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Indoor Space Layout Optimization Method Based on Multi-objective Genetic Algorithm

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Abstract

The purpose of self-evaluation of interior space layout is to assess and reflect on the layout and functionality of the interior space you have designed or arranged. Through self-evaluation, it is possible to find out whether the interior layout meets the needs and objectives of the design expectations and to identify any existing problems or opportunities for improvement. Based on this, in order to adapt to the fuzzy and polymorphic characteristics of the self-evaluation indexes of the indoor space layout of small flats, and to overcome the lack of scientificity and objectivity in the evaluation, this paper, on the basis of analyzing the utilization rate of the indoor effective activity space in small flats, adopts the multi-objective genetic algorithm to solve the problem of optimization of the indoor space layout of small flats and establishes the mathematical model using the example of a 17-square-meter small flat, and makes use of the improved genetic algorithm is used to optimize the indoor space layout. The results show that the multi-objective genetic algorithm can effectively solve the indoor space layout problem of small flats.

Keywords

Self-evaluation, interior layout, genetic algorithm, optimal design

1. Introduction

At present, the housing price in big cities is on the high side. Many people living in big cities are mainly small family. This is the place where a family lives in daily life, and it also carries the family's yearning for this city. In recent years, with the accelerated pace of urban construction, the building environment has been greatly improved. However, problems such as overcrowded residential population, poor spatial layout, and disorderly indoor environment are still prevalent, seriously affecting the quality of life of people in large cities. Among them, the spatial layout of small apartment is an important basis for planning the configuration of small apartment facilities, improving the utilization rate of space, improving the convenience of personnel activities, etc., which has an important impact on the achievement of small apartment functions and life satisfaction. Due to the large differences between domestic and foreign residents, scholars at home and abroad have different emphasis on the study of small house types. Due to the small population in foreign countries, the living environment is relatively loose and comfortable. At present, foreign scholars' research on small apartment space mainly includes: (1) dormitory space design based on the physical environment (such as indoor temperature, humidity, illumination, etc.) and interpersonal relationship in the apartment [1]. (2) Old space renovation with advantages and control disadvantages [2]; (3) Evaluate the use of dormitory facilities from the perspective of technology and function to promote the improvement of dormitory facilities [3]. Domestic scholars have studied the space environment, furniture and other contents of small units from different angles, among which the representative studies of the indoor space layout of small units include: Lin Daofa [4], Liu Sisi [5] and others put forward the optimization design method of small units through field survey; Zheng Ying et al; Hao Yu [7] used the POE analysis method to study the spatial layout of middle school dormitory in central

Inner Mongolia. According to the characteristics of research objects, scholars at home and abroad have adopted different algorithms to optimize the spatial layout. Dino et al. [8] adopted the multi-objective building design optimization tool to optimize the building space layout, energy and lighting performance. Kim Soo-Young et al. [9] proposed the objective function of the optimal pipeline route, and adopted the improved spatial evaluation method to optimize the spatial efficiency layout design of the ship engine room pipeline system. Takeda Yan et al. Sun Xin et al. [11] used the SLP method of process specialization layout to analyze the comprehensive relationship of products, and took the overall kitchen product as an example to establish a mathematical model, using improved particle swarm optimization algorithm to solve the problem, and realized the product layout optimization design. Li Yun et al. [12] used NS-GA-II algorithm to optimize the multi-objective problem of yacht cabin layout and carried out an example verification. Zhong Ting [13] used spatial syntax to conduct quantitative research on Chengdu Shaocheng space and establish a model to provide quantitative support for urban spatial optimization decision-making. The above research provides ideas and methods for the optimization of indoor space layout of small apartment. A multi-objective optimization method that combines the Non-dominated-and-crowding Sorting Genetic Algorithm II (NSGA-II) with Energy Plus is proposed for window design optimization [8]. An alternate route of meta model-based design optimization methodology is proposed in multi-scale framework based on a symbolic regression implemented using genetic programming (GP) coupled with optimal design [14]. Ref [15] implement a Pareto-optimal image encryption algorithm that uses coupled map lattice (CML) chaos function and deoxyribonucleic acid (DNA) combination to encrypt an image. The conventional methods for solving multi-objective problems consist of random searches, dynamic programming, and gradient methods whereas modern heuristic methods include cognitive paradigm as artificial neural networks, simulated annealing and Lagrangian approaches. Some of these methods are managed in finding the optimum solution, but they have tendency to take longer time to converge so that need much computing time [16]. At the same time, a new genetic algorithm coding method is proposed to avoid the generation of illegal solutions in cabin layout sequence crossover and mutation operation [17]. The genes (i.e., the implemented strategies) are described and the optimal solution in the R4 space is discussed, alongside with considerations about the solutions pertaining to the Pareto frontier [18]. A new efficient multi-objective optimization method, based on the Building Performance Optimization (BPO) technique, has been developed to improve the indoor thermal comfort and energy performance of residential buildings, i.e. a Moroccan ground floor + first floor (GFFF) house located in Marrakech region (5th climatic zone according to the Thermal Building Code in Morocco) . It is difficult for indoor space designers to use the daily-life information of users when managing indoor layouts or floor plans. Ref [20] introduce a technique to solve this problem: simple mobile application (app) logs are used to identify the daily-life patterns of users in an indoor space, and the results are used to create the optimal space layout. In order to obtain a superior performance for a diesel engine running at high altitude, multi-objective optimization was conducted in an entire operating region for a light-duty diesel engine operating at an altitude of 1960 m. Ref present a multi-objective optimization method based on an artificial neural network (ANN) model, which can help designers efficiently optimize the design of primary and secondary school classrooms in southern China.

In view of the fuzziness and polymorphism of the self-evaluation index of the small apartment space layout, and the current evaluation of the small apartment space layout scheme mainly depends on the field survey, the experience of designers and the feedback of the living population, which lacks the scientific and objective evaluation, this paper intends to take a small apartment room in a city as an example, and conduct a quantitative analysis of the shared activity space of personnel by studying the utilization rate of the effective indoor activity space of the small apartment, At the same time, combined with the characteristics of the small apartment space environment (space convenience, facility support, environmental comfort), the multi-objective genetic algorithm is used to optimize the indoor space layout design and solve. This method can provide theoretical support for research involving spatial layout and spatial utilization design.

2. Utilization rate of indoor effective activity space of small apartment

The problem of indoor space layout of small apartment is essentially the relationship between containers (space) and accessories (indoor facilities). The layout effect is related to the size of the effective activity space of personnel on the one hand, and the convenience of personnel activities, environmental comfort, and the support of indoor facilities on the other hand. This paper uses the data index of effective activity space utilization rate to evaluate the use of indoor personnel activity space. The effective indoor activity space of small apartment refers to the relatively spacious and continuous activity space, excluding the space occupied by the dormitory furniture and facilities, which cannot be used around the small apartment furniture and facilities. The larger the effective indoor activity space is, the smoother the personnel activities will be carried out; on the contrary, the space will be cramped and the activities will be limited. The effective activity space can be represented by its corresponding ground area. In order to compare the use of effective activity space under different spatial layouts, this paper introduces the evaluation index of effective activity space utilization rate:

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

where: S is the floor area corresponding to the effective indoor activity space; A is the total indoor floor area. It can be seen from formula (1) that the value of E should be between 0-1. The larger the value of E, the higher the utilization rate of indoor effective activity space, the better the effect of the scheme. The effective indoor activity space area of small apartment is:

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

where: S_1 is the sum of the floor area corresponding to the space occupied by small household furniture and facilities; S_2 is the sum of the floor area corresponding to the small household furniture and the small space that cannot be used around the facilities. S_2. It consists of two parts: (1) the floor area corresponding to the space inaccessible to personnel; (2) The floor area corresponding to the space where people can enter but cannot carry out effective activities. In actual measurement and calculation, S_2 can be obtained by the following method. Small household furniture is generally placed along the wall. Select the furniture vertices that are not close to the wall (such as A, B, C and D in Figure 1) and connect them with orthogonal lines in turn. These orthogonal lines divide the small household space into several subspaces (such as 1, 2, 3 and 4 in Figure 1), and judge whether each subspace can carry out personnel activities.

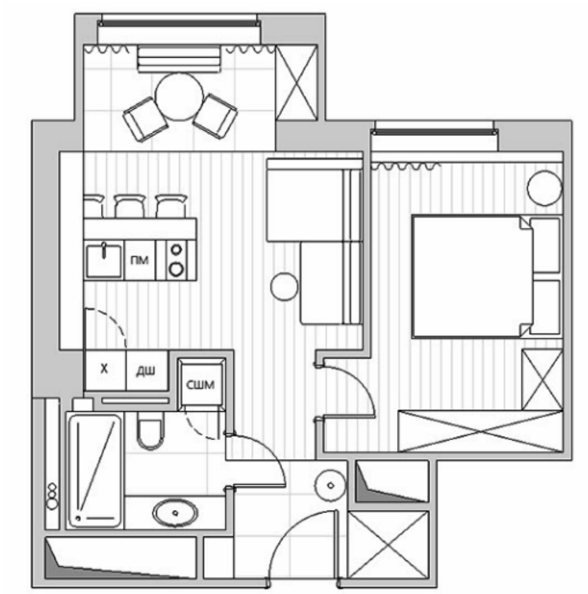

Figure 1. Interior space division.

Evaluation criteria: (1) The width of the entrance into the sub-space shall not be less than 800mm (the width shall be set according to the width dimension standard of the indoor door); (2) The floor area corresponding to the subspace shall not be less than 0.753m2 (this area can be determined according to the expanded size of the two elbows of the 95th percentile male aged 18-55 in the 1988 national standard of human body size, 941mm, and the entrance size, 800mm). If the subspace cannot meet any of the above two criteria, it will be listed as S_2. The effective activity space utilization rate is calculated according to the floor area corresponding to the space, while the small apartment is a three-dimensional space with personnel activities, and the indoor furniture layout will also have an impact on the convenience of personnel activities and environmental comfort. Therefore, the optimization of indoor space layout also needs to fully consider the characteristics of the space environment and the needs of personnel activities.

3. Mathematical model for optimal design of indoor space layout

The indoor space layout of small family includes space, small family furniture and their interrelationship and requirements. These relationships and requirements are the constraints of the layout. The convenience of personnel activities and the comfort of the environment should be comprehensively considered from multiple perspectives, such as the configuration of small household furniture, the location of furniture and the psychological needs of personnel. Therefore, this paper uses multi-objective genetic algorithm to establish a mathematical model for the indoor space layout of small units [12].

3.1 Objective functions

1) There is no interference between small household furniture, and the greater the distance between them, the better. $F_1(x)$ is used to describe:

$$F_1(x) = \sum_{\substack{i=1 \\ j=1}}^{n} (x_i - x_j)^2 \tag{3}$$

where: x_i, x_j is the location parameter of furniture with requirements for interference distance; n is the total number of furniture required for interference distance.

2) The area occupied by the furniture and activity area is certain when the area, quantity and size of furniture are fixed. In order to maximize the utilization of the central area of personnel activities in the design, $F_2(x)$ is used to describe the distance of this activity：

$$F_2(x) = \sum_{i=1}^{n} w_i (x_i - x_a)^2 \tag{4}$$

where: w_i is the importance weight coefficient of the corresponding area of each furniture in the indoor space layout design, and $\sum_{i=1}^{n} w_i = 1$； x_a is the central position parameter of the activity area.

3.2 Design Variable

In this paper, the design variable is defined as the location parameter x_i (*i*=1, 2, ..., n) of furniture, that is

$$\boldsymbol{X} = \{\boldsymbol{X}_1, \boldsymbol{X}_2, \cdots, \boldsymbol{X}_n\} = \{(x_1 \cdot \mathcal{Y}_1), (x_2 \cdot \mathcal{Y}_2) \cdot \cdots \cdot (x_n \cdot \mathcal{Y}_n)\} \tag{5}$$

where: x_i is the x coordinate of the accessory *i* (i=1, 2,..., n); $\mathcal{Y}_i$ is the y coordinate of the attribute i (i=1, 2,..., n); *i* is the furniture number, and n=16 is taken in this study.

3.3 Constraint Condition

The constraint conditions for the optimal layout of the indoor space of the small apartment mainly involve the following three categories:

1) The furniture layout is mainly constrained by the small apartment in the dormitory, which can not exceed the boundary of the small apartment, but also meet the location relationship between adjacent furniture with requirements for distance, namely:

$$\begin{cases} \frac{s_i}{2} \leq x_i \leq L - \frac{s_i}{2} \\ \frac{q_i}{2} \leq y_i \leq W - \frac{q_i}{2} \\ | x_i - x_j | = d_{xij} \\ | y_i - y_j | = d_{yij} \end{cases} \tag{6}$$

where: (x_i, x_j) is the position parameter of the furniture (j=1, 2,..., n); s_i, q_i is the size of furniture i in x and y directions; d_{xij} and d_{yij} is the distance requirement between furniture *i* and *j* in *x* and *y* directions; L and W are the length and width of the room respectively.

2) The furniture in the small house shall not interfere with each other and shall not be staggered：

$$\begin{cases} | x_i - x_j | \geq \frac{s_i + s_j}{2} \\ | y_i - y_j | \geq \frac{q_i + q_j}{2} \end{cases} \tag{7}$$

where, s_j and q_j are the dimensions of furniture *j* in *x* and *y* directions respectively.

3) To ensure that the furniture does not affect the access of personnel, the constraints are:

$$\begin{cases} | x_i - x_d | \geq \frac{s_i + L_D}{2} \\ | y_i - y_d | \geq \frac{q_i + W_D}{2} \end{cases} \tag{8}$$

where, x_d and y_d are the positioning parameters of the furniture relative to the door; L_D and W_D are the length and width of the door. The above optimization design model of indoor space layout of small apartment takes the maximum utilization rate of indoor effective activity space as the goal, taking into account the convenience of personnel activities, environmental comfort and facility support, and combining with appropriate optimization algorithm, the optimization design of indoor space layout of dormitory can be carried out.

4. Optimization example

The indoor space layout of a small family in a city is shown in Figure 2 (size unit: mm). The indoor space consists of living space and balcony. Living space is the main activity area of dormitory members and the space layout is flexible, while the balcony is mostly used for stacking sundries and drying clothes, which is the auxiliary living space and less for personnel activities. Therefore, the optimization of the indoor space layout of the four-person student dormitory takes the living space as the research object.

4.1 Utilization rate of indoor effective activity space

The total area of living space is 16.08m^2. The dormitory furniture covers a total area of 6.605m^2, including 3.6m^2 of bed, 1.98m^2 of desk and 1.025m^2 of wardrobe. Select the furniture vertices that are not against the wall, connect them with orthogonal straight lines in order, and divide the dormitory space into six subspaces: C_1, C_2, C_3, C_4, C_5, C_6 (as shown in Figure 2). Sub-spaces C_1, C_2, C_3, C_4, C_5 and C_6 cover an area of 3.1m^2, about 3.55m^2, 1.54m^2, 0.36m^2, 0.51m^2 and 0.25m^2 respectively.

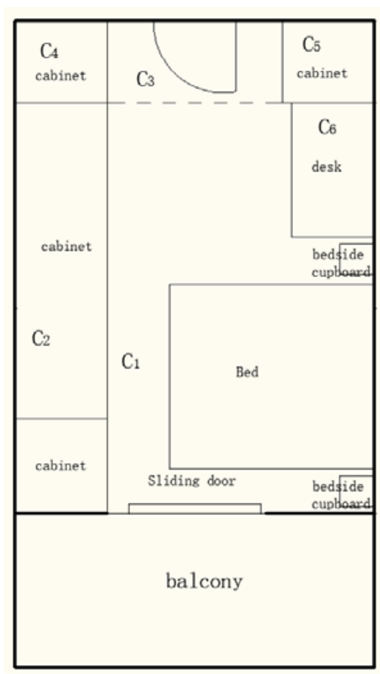

Figure 2. Indoor space layout.

Since the floor area of the subspaces C_4, C_5 and C_6 is less than $0.753m^2$, the area of S_2 is $1.12m^2$. According to formula (2), the effective activity space area in the dormitory is $8.355m^2$ (gray area in Figure 2). According to formula (1), the utilization rate of effective activity space in the dormitory is about 51.96%. According to the above analysis, it can be seen that: 1) the effective indoor activity space utilization rate of the dormitory is good, and the indoor space layout can meet the needs of daily life; 2) the layout of indoor space tends to be flat, and the vertical height space is not fully utilized; 3) the location of dormitory furniture is easy to interfere with personnel activities and cannot form a relatively independent personal privacy space. For example, desks are placed side by side along the wall, which is not easy to form a relatively quiet learning space; The upper and lower bunks are easy to interfere with each other and cannot form a relatively private sleep space.

4.2 Indoor space layout optimization scheme

Under the MATLAB environment, the indoor space layout of the dormitory is optimized based on the improved genetic algorithm and the results are shown in Table 1 and Table 2.

Table 1. Results of optimized layout parameters 1

Number	Furniture name	Length/mm	Wide/mm	Layout optimization results	
				x/mm	y/mm
1	Bed	2200	1400	450	1000
2	bedside cupboard	500	500	2550	1000
3	wardrobe	4200	900	2550	3800
4	desk	2200	500	450	3800

Table 2. Results of optimized layout parameters 2

Number	Furniture name	Length/mm	Wide/mm	Layout optimization results	
				x/mm	y/mm
1	Bed	2300	1400	450	1000
2	bedside cupboard	600	600	2550	1000
3	wardrobe	4100	900	2550	3800
4	desk	2100	500	450	3800

Based on the above optimization results, an optimization scheme for the indoor space layout of the dormitory is established as shown in Figure 3 (dimension unit: mm).

4.3 Effective activity space utilization rate of optimization scheme

The total area of living space is $16.08m^2$. Floor area of the small apartment furniture: the desk, bookcase and wardrobe are all located under the bed and coincide with the floor area corresponding to the bed. Therefore, the floor area of furniture only needs to be calculated. Therefore, S_1 is $7.2\ m^2$. In the optimization scheme, the floor area of subspaces C_1, C_2 and C_3 is $3.1\ m^2$, $2.68\ m^2$ and $3.1\ m^2$ respectively, which are greater than $0.753m^2$, so the area of S_2 is 0. To sum up, the area of indoor effective activity space is $8.88m^2$ (gray area in Figure 3), and the utilization rate of indoor effective activity space is about 55.22%. It can be seen that using genetic algorithm to optimize the indoor space layout of the small apartment can significantly improve the utilization rate of effective activity space.

4.4 Improve the convenience of personnel activities and environmental comfort

According to the activities and living needs of personnel in the small apartment, this paper divides the small apartment space into sleep space, learning space, communication space and storage space. The space layout optimization plan arranges the bed and desk along the wall of the small apartment and places them at the four corners of the room, reducing the interference of the external environment on the sleeping space and learning space, and ensuring the relative independence of the personal activity space. The sleep space has the strongest demand for privacy, so the combination of bed and table can provide users with a better privacy environment. Communication space is a shared activity space for potential guests in small apartments. The optimization plan focuses on the central area of the room (gray area in Figure 3), which is convenient for daily access and communication activities. The combination of multi-function desks for small household furniture can reduce the floor area of furniture, and can be placed in four corners of the room to ensure the concentration and maximization of effective indoor activity space. Personal wardrobe and bookcase are set under the bed for the convenience of personnel.

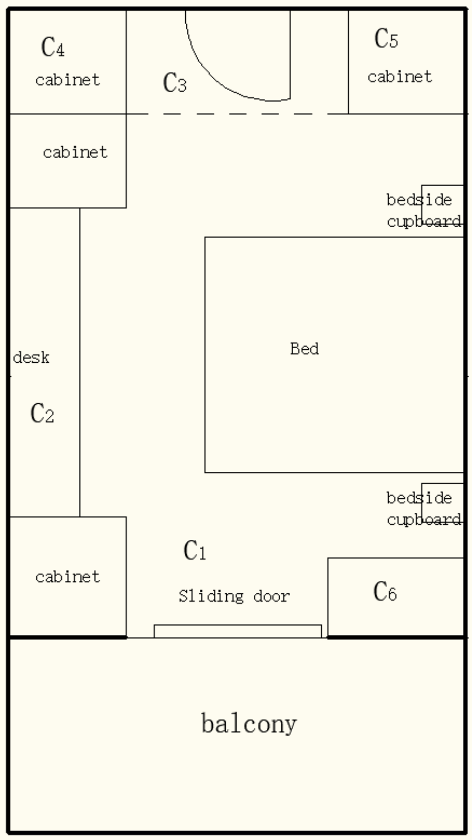

Figure 3. Optimization Scheme of the small apartment furniture Space Layout.

5. Conclusions

The reasonable spatial layout provides support for improving the functional achievement of small family rooms and is an important basis for improving the quality of life of small family. In this paper, by analyzing the utilization rate of the effective indoor activity space of the small apartment, the multi-objective genetic algorithm is used to solve the optimization problem of the indoor space layout of the small apartment. Taking a small apartment room in a city as an example, the interior space layout of the room is optimized by using improved genetic algorithm based on the comprehensive consideration of space environment characteristics, personnel psychological needs and other aspects, and the design of constraints.

The optimization practice case shows that: 1) the indoor space layout optimization scheme of small apartment based on multi-objective genetic algorithm can significantly improve the utilization rate of indoor effective activity space; 2) The spatial layout optimization plan properly and reasonably planned the functional space of small apartment, fully utilized the vertical height of indoor space, and laid an important foundation for the follow-up research of small apartment interior; 3) The spatial layout optimization scheme has better met the requirements of convenience and environmental comfort for personnel activities, and improved the quality of life of small family members. It should be pointed out that the impact of physical environmental factors (such as light efficiency, temperature, etc.) on the indoor space layout of small houses is not involved in this study. In the future research, the team will continue to pay attention to the functional requirements of the indoor space of small units, and study and discuss relevant issues.

References

[1] Hare K. Design of living spaces in small space. Procedia-Social and Behavioral Sciences, 2013, 92(10):445-451.

[2] Iman K, Brenda V. Shared student residential space: a post occupancy evaluation. Journal of Facilities management, 2002, pp. 331-336.

[3] Mohammad A H. On the performance evaluation of sustainable student housing facilities. Journal of facilities management, 2008, pp. 332-338.

[4] Lin Daofa, Zhu Xiaoyong, Lan Ying. Discussion on the optimization design of college dormitory space. Furniture and Interior Decoration, 2014, (2): 85-87.

[5] Liu Sisi. Research on the optimization design of postgraduate dormitory space. Shanxi Architecture, 2007, 33 (20): 20-21.

[6] Zheng Ying, Zhang Xiaoqin. Research on the optimal design of the box unit space of university dormitory. Sichuan Architecture, 2010, 30 (5): 61-63.

[7] Hao Yu. Research on the spatial layout of middle school students' dormitories based on POE theory: taking the central part of Inner Mongolia as an example [D]. Hohhot: Inner Mongolia University of Technology, 2018.

[8] Yingni Zhai, Yi Wang, Yanqiu Huang, Meng Xiaojing. A Multi-objective Optimization Methodology for Window Design Considering Energy Consumption, Thermal Environment and Visual Performance. Renewable Energy, 2019.

[9] Kanak Kalita, Tanmoy Mukhopadhyay, Partha Dey, Salil Haldar. Genetic Programming-assisted Multi-scale Optimization for Multi-objective Dynamic Performance of Laminated Composites: The Advantage of More Elementary-level Analyses. Neural Computing and Applications, 2019.

[10] Shelza Suri; Ritu Vijay. A Pareto-optimal Evolutionary Approach of Image Encryption Using Coupled Map Lattice and DNA. Neural Computing and Applications, 2019.