac{\sum_{m,n\in M, m\neq n}\left(I_m^l \cap I_n^l\right)}{\sum_{m,n\in M, m\neq n}\min\left(I_m^l, I_n^l\right)} \tag{5}$$

$$L_w(m) = \theta_m \tag{6}$$

where m denotes a mesh primitive in the mesh primitive group $M = \{m\}$, I_m^l denotes the rendered image corresponding to m, and in addition, I is the binary image of the input boundary constraints. The boundary fitting constraint L_b forces all primitives to fit the shape of the input boundary by calculating the IOU deformation through intersection and ratio, the mesh primitive overlap penalty constraint L_o avoids overlapping conflicts of the mesh primitives, and the user-specified deformation weight constraint $theta_m$ determines the degree of deformation of each mesh primitive to reflect the magnitude of the spatial division. In this case, the deformation weight constraints can be omitted from the input, and if the user does not specify the deformation weight constraints, the deformation weight constraints $theta_m$ for all mesh primitives will be defaulted to be equal to the initial size of the primitives. Since each mesh primitive is calculated individually during the computation process, the loss function for the complete computation is the sum of the mesh primitive loss functions, and the total loss function is defined as:

$$L(m) = \sum_{m\in M} b(m)L_w(m) + L_o(m) \tag{7}$$

In addition, since each grid primitive represents a sub-area in the spatial division, in order to generate reasonable division results, the evolved grid primitives can neither be too large nor too small, therefore, in the optimization process, the ratio of the area of the grid primitives to the total area $R\left(I_m^l\right)$ is constrained, and the total loss of the primitives m with the ratio of the area of the evolved primitives being less than 0.3 or the ratio of the area of the evolved primitives being more than 0.7 is adjusted, so as to achieve an evolutionary suppression of the evolutionary suppression of out-of-range grid primitives. Therefore, an additional penalty term is added to the total loss function, i.e., $L(m) + \beta\mu(m)$. In the implementation, a weight $\beta = 0.0005$ is set to balance the effect of the penalty term, $\mu(m)$ defined as follows:

$$\mu(m) = \begin{cases} 1 - R\left(I_m^l\right) & R\left(I_m^l\right) < 0.3 \\ 0 & 0.3 \le R\left(I_m^l\right) \le 0.7 \\ R\left(I_m^l\right) & R\left(I_m^l\right) > 0.7 \end{cases} \tag{8}$$

Based on the loss function L for iterative calculation to realize the boundary constraints under the housing space scene spatial layout evolution generation, the realization of the weight will be set to 0.0001 in order to balance the impact of the constraints between the optimal indoor floor plan layout generation effect.

III. B. 2) Layout evolution process

With BIM technology as the basic support for housing indoor layout evolution, this paper introduces the WFC algorithm for parameter adaptive evolution, in order to obtain the optimal interior design scheme, which can perfectly realize the deep integration of housing functional zoning and environmental art design.

Figure 3 shows the process of adaptive indoor layout evolution. The input data include indoor environmental art design objectives, architectural design parameters and value ranges, as well as climatic environment parameters and building thermal parameters. The WFC algorithm in the multi-objective optimization tool searches for feasible solutions based on the design parameters and value ranges, and evaluates the advantages and disadvantages of the feasible solutions through the performance objective function, so as to make the solution set converge to the nondominated solution frontier generation by generation. When the resulting set of non-dominated solutions meets the performance objective criteria, the optimization results are output.

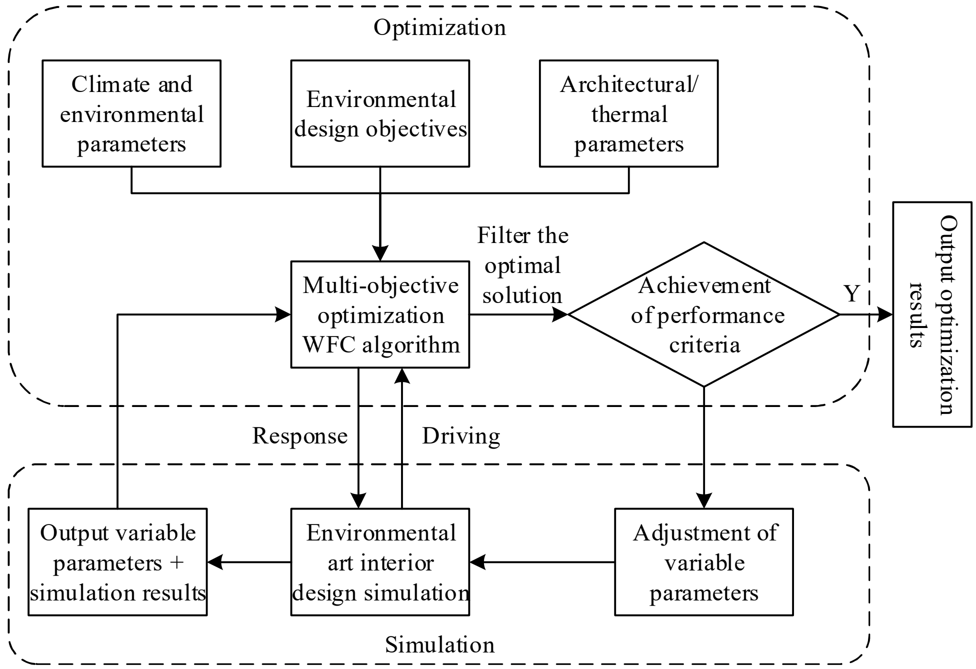


Figure 3: Adaptive process of indoor layout evolution

In this study, a multi-objective optimization platform with unified operation logic for housing interior designers was constructed using a BIM platform. The platform contains several program modules aimed at supporting interior design based on the integration of housing functional zoning and environmental art oriented interior design, and realizing the functions of interior layout simulation, scheme optimization and presentation. Through this platform, designers can more specifically combine the parametric modeling of housing interiors with environmental art design to obtain better interior design solutions.

IV. Validation and analysis of functional interior design of housing

Taking environmental art as the guide of housing functional zoning design and exploring innovative modes of interior design can help further enhance the optimization of housing interior design and better meet people's artistic and personalized needs for housing functions. This paper proposes a housing functional interior design model based on BIM technology, and carries out the adaptive evolution of indoor plan layout through WFC algorithm to provide a new research basis for the deep integration of housing functional zoning and environmental art, so as to meet people's growing artistic needs.

IV. A. Evolution of Interior Design Floor Plans

IV. A. 1) Comparison of layout evolution

For the housing interior design plan layout evolution algorithm designed based on the WFC algorithm in this paper, the Simulated Annealing Algorithm (SAA) is selected for comparative analysis in order to verify the effectiveness of the algorithm. For the SAA algorithm, rectangular rooms of the same size are first added to the defined area of the layout as the initial layout, and then one of the following operations is performed iteratively during the optimization process, one is to exchange the position of any two rooms, and the other is to move any wall, and the quality of the generated interior design layout is evaluated by calculating the energy E' of the current result. If the energy E' is less than the previous layout energy E then the generated layout is accepted as the current layout, otherwise the generated interior design layout is accepted with a probability of $\exp(-E'-E)/t$, where t is the temperature, which is gradually reduced in each iteration t. The algorithm terminates when E is less than a threshold value. Fig. 4 shows the performance comparison of the two algorithms at different complexities, defined as the sum of the number of rooms and the number of design constraints.

As can be seen from the figure, the running time of the SAA algorithm increases significantly as the complexity increases, while the running time of the interior design floor plan layout algorithm given in this paper increases more slowly overall. When the sum of the number of rooms and the number of design constraints exceeds 50, the SAA algorithm takes nearly 200s, while the algorithm in this paper only takes about 25s, which is about 87.5% lower than the SAA algorithm. Combined with the BIM visualization results, the indoor space layout results generated by this paper's algorithm are more in line with the optimization requirements, while the layout results generated by the SAA algorithm still fail to find a feasible solution that satisfies all the constraints. Moreover, there are several unfilled areas in the interior layout generated by the SAA algorithm, and some areas are too small to place reasonable furniture. Therefore, the WFC algorithm under parameter constraints designed in this paper can obtain better indoor layout results, which can satisfy the effective integration of functional zoning and environmental art in housing.

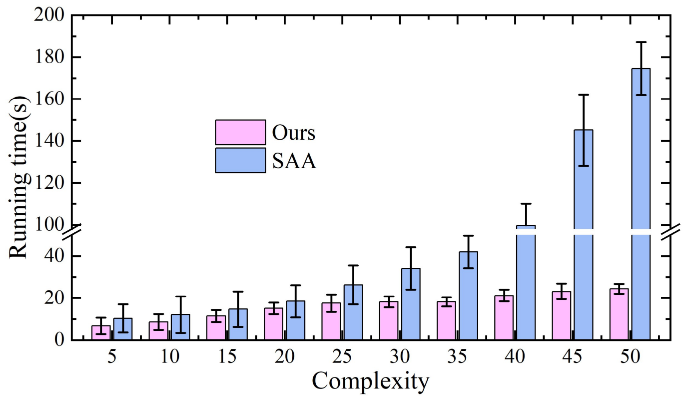
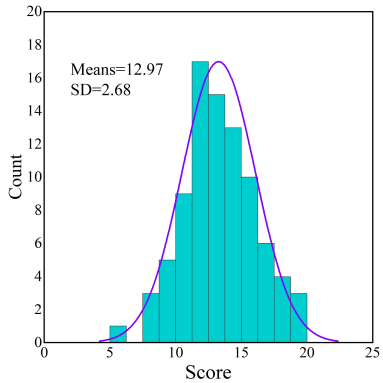


Figure 4: The performance of two algorithms in different complexity

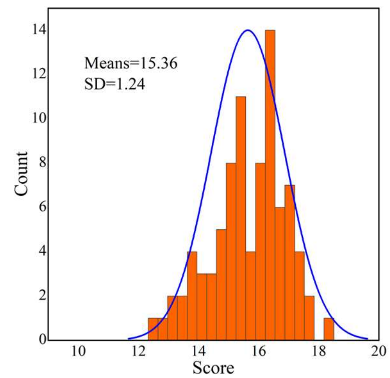
In addition, this paper also compares the WFC algorithm with other methods and manual design by means of user research, mainly ISSNet is chosen as a comparison, and Human denotes the manual designer. In the user research process, for a pair of interior layout floor plans with the same boundary, users are asked to make a mandatory comparison selection. In each comparison task, experimental participants were required to select the indoor layout floor plan from which they considered more reasonable. Based on experimental fairness considerations, a random sample of user research was selected from the generated results. Note that in each comparison task, the order in which the interior layout floor plans were placed was randomized. We designed three questionnaires for each of the three comparisons. Each questionnaire consisted of 20 forced-choice comparison questions, and for every 10 questions, we designed one question as a "warning test" that included a clearly irrational interior layout plan.

Participants were divided into two categories: general users and designers specializing in interior design. If a participant did not achieve 100% accuracy in the vigilance test, we excluded that participant's experimental data. For each participant, we recorded the number of choices to utilize our method to generate layout floor plans, N. Fig. 5 shows the mean and standard deviation distribution of N in the user study, where Figs. 5(a)~(f) show the average scores of general users and designers under ISSNet algorithm, WFC algorithm, and manual design generation, respectively.

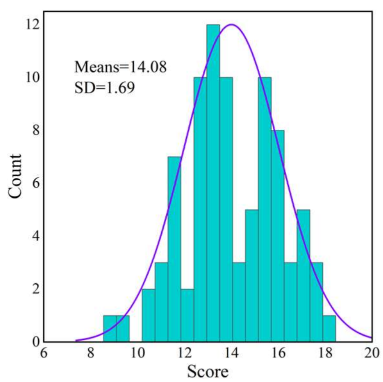
Based on the scores of different types of users in the figure, the interior design results generated by the WFC algorithm designed in this paper have scores of 14.08 and 16.23 on ordinary users and designers, respectively, while the score of manual design on ordinary users is 13.75, and the score of this paper differs from it by only 2.4%. This indicates that this paper utilizes the WFC algorithm for floor plan layout optimization in interior design, which is comparable to human interior design thinking and significantly higher than the ISSNet algorithm. In addition, it is noted that the score of ordinary users in the manual design is significantly higher than that of designers by 2.37 points, which is due to the fact that designers usually focus on the details of the interior floor plan layout, such as the orientation and dimensions of the rooms, while ordinary users usually judge the reasonableness of the layout design based on their personal preferences. The method designed in this paper can better explore the detail changes under different indoor spatial layouts, so the overall score is significantly higher than that of the comparison method and the manual design results, which can provide support for the realization of the effective integration of housing functional zoning and environmental art in the interior design layout scheme.



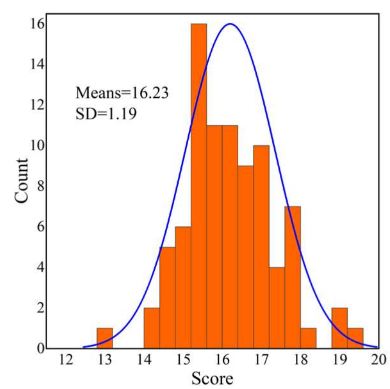
(a) ISSNet-Users



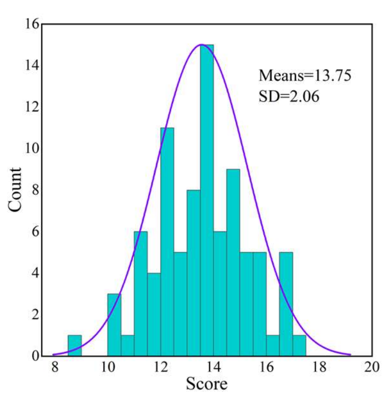
(b) ISSNet-Designers



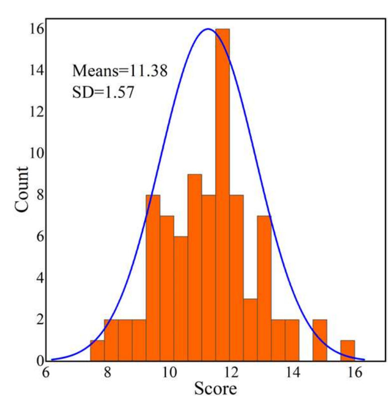
(c) WFC-Users



(d) WFC-Designers



(e) Human-Users



(f) Human-Designers

Figure 5: User research results

IV. A. 2) Intensity of information interaction

With the help of BIM technology to carry out housing interior design, its purpose is to further optimize the housing interior design process between the various design processes more efficient interaction, improve the integration of housing functional zoning and environmental art. Based on the adaptive interior layout design, the results of housing functional zoning and environmental art are more in line with people's needs. As a result, this paper compares the information interaction intensity between the optimized housing interior design processes with BIM technical support, and obtains the relationship between the information output and feedback intensity of different design processes as shown in Figure 6. Where T1~T18 indicates the specific design operations included in the four-step process of housing interior.

Compared with the traditional interior design process, the number of information interaction points between each design process based on BIM technical support is reduced by 59.41 times, and the intensity of information output and information feedback of the remaining information interaction points are changed. The sum of information interaction strength is 462.12 times, of which the number of information outputs totals 373.91 times and the number of information feedbacks totals 88.21 times. In the information output strength relationship, the number of strong ties was 164.28, the number of medium ties was 125.94, and the number of low strength ties was 83.69. In the feedback strength of information, the number of strong contacts is 42.95, the number of medium contacts is 34.17, and the number of low intensity contacts is 11.09. Such an information interaction strength relationship means that the optimized housing interior design process strengthens the co-ordination between various design elements, and from systematic considerations, puts the design process with high information feedback strength in front of the early stage of the design process, so that there are fewer strong contacts in the later stage of the design process, in order to achieve the purpose of reducing the rework that can easily be caused due to the high feedback strength between the elements of the design process in the later stage. It can also be seen from the optimized information strength relationship that in the pre-design stage, the information output strength of the design process becomes stronger, while the information feedback strength becomes stronger in the middle of the design process, with the most coupling tasks, and as for the later stage of the design process, the information output and feedback strength are weakened.

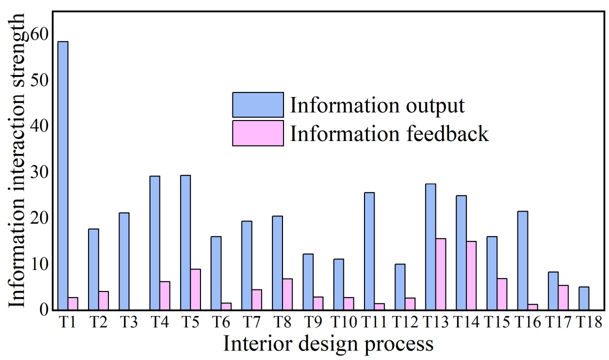


Figure 6: Information interaction strength of interior design process

IV. B. Household Floor Plan Design and Satisfaction

IV. B. 1) Household floor plan

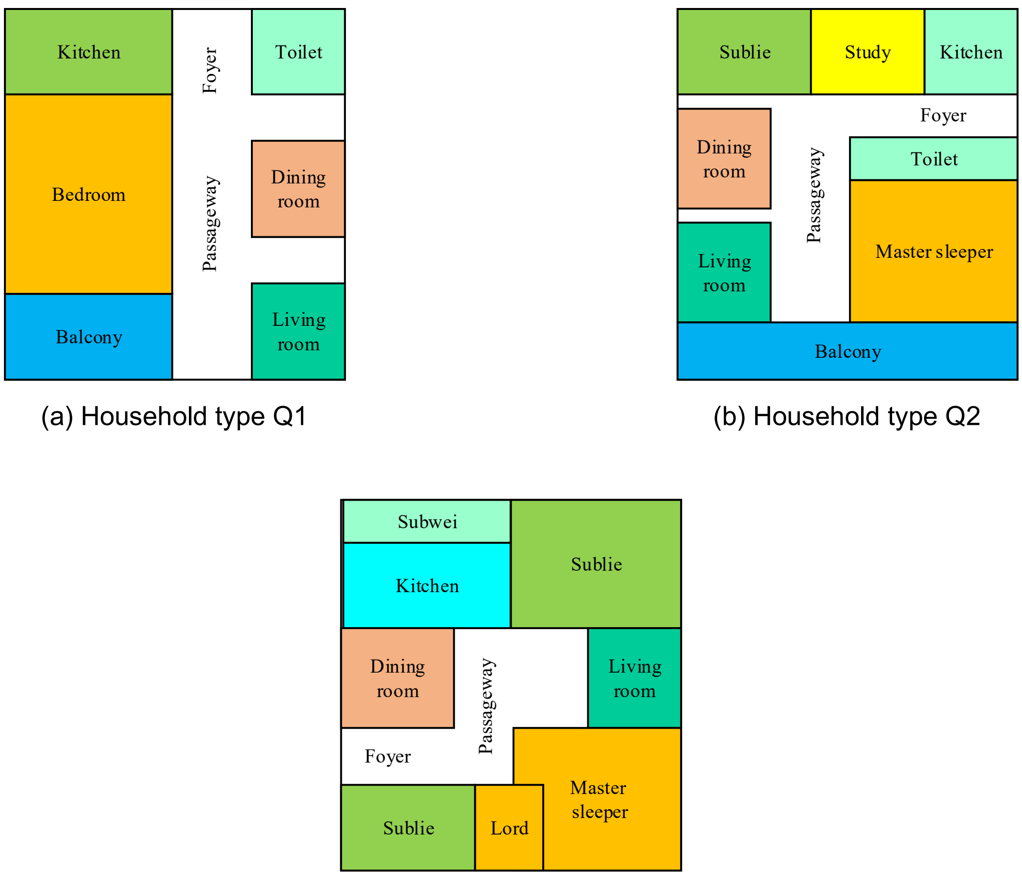
According to the contour and functional layout of the house type derived from the WFC algorithm, the floor plan design of the housing type is carried out. Because the regularity of the outline of the house type will have a great impact on the adaptability of the indoor space of the building, and the building unit plan composed of the regular building house type plan will also present a regular pattern, so that the shape factor of the building will be lower, which is conducive to building energy saving, reduce the heating energy consumption of the building, and be friendly to the environment. In addition, from the economic point of view, the regular house plan is also conducive to building construction, accelerate the construction speed of the building, reduce the total construction cost. At the same time, the regular floor plan is also suitable for the industrialization of the building, suitable for the modular construction of building components factory construction. Therefore, in the design of house type plan, this paper regularizes the outline of the house type, and uses the WFC algorithm designed in the previous section combined with BIM technology to obtain three house types with different area sizes, which are 40m² house type Q1, 80m² house type Q2 and 100m² house type Q3, and the layout of the three types of house types is shown in Fig. 7.

House type Q1 is a rectangular plan with a width of 5m and a depth of 8m, with a neat outline and no load-bearing walls, so it can be used as a lightweight partition wall or other flexible elements to freely divide the interior space, which provides a high degree of flexibility. The initial floor plan is designed as a one-bedroom apartment with single-sided lighting, with a bedroom, a living room, a dining room, a kitchen, a bathroom, and a multi-functional space, which can be used as a living and leisure space as well as a study and work space. At a later stage, according to the needs of the family, flexible elements can be utilized to redistribute the functional space or increase the living space by combining and merging the house types to meet the diversified needs brought about by the changes in the life cycle of the family.

House type Q2 is a rectangular house type with a face of 8m and a depth of 10m, with a regular outline, north-south ventilation, no load-bearing walls, and flexible elements such as lightweight partition walls and changeable furniture can be used to freely divide the indoor space, which is highly adaptable. The initial house type is designed as a two-bedroom house with two bedrooms, a study, a living room, a dining room, a balcony, a kitchen and a bathroom. Later on, according to the needs of the family, the functional space can be re-divided or combined and merged to increase the living space to meet the diversified needs brought about by the changes in the family's life cycle.

House type Q3 is a rectangular plan with a width of 8m and a depth of 12.5m, with a regular outline, north-south ventilation, and a large interior space, which can be freely divided into indoor spaces with flexible elements such as light partition walls and changeable furniture, and is highly adaptable. The initial floor plan is designed as a three-bedroom house with three bedrooms, a study, a living room, a dining room, a balcony, a kitchen and two bathrooms. At a later stage, according to the needs of the family, the functional space of the interior can be re-divided or the combination and merger of house types can be used to increase the living space to meet the diversified needs brought by the changes in the family's life cycle.

In summary, the use of the WFC algorithm designed in this paper combined with BIM technology can realize the construction of an innovative model for housing interior design, and based on this model can better realize the design of functional zoning of housing, and again based on the combination of environmental art design can better meet the user's needs for artistic and personalized housing interior design.



(a) Household type Q1 (b) Household type Q2

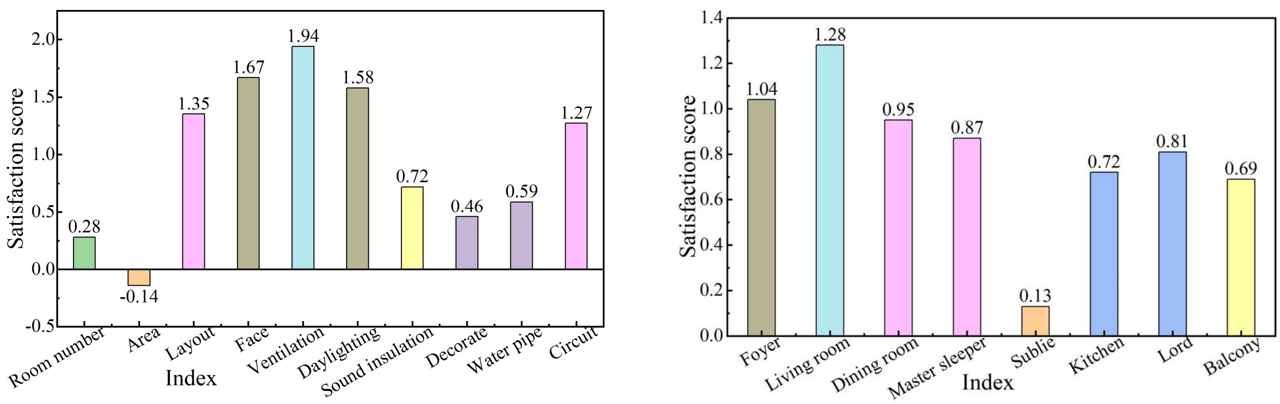
(c) Household type Q3

Figure 7: Three types of flat layout

IV. B. 2) Household satisfaction

In order to further analyze the practical application effect of the interior design innovation model proposed in this paper, this paper selects a city's public rental housing construction project as the object, using this paper's method of household planning, assisting tenants to carry out the interior design, and drawing the current situation of the use of housing sets, housing performance and functional space satisfaction research. Households are invited to use the various spaces and the performance of the housing research questionnaire scoring, from low to high in the order of -3 ~ +3, i.e., very dissatisfied to very satisfied. A total of 100 valid questionnaires were distributed, and 94 questionnaires were valid. After organizing the acquired data, the satisfaction situation of the residents was obtained as shown in Fig. 8, where Fig. 8(a)~(b) shows the satisfaction situation of the comprehensive performance of the housing and each functional space, respectively.

For the comprehensive satisfaction research of housing performance, it shows that tenants' satisfaction with the layout, orientation, ventilation, lighting, and electric circuit of the housing is relatively high, with scores of more than 1, followed by sound insulation and plumbing, with scores between 0.5 and 1.0, and the satisfaction with the number of rooms and decorations is average, with scores between about 0 and 0.5, and the lowest-scoring item is the area -0.14, which shows that the area is the safeguarded housing's greatest constraint. In the evaluation of the satisfaction of each functional space of the residence, the satisfaction score of the functional space of the foyer and the living room is 1.04 and 1.28 respectively, but there are 6 indicators whose satisfaction score does not exceed 1, which fully explains that the overall satisfaction of each functional space is general in public rental housing. In comparison, satisfaction with the dining room, master bedroom, kitchen, master bathroom and balcony is relatively good, with scores ranging from 0.65 to 1.0, and the lowest score is for the second bedroom, with only 0.13, which indicates that the least satisfactory space among all functional rooms for tenants is the second bedroom. In summary, in carrying out the integration of housing functional zoning and environmental art in interior design, further consideration needs to be given to the distribution of the design of the second bedroom to provide support for improving tenant satisfaction.



(a) Comprehensive housing energy

(b) Housing function space

Figure 8: Satisfaction of residents

V. Conclusion

This paper proposes an interior design model based on BIM technology, which aims to integrate housing functional zoning and environmental art design to further optimize the housing interior design, and proposes an adaptive evolution method of interior plan layout based on WFC algorithm. For the effectiveness of the above method, this paper carries out a validation analysis. When the sum of the number of rooms and the number of design constraints exceeds 50, the algorithm in this paper only takes about 25s, which is 87.5% lower than the SAA algorithm. The number of information interaction points between each design process supported by BIM technology is reduced by 59.41 times, and there is also a significant decrease in the intensity of information interaction between each design process. Using the adaptive evolution algorithm of interior layout designed in this paper, we can get the layout plan of different housing types, which provides reliable and various layout choices for the functional zoning and environmental art design of housing. The introduction of BIM technology into housing interior design can significantly improve the efficiency of interior design, better realize the effective integration of housing functional zoning and environmental art design, and better meet the functional needs of users and the pursuit of art.

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